

Charis M. Galanakis *Ed.*

Biodiversity, Functional Ecosystems and Sustainable Food Production



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Preface

Over the last decades, different practices like the cultivation of a few high-yielding crop varieties on large scales, the application of heavy machinery and continued mechanization of agriculture, the removal of natural habitats, as well as the application of pesticides and synthetic have resulted in the simplification of agro-ecosystems at various spatial scales. Agriculture's intensification has resulted in a significant increase in food production, but at the same time, it has transformed landscapes. Indeed, there is a concern that declines in biodiversity affect the delivery of ecosystem services. Although they have increased food production, the above practices cannot be considered sustainable in long-term applications. Subsequently, the importance of diversity and diversification in increasing the resilience of food systems is becoming a key issue. Biodiversity and microbiome activities support processes across soils, plants, animals, the marine environment, and humans. The resilience of food systems can be achieved through better use of the plant, animal genetic, and microbial genetic resources. To this line, there is a need for a new reference.

Food Waste Recovery Group (www.foodwasterecovery.group) is a leading consulting network that has developed numerous initiatives such as workshops, e-courses, reports for governmental bodies and companies, a new open-access journal (*Discover Food*, Springer Nature), and more than 50 books in the broad fields of bioresources, environment, sustainability, food, and nutrition. The present book covers all the essential aspects of biodiversity, functional ecosystems, and sustainable food production. It covers ecosystems in terms of emerging risks to plant health, pest and disease control, crop and animal production, soil fertility, and productivity. It emphasizes the interconnection of ecosystem functions, food production, and quality with consumer health. It also exhibits diverse practices that contribute to sustainable food production at different levels.

The book consists of ten chapters. Chapter 1 provides a synthesis of published evidence of the complex and crucial relationships between elements of agro-biodiversity, climate change, and the food chain. It highlights the trends of changes in the components of agro-biodiversity, the factors enhancing such changes, and the points needed to be considered to maintain a sustainable way of food production for

obtaining a stable food chain. In addition, the present status of studies relating to both agro-biodiversity and genetic resources is denoted. Chapter 2 revises climate change, its impacts on pests' behavior, and the spread of emerging pests. Since climatic factors such as temperature, relative humidity, solar radiation, precipitations, and carbon dioxide level significantly impact different organisms, climate change can lead to various challenges for organisms such as pests. Furthermore, climate change consequences can lead to changes in the abundance and geographic distribution of different pests. These changes are responsible for emerging pests commonly related to the global trade in agricultural products.

Chapter 3 discusses the future-proofing of plants against climate change, as the world must immediately act on it to end hunger and malnutrition. To ensure rapid and advanced agricultural development in a short period, precision farming practices and innovative breeding strategies need to follow, such as machine learning, deep learning, big data analysis, remote sensing, artificial intelligence, system biology study, genomic prediction, speed breeding, and haplotype breeding. These techniques can prove the future plants against climate variability with increased yield potential and improved resilience to achieve the goal of resilient climate agriculture.

Chapter 4 deals with the role of integrated pest management for sustainable food production, giving soybean as an example. Integrated pest management is based on the principle that some degree of plant injury is tolerable without requiring pest control. Moreover, the most environment-friendly pest control tools should be combined to have a longer-lasting pest solution. Those tools that include biological control and transgenic plants, among others, are discussed in detail, highlighting commercially available ones combining environmental, economic, and social benefits.

Over the years, the indiscriminate use of pesticides has caused several problems, including pest resistance and contamination of important global sources such as water, air, and soil. Therefore, plant-based pesticides can be an ecological alternative to synthetic pesticides to improve the efficiency of agricultural production and sustainably reduce the food crisis while protecting consumers' health. In addition, they are cheap, biodegradable, environmentally friendly, and act more specifically through multiple mechanisms of action. Chapter 5 presents in detail the use and activity of plant-derived pesticides.

Chapter 6 discusses antimicrobial use in animal food production. The push towards intensive livestock production systems to meet food demand has increased antimicrobial use in livestock metaphylactically and prophylactically as growth-promoting agents. However, it has become increasingly recognized that the widespread application of antimicrobials in food production contributes to the emergence and proliferation of antimicrobial-resistant species. The presence of clinically relevant multidrug-resistant species in food-producing animals may result in human cases of infectious disease. As a result, antibiotics in human medicine are being monitored in most developed countries. Nevertheless, antimicrobial use in livestock and food production is poorly scanned and assessed. Better monitoring, surveillance, and understanding of the consequences of the expressive use of antibiotic

agents in veterinary medicine are needed to determine their potential impact on animals and humans health wise.

Chapter 7 discusses the functional properties of bee pollen of some environmental-friendly novel unit operations. In this context, fluidized bed-assisted cold drying, microwave, freezing, vacuum, infrared, and microwave-assisted vacuum drying are investigated as new environment-friendly unit operations. The chapter also discusses the protective properties of these unit operations on the raw material properties during processing, storage, and kitchen applications. In addition, many specific bioactive properties of bioactive pollen components, such as antimicrobial, antioxidant, and anti-carcinogenic properties, are discussed. Finally, the pollen production chain, sustainability in this life cycle, and the environmentally-friendly features of these new applications on sustainability are revealed.

Chapter 8 is divided into two parts. The first part provides critical insights to allow scientists to generate discoveries across microbiome applications for sustainable food systems. It offers a broad view of research of interest to early and experienced scientists and an understanding of the role of microbiomes as vital ecosystems and inter-relations among microbiomes across food chains. In the second part, the reuse of spent coffee grounds to increase the resilience of agro-food systems is described as an example of a successful application of a microbiome-related intervention.

Chapter 9 focuses on the role of dynamic value chains using underutilized biodiversity crops to improve food system resilience and deliver foods with good nutritional and healthy properties while ensuring a low environmental impact. Consumers pay attention to healthier food attributes and diets due to sustainable production processes. Other significant trends include increasing demand for less processed and regionally supplied food. To meet these demands, food production and processing need to evolve to preserve raw materials' "natural" character while ensuring sustainable, tasty, and, most importantly, healthy food. Likewise, it is vital to understand the influence of consumers' preferences in preserving the beneficial attributes of food up to the time of consumption.

Chapter 10 deals with new alternative protein and traditional protein sources of terrestrial origin for food and feed such as insects, plants (legumes and grasses), and by-products of crops. Protein supply is critical for animal feed and human consumption. Therefore, integrating a variety of alternative protein sources into existing products or processes should be explored to ensure more resilient supply chains, highlighting consumer preference by a clean labeling strategy and respective market opportunities.

Conclusively, the current book assists food producers and researchers working at the edge of food and environmental fields, agriculturalists and food scientists seeking to improve production system efficiency, and professionals active in the food supply chain from farm to fork. Likewise, university libraries and institutes worldwide could suggest this reference as ancillary reading in graduate and postgraduate courses dealing with agricultural and environmental science, sustainable food systems, and bioresources.

I want to thank and acknowledge, one by one, all authors of this book. Their acceptance of my invitation, and their dedication to the editorial guidelines and schedules are much recognized. I would also like to thank Arjun Narayanan, the book manager; Daniel Falatko, the acquisition editor; and the production team of Springer Nature for their assistance during the development of this book. Finally, I have a message for all the readers of this book. This collaborative effort ended up in a manuscript containing hundreds of thousands of words, and thus it may collect some errors. Criticism and constructive comments are welcome, so please do not hesitate to contact me to suggest changes if you have any objections.

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Chapter 1

Agro-Biodiversity Across the Food Chain



**Shamim Ahmed Kamal Uddin Khan, Md. Moshir Rahman,
and Md. Matiul Islam**

Abstract Currently, we are at a point of unprecedented changes in the climate, which is affecting the food chain across the agro-biodiversity. The changes in species diversity in the food web indicate the changes in variety at any of the trophic levels. Adaptation with the environmentally changed conditions depends on the effective use of biological components of the local agro-ecosystem, which is also the focal point of sustainable approaches. Sustainable management of natural resources in the agro-biodiversity is essential for food and livelihood security of the living beings in an ecosystem. In this chapter, a synthesis of published evidence of the complex and crucial relationships between elements of agro-biodiversity, climate change, and the food chain is provided. A review of published articles highlights the status and trend of changes in the components of agro-biodiversity, the factors enhancing such changes, and the points needed to be considered to maintain a sustainable way of food production for obtaining a stable food chain. Finally, the present status of studies and researches relating both of the agro-biodiversity and genetic resources are identified. Nevertheless, despite the need for more knowledge of agro-biodiversity and the food chain, it is clear that more effective action would be taken.

Keywords Agro-biodiversity · Change in diversity · Affecting factors · Sustainability

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Highlights

- The mass extinction of biodiversity in the ecosystems is associated with climate warming, increased nitrogen deposition, land-use change, biotic exchange, and an increased atmospheric CO₂ level.
- The status of preservation of crop germplasm is insufficient to the alarming pace of threats posed by climate change. The collection and preservation status is low for crop wild relatives, wild food plants, and neglected and underutilized crop species.
- About 75% of all crop genetic diversity has been lost since the previous century, primarily due to changes in the agricultural food system, which values uniformity.
- The productivity of a fishery remains high, especially in inland waters, as lower trophic-level species increase in abundance without larger predators.
- Introduction of alien species causing genetic erosion by the disappearance of traditional species through introgression.
- The knowledge on the effects of environmental stressors on biodiversity and the food chain is still far from our understandings as the studies, including multiple environmental stressors, are scarce.
- During the last two decades, studies on food-web ecology are being conducted, including smaller trophic entities consisting of only two to seven species which are unable to predict emergent patterns of food webs. A robust geographic bias in respect of sampling was observed, and the number of studies conducted within each biome is not proportional to the overall size of the biome.

1 Introduction

The concept of ecosystem differs in respect of economic, cultural, and societal needs where biological diversity is one of the central components. ‘Biological diversity’ refers to the variability among living organisms in terrestrial and aquatic ecosystems, also known as ‘biodiversity.’ It also includes the ecological complexes within and between species in an ecosystem (Secretariat of the Convention on Biological Diversity, 2004). Biodiversity has enormous impacts on agriculture and food productions. It embraces not only the domesticated crops and livestock but also other species of plants, animals, and micro-organisms. These components of biodiversity deliver a range of vital services such as building healthy soils, pollinating plants, purifying water, providing protection against extreme weather events, enabling ruminant animals to digest fibrous plant materials, etc. (FAO, 2019a). Ecological components also contribute to agricultural production as the tree or herbaceous crops are protecting the soil against erosion and creating a favorable micro-climate for other components (e.g., soil-inhabiting flora and fauna) of the production systems (Balvanera et al., 2017).

The ecosystems used for agriculture and the production of food and non-food products are known as ‘agroecosystems,’ which comprise all biological resources and their biodiversity, including the physical environment and the practices managed by human beings (FAO, 2018a). The words ‘agro diversity’ and ‘agro-biodiversity’ are used interchangeably to indicate the biological diversity of lands used for agricultural purposes (Brookfield & Stocking, 1999). Agro-biodiversity, as defined by FAO (1999), is the combination of varieties and variability of different biological components related directly or indirectly to food and agriculture. These components include crops, livestock, forestry, and fisheries (considered as agricultural products) and comprise the diversity of their genetic resources. The variety of non-harvested species playing the supporting roles in production (soil micro-organisms, predators, pollinators) and maintaining the wider environment to keep the diversity of agro-ecosystems (agricultural, pastoral, forest, and aquatic) are also included in the agro-biodiversity. However, Thrupp (1998) mentioned the agro-biodiversity as the vital sub-set of biodiversity, which results from natural selection processes maintained by the peoples related to agriculture over millennia. Sustainable management of biological resources in the agro-biodiversity is vital for the food and livelihood security of the living beings in an ecosystem (FAO & PAR, 2011). All species of a biological community form a ‘food web’ through trophic interactions between them (Banašek-Richter, 2004). Elton (1926) first acknowledged the scientific significance of food webs and used the term ‘food chain’ to express the relationships between the animals that feed on one another (Lawton, 1989) (Fig. 1.1).

A functional food web or chain is an expression of the relationship between biodiversity and the ecosystem through resource use complementarity (Norberg, 2000) and species abundances (Wootton, 1994). Ecosystem response to nutrient enrichment for crops through the trade-offs between competing plants and their resistance to herbivores (Chase et al., 2000). Species coexistence and the trophic position of species in the food web are inter-related. For instance, increasing consumer diversity may decrease producers’ biomass through predator-mediated coexistence (Duffy et al., 2003). Similar effects of plant diversity have been recorded on soil-resource depletion (Symstad & Tilman, 2001). The changes in species diversity in the food web depend on the changes in variety at any of the trophic levels, which ultimately propagate to both higher and lower trophic levels of an agro-biodiversity (Dyer & Letourneau, 2002).

Agro-biodiversity plays a vital role as a source of food for humanity and also maintains a healthy environment for better living and sustainable development (Esquinas-Alcázar, 2005). Adaptation with the current environmentally changed conditions by reducing the risk exposures depends on the richness of agro-biodiversity and crop genetic diversity (Vigouroux et al., 2011). Increasing the quantity and the nutritional quality of food products through more effective use of the functions performed by the local agroecosystem’s biological components is the focal point of sustainable approaches (FAO, 2019a). Sustainable agro-biodiversity ensures the better utilization of the components of biological diversity that does no harm to the biodiversity. It also maintains the present and future potentials of the

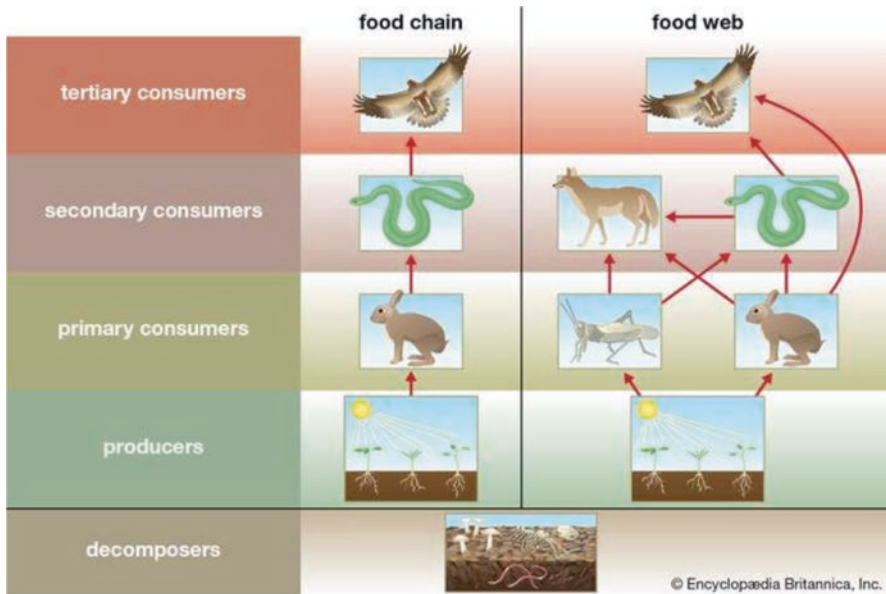


Fig. 1.1 A food chain shows how matter and energy from food are transferred from one organism to another. In a natural ecosystem, many food chains intertwine to form a complex food web (Encyclopedia Britannica, 2020)

biodiversity for better agricultural production (Secretariat of the Convention on Biological Diversity, 2004). Sustainable use of biological components and their conservation are interrelated. Zimmerer et al. (2019) highlighted four significant themes in the Anthropocene as ecology, governance, nutrition-health, and global change to explain the impact of ongoing complex human-environment interactions on agro-biodiversity. The sustainability of an agro-biodiversity depends on the conservation of neighboring or distant ecosystems that provide it with essential services (FAO, 2019a).

Sustainable use of agro-biodiversity is inevitable to ensure a 50% increase in food production (FAO, 2017) for a world population predicted to increase to almost 9.8 billion by 2050 (United Nations, 2017). The majority of the smallholder farmers and the 2.7 billion poor who live on less than two dollars a day depend on locally grown food for their living (Rapsominikis, 2015). Food security for these people falls at risk when agro-biodiversity faces threats due to changes in production systems. As a part of agricultural production systems in the 1990s, the developing countries adopted modern varieties of wheat, rice, and maize at around 90%, 70%, and 60%, respectively, which threatened the agro-biodiversity there (FAO, 2017). In the last couple of decades, the modern rice varieties leaped from 4% to 58% in Latin America and 12% to 67% in Asia (Dronamraju, 2008). FAO (2017) reported that more than 90% of crop varieties had been disappeared from farmers' fields in the past 100 years. Crop varieties and livestock breed are being lost annually at a rate of

2% and 5%, respectively (United Nations, 2019). The modern cultivation practices simplified the crop production system leading to a less resilient agro-ecosystem (Altieri et al., 2015). For example, over 50 pollinator species are at risk of extinction, and wild honeybee populations have dropped 25% since 1990 in the USA (Dronamraju, 2008). Maintenance of a sustainable agro-biodiversity through traditional crop production system is successful in restoring yields (Altieri, 1999). Extensive studies and researches warrant further attention on agro-biodiversity across the food chain in these circumstances. The overall objective of this chapter is to explore the status and trend of changes in the components of agro-biodiversity, the factors enhancing such changes, and the points needed to be considered to maintain a sustainable way of food production for obtaining a stable food chain.

2 Changing Biodiversity and Food Chain in the Global Aspect

Nature includes living organisms, their diversity, and interactions (among themselves and with their abiotic environment). Nature's contributions to people (NCP) may be either positive or negative to people's quality of life (IPBES, 2017; Díaz et al., 2018). The positive or negative contribution of nature depends on spatial, temporal, social, or cultural context (Saunders & Luck, 2016; Rasmussen et al., 2017). Though the positive contributions may be due to the expression of dominant climatic and socio-economic factors, which may become recessive in times, and the less powerful elements can take place (Cáceres et al., 2015). In this respect, it is essential to verify the trend of the changes in the factors governing the well beings, including the food web in the agro-biodiversity.

2.1 Demographic and Economic Trends

The demographic status and trends indirectly influence the changes in nature, which ultimately govern the NCP (Nature's contribution to people) and GQL (Good Quality of Life) at local, national, regional, and global levels. The World Bank (2017) has estimated a 2.5 times increase in world population from 1960 to 2016. The growing population has impacted the use of land through urbanization and the development of infrastructures and transportation networks (IPBES, 2016). By the mid of this century, all archetype scenarios show a significant increase in population size, which reduced by the end of the century except in regional rivalry (O'Neill et al., 2017; Samir & Wolfgang, 2017) (Fig. 1.2). The increasing economic globalization in recent decades has expedited the economic activities worldwide, which ultimately influenced the changes in the ecosystem, biodiversity, NCP, and GQL through various direct and indirect pathways (IPBES, 2016).

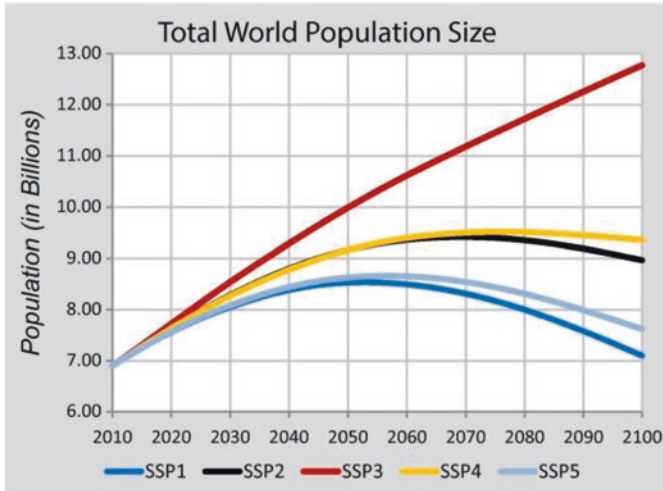


Fig. 1.2 Projected changes in world population according to the five Shared Socio-economic Pathways (SSP). (Adapted from Samir & Wolfgang, 2017). SSP1: Sustainability (Taking the Green Road- Low challenges to mitigation and adaptation), SSP2: Middle of the Road (Medium challenges to mitigation and adaptation), SSP3: Regional Rivalry (A Rocky Road- High challenges to mitigation and adaptation), SSP4: Inequality (A Road divided- Low challenges to mitigation and high challenges to transformation) and SSP5: Fossil-fueled Development (Taking the Highway- High challenges to comfort and common challenges to adaptation) (Riahi et al., 2017)

The worldwide economic development is the critical indirect anthropogenic driver of changes in nature, ecosystem, and biodiversity across all scales (global, regional, national and local). According to the World Bank (2017), the global GDP (at constant 2010 USD) increased about 7-times from 1960 to 2016. The current global economic trends have generated stresses on natural resources, the environment, and ecosystem functions (Schneider et al., 2011). Growing per capita GDP increased the demand for critical natural resources like food, water, and energy, adversely affecting the ecosystems and biodiversity through unsustainable patterns of production and consumption. These demands have exceeded the planet's biocapacity for more than 40 years. From an assessment by WWF (2016), it has been found that 1.6 Earths would be required to meet the human demands each year. Ecological Footprint also shows that the consumption patterns in high-income countries make stresses renewable resources, often at the expense of people and nature elsewhere in the world (WWF, 2016).

2.2 Trends in Land Use Pattern

Depending on the trade and the degree of globalization of future agricultural and forestry markets, all SSP (Shared Socio-economic pathways) scenarios show land-use changes due to agricultural and industrial demands for food, timber, and

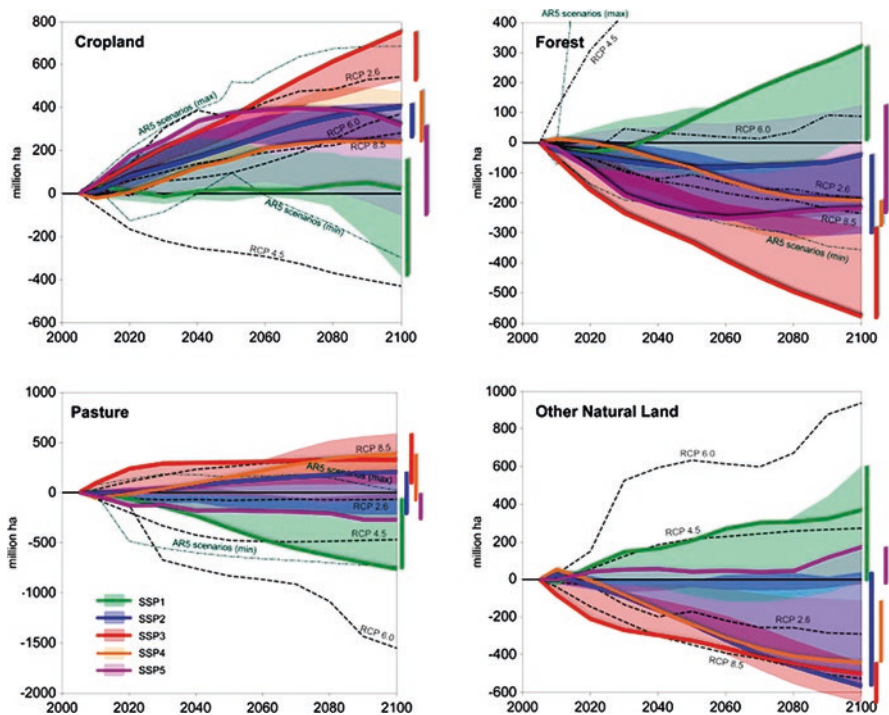


Fig. 1.3 Trends in land use patterns for different SSPs. The thick lines show the SSP marker baseline scenarios and colored areas range from other non-marker strategies. (Adapted from Riahi et al., 2017). Changes shown here are relative to the base year of 2010 = 0. The development of the RCPs (Representative Concentration Pathways) (van Vuuren et al., 2011) and the range of the IPCC AR5 (Intergovernmental Panel on Climate Change Fifth Assessment Report) scenarios (Clarke et al., 2014) have also been showing here. The croplands include energy crops, and other natural land consists of all land-categories beyond forests, pasture, cropland, and build-up areas

bioenergy (Popp et al., 2017). The SSP scenarios show that the total cultivated land can be expanded or contracted by hundreds of millions of hectares over this century (Fig. 1.3). Comparatively large pressure on the global land-use system has been reported for SSP3 featuring massive growth of population, relatively low agricultural productivity, and little emphasis on environmental protection. Such a land-use pattern in SSP3 leads to large-scale losses of forests and other natural lands due to an expansion of cropland and pasture land (Fig. 1.3). The SSP1 scenario features a sustainable land transformation with comparatively little pressure on land resources due to low population projections, healthy diets with limited food waste, and high agricultural productivity. All other SSP scenarios feature modest land-use changes with some expansion of overall cultivated lands (Riahi et al., 2017) (Fig. 1.3).

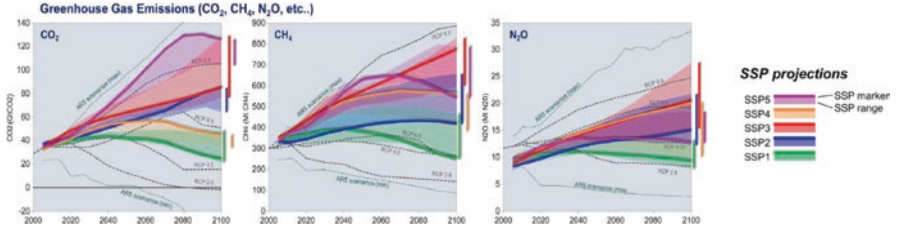


Fig. 1.4 Global emissions and the global average change in radiative forcing. (Adapted from Riahi et al., 2017). SSP baseline marker scenarios (and ranges of SSP non-marker baseline scenarios) are compared to the RCPs (van Vuuren et al., 2011) and the full range of the IPCC AR5 scenarios (Clarke et al., 2014)

2.3 Climate Change Scenario with Respect to Greenhouse Gases

The emission of greenhouse gases (GHG) in respect of SSP and broadly representative of the baseline range has been shown in Fig. 1.4. CO_2 emission is strongly correlated with the combustion of fossil fuels. Higher dependence on fossil fuels in the SSP3 and SSP5 baselines results in higher CO_2 emissions. On the other hand, low CO_2 emission in the SSP1 and SSP4 has been estimated due to lower dependency on fossil fuel and increased deployment of non-fossil energy sources. An intermediate emission of CO_2 was reported for the SSP2 baseline (Riahi et al., 2017). CH_4 (the second largest contributor to global warming) is emitted from non-energy sources like manure from livestock, rice cultivation, and enteric fermentation. In contrast, the energy-related sources, including the production and transport of coal, natural gas, and oil, contribute to its emission to a lesser extent. Changes in demographic status and food demand determine the future CH_4 emissions across the SSPs, which is depicted through higher CH_4 emission in the SSP3 baseline and lowest in SSP1. All other SSPs show intermediate levels of CH_4 where the combination of different energy and non-energy drivers leads to emissions in the long term. The major contributors to N_2O emission across all the SSPs are agricultural soils and fertilizer use. N_2O emissions are lowest in SSP1, featuring sustainable farming practices and low population. On the other hand, the highest emission of N_2O was reported for SSP3 and SSP4 baselines due to increased population and a higher rate of fertilizer use for more food production (Riahi et al., 2017).

2.4 Changes in Plant Genetic Resources

Food security, nutrition, and livelihood of the people depend on the plant genetic resources. The richness of plant genetic resources can allow crops to adapt to evolving environmental conditions and sustainable intensification of agricultural production. According to FAO (2020a), the plant genebank holdings in 103 countries, 17

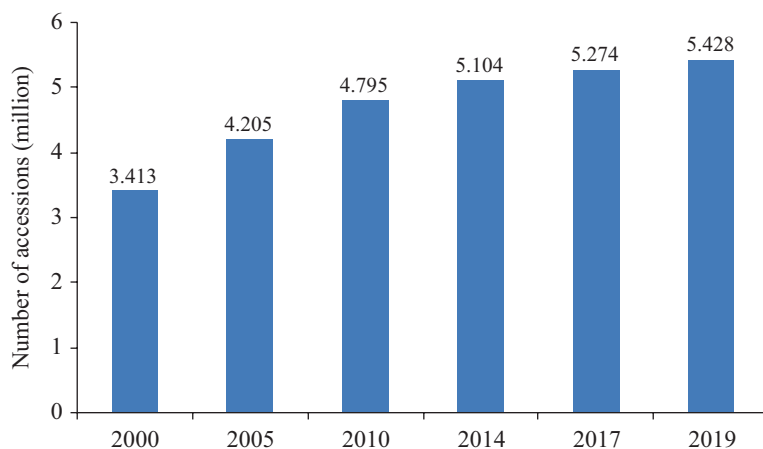


Fig. 1.5 A number of accessions of plant genetic resources secured in medium- or long-term conservation facilities in the world, 2000–2019 (FAO, 2020a)

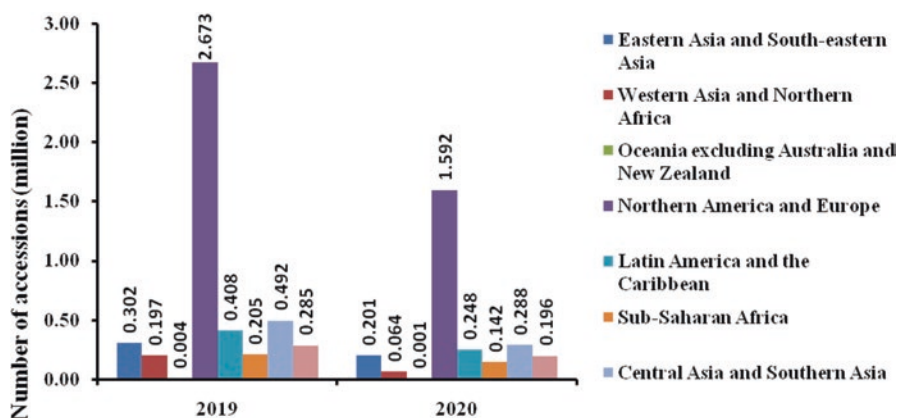


Fig. 1.6 A number of accessions of plant genetic resources secured in conservation facilities under medium- or long-term conditions by region in 2019 and 2020. (Adapted from FAO, 2020a)

regional and international research centers were estimated at 5.43 million accessions in 2019 (Fig. 1.5), which was about a 1% increase on the previous year. The gene bank holdings virtually increased worldwide between 2015 and 2019. Over the year, the conserved germplasm increased in 40 out of 59 countries and 7 out of 12 international centers. However, a net decrease was also reported by FAO (2020a) (Fig. 1.6). A greater than 1% decrease in germplasm was recorded in six countries, out of which three are in Europe and one each in Western Asia (−1.7%), Eastern Africa (−10.7%), and South America (−11.4%).

Almost 96,000 germplasm samples from over 1700 species listed in the IUCN categories of primary global concern were conserved in 290 genebanks around the world by the end of December 2019. These samples include wild relatives of crops

significant for global and local food security (FAO, 2020a). However, in recent years the worldwide response of preserving crop germplasm has been insufficient to the alarming pace of threats posed by climate change to crop and crop-associated diversity. Particularly for crop wild relatives, wild food plants, and neglected and underutilized crop species, the collection and preservation status is low (FAO, 2020a).

A combination of short-lived and perennial crops and timber and non-timber products developed over centuries in rural areas made diverse agricultural systems. Such diversity facilitates the maintenance of biodiversity and lowers nature's degradation (Balvanera et al., 2014; González-Esquivel et al., 2015; Kanter et al., 2018). Though pesticide-based monocultures in the Asia-Pacific region caused a reduction in genetic resources and about 70% decline in the cultivation of native plant varieties (IPBES, 2018).

2.5 Changes in Forest Genetic Resources

Precise monitoring of the status and trends of forest genetic resources as well as monitoring the quality of forest degradation, forest restoration, and species composition are difficult tasks (Newton et al., 2015). The number of extant tree species in the world has been estimated by (Beech et al., 2017) as about 60,000. However, FAO (2014) on The State of the World's Forest Genetic Resources (SoWFGR) listed nearly 8000 species of trees, shrubs, palms, and bamboo, of which about 2400 are actively managed for cultivation, and more than 700 species are now included in tree-breeding programs globally.

About 93% (3.75 billion ha) of the forest area globally is composed of naturally regenerating forests, and 7% (290 million ha) is planted (Figs. 1.7 and 1.8). The size of naturally regenerating forests has decreased since 1990, but the area of planted forests has increased by 123 million ha though the rate of increase slowed down in the last 10 years (FAO, 2020b).

Forest genetic resources are being threatened and eroded globally by converting forests to agriculture, unsustainable harvesting of trees for wood and non-wood products, grazing and browsing, climate change, forest fires, and invasive species (FAO, 2014). Forests cover about 30.6% of the world's land area, and the occupied space is continuously shrinking (FAO, 2018b). The extension of commercial and

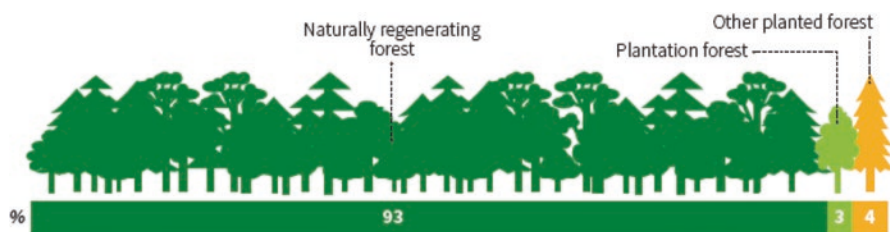


Fig. 1.7 Naturally regenerating versus planted forests, 2020 (% of global forest area) (FAO, 2020b)



Fig. 1.8 Annual net change in the area of naturally regenerating and planted forest, by decade, 1990–2020 (FAO, 2020b)

large-scale agriculture accounted for 40% of forest loss from 2010 to 2015 (FAO, 2016a). On the other hand, smallholder farming accounted for 33% of the failure, urbanization, and infrastructure for 10% each, and mining causing 7% of forest loss (FAO, 2016a). The world has lost 178 million ha of forest since 1990, but the loss rate has slowed down. The quality of net forest loss over the period 1990–2020 has reduced due to a reduction in deforestation in some countries, increases in forest area in others through afforestation, and the natural expansion of forests. The rate of net forest loss declined from 7.8 million ha per year in the decade 1990–2000 to 5.2 million ha per year in 2000–2010 and 4.7 million ha per year in 2010–2020 (Fig. 1.9) (FAO, 2020b).

A reasonable amount of forest (420 million ha) has been lost worldwide through deforestation since 1990 with a declining loss rate. The annual rate of deforestation in the most recent years (2015–2020) has been estimated as 10 million ha, down from 12 million ha in 2010–2015 (Fig. 1.10) (FAO, 2020b).

However, the pattern of forest loss varies considerably from region to region. For example, from 2000 to 2010, the forest-area loss in Latin America, Africa, and Asia was 70%, 35%, and 40%, respectively, due to the transformation to commercial agriculture (Hosonuma et al., 2012).

2.6 Trends in Animal Genetic Resources

Accurately measuring global animal genetic resources is a challenging task due to the under-reporting of national inventories. About 94.5% of local livestock breeds have no information as to their conservation status. Only about 30 countries

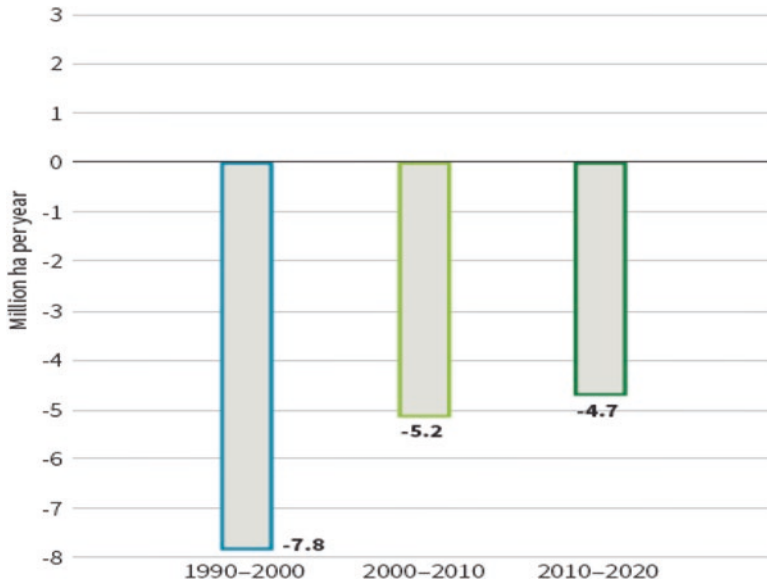


Fig. 1.9 Global annual forest area net change, by decade, 1990–2020 (FAO, 2020b)



Fig. 1.10 Annual rate of forest expansion and deforestation, 1990–2020 (FAO, 2020b)

(majority in Western Europe) report data on this indicator, and even this data is not regularly updated. More than half of these countries have not provided new data since 2015 (FAO, 2020a). Ongoing efforts to preserve animal genetic resources appear inadequate in the face of climate change and the rising demand for livestock products to achieve the SDG for food and agriculture. Between 2010 and 2019, the number of local breeds stored in genebanks increased from 10 to 101. However, it is a fraction of the approximately 7600 species reported globally and is still far from the targeted SDG for food and agriculture. By the end of 2019, 7643 local breeds were registered globally (including extinct ones), out of which 400 (5.2%) were reported with some genetic material stored, and 101 (1.3%) were reported with sufficient material stored to allow them to be reconstituted. This was a little progress

compared to the preceding year when only 3.3% of local animal breeds had some material stored. Only 0.9% had enough material to allow the species to be reconstituted in case of extinction (FAO, 2020a).

An alarming proportion of local breeds are at risk of extinction as the animal genetic resources are not being adequately conserved in medium- and long-term conservation facilities. In 2019, most assessed local livestock breeds (2025 out of 2761) were determined to be at risk of extinction based on their population size, reproductive rates, and other biological characteristics (FAO, 2020a). This is marginally better than 1 year ago when 78% of assessed breeds were determined to be at risk of extinction. However, the results on the risk of extinction for local livestock breeds in different regions differ significantly. For example, 84%, 44%, and 71% of local species are considered at risk in Europe, South America, and South Africa, respectively (FAO, 2020a). For most local breeds around the world (4343), the risk status remains unknown due to a lack of data. Only 77 countries reported data in 2020 – seven more than the previous year (FAO, 2020a).

2.7 Trends in Aquatic Genetic Resources

Marine genetic resources (AqGR) for food and agriculture include both capture fisheries and aquaculture. The growing number of the human population shows an increase in fish consumption of approximately 1.2% annually up to 2030 when the total production of fish and fish products (capture plus aquaculture, excluding aquatic plants) will reach 201 million tonnes (FAO, 2019b). The global production from capture fisheries has plateaued at about 90–95 million tonnes per annum with little scope for additional production, and thereby, the targeted production goal needs to be achieved mainly from aquaculture (Fig. 1.11) (FAO, 2019b).

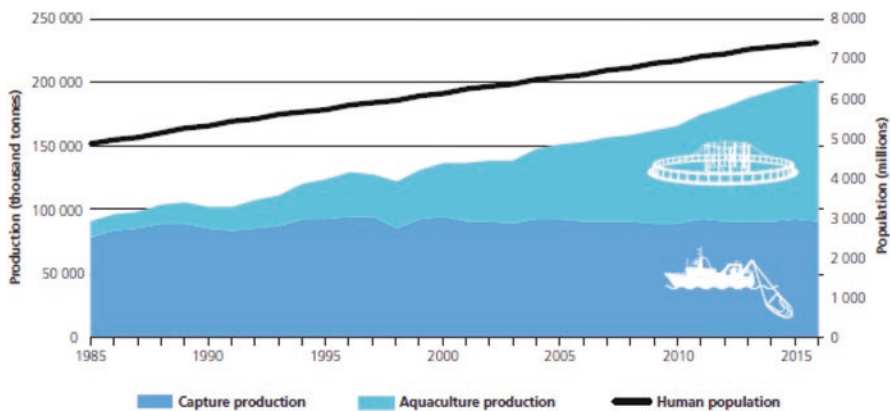


Fig. 1.11 The growth of total aquaculture and capture fisheries production (including aquatic plants) relative to human population growth (FAO, 2020a)

In recent decades, the relatively new food production system named aquaculture is spreading rapidly in the developing countries (FAO, 2019b). Over 1800 species, including fish, crustaceans, molluscs, echinoderms, coelenterates, and aquatic plants have been harvested globally in 2016 (FAO, 2018c) where the farmed marine species occupy comparatively a small portion. FAO recorded a total of 598 species as being cultivated around the world (Table 1.1). The total production from capture fisheries and aquaculture, including aquatic plants, was 202.2 million tonnes in 2016 (Table 1.2). The species diversity of AqGR for food and agriculture includes several phyla as reported by FAO (2018c) and listed in Table 1.3.

Table 1.1 Diversity of aquatic species identified in the wild and the number of farmed and fished species or species items and families represented in FAO production statistics, 2016 (FAO, 2019c)

Taxon	Wild species (marine)	Wild species (freshwater)	Number of farmed species	Number of farmed families	Number of captured species	Number of captured families
Finfish	18,768	12,834	344	80	1452	237
Molluscs	47,844	4998	95	27	151	37
Crustaceans	52,412	11,990	60	13	181	34
Other aquatic animals	^a	^a	15	10	26	13
Aquatic plants	12,128	2614	40	21	29	14
<i>Total</i>	<i>131,152</i>	<i>32,436</i>	<i>554</i>	<i>151</i>	<i>1839</i>	<i>335</i>

^aThese include echinoderms, coelenterates, and tunicates too numerous to list (many of which have no potential as food and are all marine species) and a few amphibians and reptiles

Table 1.2 World total capture fisheries and aquaculture production, 2016 (thousand tonnes, live weight) (FAO, 2019c)

Taxon	Capture fisheries	Aquaculture	Total
Finfish	77,267	54,091	131,359
Molluscs (edible)	6326	17,139	23,465
Molluscs (pearls and ornamental shells)	9	38	47
Crustaceans	6711	7862	14,573
Aquatic invertebrates	608	443	1051
Frogs and turtles	2	495	497
Aquatic plants	1091	30,139	31,230
<i>Total</i>	<i>92,015</i>	<i>110,208</i>	<i>202,223</i>

Table 1.3 Aquatic genetic resources for fisheries and aquaculture, categorized according to phyla (FAO, 2019c)

Phylum	Examples
Aquatic plants (multiple phyla)	Algae (seaweeds and microalgae), vascular plants
Phylum Chordata	Finfish, amphibians, reptiles
Phylum Mollusca	Bivalves (clams, mussels, oysters), gastropods (snails, abalone), cephalopods (octopus, squid)
Phylum Arthropoda	Crabs, shrimps, lobsters, cladocerans, brine shrimp
Phylum Cnidaria	Jellyfish, corals
Phylum Echinodermata	Sea urchins and sea cucumbers

More than 31,000 species of finfish, 52,000 species of aquatic molluscs, 64,000 species of marine crustaceans, and 14,000 species of aquatic plants are there in the world (WoRMS, 2018). In recent days, more species are being farmed than ever before, primarily as more marine fishes are being bred in captivity (FAO, 2016b). FAO (2018c) assessed the state of the world's marine fisheries by analyzing over 400 stocks of fish and reported that the percentage of overfished, maximally sustainably fished, and overfished in 2015 were 33.1%, 59.9%, and 7% respectively. It was also said that the share of fish stocks within biologically sustainable levels (maximally sustainably fished or underfished) declined from 90% in 1974 to 66.9% in 2015 (ibid). A decline in the number of top-level carnivores has been recorded from many marine and inland fisheries (Pauly, 1998), which is referred to as "fishing down the food web" and it reflects the state of overfishing (ibid.). However, in such cases, the productivity of a fishery remains high, especially in inland waters, as lower trophic-level species increase in abundance in the absence of larger predators (Welcomme, 1999).

Aquaculture reflects diversity than fisheries in terms of fish varieties and their environmental tolerances, food habits, feeding strategies, and culture systems. Only a few well-developed farmed types are there in aquaculture, which is highly similar to their wild relatives. Hence the wild relatives in aquaculture are essential fishery resources, but they are also exploited as sources of eggs and broodstock. To support capture fisheries, farmed aquatic species are often released back into the wild, and such interactions highlight the crucial linkages between capture fisheries and aquaculture. This interactivity between cultured species and their wild relatives might cause threats to AqGR through declining populations of important wild relatives on which aquaculture depends (FAO, 2019c).

3 Factors Affecting the Changes in Agro-Biodiversity and Food Chain

The biodiversity that includes crops, animals, and other interacting species of symbionts, pests, parasites, predators, and their competitors is known as agro-biodiversity (Boef, 2000). Such a subset of biodiversity is affected by several factors, which are also associated with the changing of an agro-ecosystem that ultimately affects the food chain. The followings are the major factors influencing the change in an agro-biodiversity:

3.1 Climate Change

Climate changing variables such as drought, heavy rainfall, elevated CO₂, and high temperature significantly affect crop production and quality, dynamics of pests and pathogens, and plant and soil biodiversity (Dwivedi et al., 2013). These

climate-changing variables can also enhance the spread and severity of pathogens (Jeger & Pautasso, 2007), increase infestation of insects (Holton et al., 2003), and infection rate of diseases to cause severe losses in yields (Soriano et al., 2004). Parmesan (2006) demonstrated that the increase in global temperature alone could affect species abundance, their habitats, and interactions with their ecosystems. In a study, Lurgi et al. (2012) showed that global warming sufficiently generated changes in the size structure, distribution, and food web properties of the vertebrates in the Pyrenees. In addition to climate change, soil biodiversity vulnerability has escalated the threats on agro-ecosystems at a global scale (Dwivedi et al., 2013).

3.2 Nutrient Enrichment

Nitrogen and phosphorus are the essential nutrients that are very important for terrestrial as well as aquatic ecosystems (Tilman & Pacala, 1993; Leibold, 1999). Clark et al. (2013) identified nitrogen enrichment as a primary threat to any ecosystem and biodiversity because the more considerable increase of this nutrient can stimulate eutrophication, cause acidification, enhance secondary stressors (i.e., fire, drought, frost, or pests) and directly damage leaves by toxicity. Thus, the vast amount of nitrogen deposition can reduce plant biodiversity that may lead to a reduction in species diversity, loss of habitats, increase infestation of pest organisms, and change in soil microbial activities (McKinney & Lockwood, 1999; Treseder, 2004). Evidence showed that an excessive amount of N and P in a marine ecosystem could cause algae blooms, anoxic conditions, and ocean acidification, leading to kill fish, produce toxins, affect species diversity, disrupt food webs, etc. (Ngatia et al., 2019).

3.3 Homogenization of Agricultural Production Systems

The global agricultural production becomes more homogenized by producing only some very particular species to fulfill the consumers' demand (Thrupp, 2000). The monoculture of fishes and high-yielding varieties (HYV) of rice in India, Bangladesh, and the Philippines decreased rice varieties and fish species (Shiva, 1991; Hussein, 1994). The 'Green Revolution' movement also reduced native species diversity of agricultural items in Africa by producing modern crop varieties following monoculture rather than the polyculture of traditional species (Mann, 1990; IFOAM, 1994). Traditional diverse varieties of bananas, cacao, and cotton are virtually disappeared from South America because of the competitive production of selected high-value export species (Fowler & Mooney, 1990). Many varieties of fruits and vegetables in North America have become extinct because of the selective output of select varieties, while thousands of flax, wheat, oats, and rye vanished after HYVs were introduced in Europe (Harlan & Bennett, 1979; Thrupp, 2000).

3.4 Invasive Species

Many agricultural items are being introduced from one part of the world to another component causing the rehabilitation and establishment of the submitted items outside their natural grounds and in the new ecosystems. The trades, transport, travel, and tourism across the world, accidentally or intentionally, are spreading the invasive species globally. Paini et al. (2016) observed that 40 out of 124 countries are highly invaded by many insect or pathogen species. Some similar studies also reported that species invasion could alter biodiversity (Vilà et al., 2011) and the functionality of the ecosystem (Pejchar & Mooney, 2009). As a consequence of the introduction of non-native species to some areas (such as rabbits and cats in Australia, goats in St. Helena, and American mink in Great Britain), vulnerable ecosystems face threats of losing native species and thereby diminishing biodiversity (Wittenberg & Cock, 2001).

3.5 Genetic Erosion

The loss of genetic diversity in agriculture quantifies the genetic decline as a complete loss of crop varieties or alleles (Tsegaye & Berg, 2007; Willems et al., 2007). As a result, a reduction in richness (i.e., a reduction in the total number of crop varieties or alleles) (Nabhan, 2007) or evenness (i.e., the diversity indices used in vegetation ecology and population genetics) (Ford-Lloyd, 2006) may arise in the agro-ecological systems. Such reductions indicate the erosion of genetic resources. A number of species become endangered and some disappear from agro-biodiversity through this genetic erosion (Hammer & Khoshbakht, 2005). On the other hand, new species are still being domesticated (Boches et al., 2006). Although introducing some closely related species can increase the diversity level of local genetic resources, the ultimate genetic erosion may be caused by the disappearance of traditional species through introgression (Ishikawa et al., 2006).

3.6 Destruction, Conversion, or Degradation of Agro-Ecosystems

Agricultural lands or areas rich in biodiversity are continuously transformed, degraded, or destroyed by urbanization (McDonald et al., 2013), industrialization (Richer, 2008), changes in land use policy (Huijun et al., 2002), alteration of cropping patterns (Mmom, 2009), pollution (Swaminathan, 2003) and natural disasters (Sudmeier-Rieux et al., 2006). Different studies have projected the significant impact of urban growth on the biodiversity of the eco-regions, protected areas across the world, and rare species (McDonald, 2008; McDonald et al., 2013). For example,

the unprecedented industrialization and development of Qatar threatened the ecosystem services and biological diversity, particularly the mega projects for coastal development negatively affected marine species and threatened commercial fishing (Richer, 2008). The desertification and soil salination due to over-exploitation of water also affect the overall condition of biodiversity. Evidence showed that natural disasters negatively affect biodiversity by spreading invasive species, killing mass species, and destroying habitats (Sudmeier-Rieux et al., 2006).

3.7 Unsustainable Management Practices and Pollutions in Agricultural Landscapes

Unsustainable farming practices cause pollution of farming landscapes by using non recommended amounts and banned pesticides and fertilizers. The expansion of agricultural cultivation in forests, marginal and grazing lands, for example, in Nepal, causes the loss of genetic diversity, reduction/extinction of some plant and animal species, change of micro-environment, etc. (Upreti, 2000). Studies also showed that the expansion of agricultural farming reduced species number in tropical forests (Newbold et al., 2014), the land-use changes in Italy declined some Mediterranean species (Falcucci et al., 2007), and the unplanned livestock grazing in Australia was associated with losses of different plant diversity (Eldridge et al., 2015). Recent evidence showed the devastating effects of land-use changes on diverse insect populations essential to many ecosystems (Hallmann et al., 2017; Sánchez-Bayo & Wyckhuys, 2019). The unprecedented climate change and unsustainable shrimp farming increase salinity in the coastal areas (e.g., in Bangladesh), which causing severe anomalies or loss in agro-biodiversities of rice, vegetables, and fruit trees and threatening the production of agricultural commodities (Rahman et al., 2011). Both natural (e.g., climate change) and anthropogenic activities pollute the air, water, and soil (Karmakar et al., 2016; Mo et al., 2017), which ultimately affect agro-biodiversity. Isenring (2010) has placed many examples of how pesticides affect birds, mammals, beneficial insects, aquatic species, and plant communities. Applied fertilizers and pesticides also affect the soil microflora by influencing a range of soil functions and properties (Prashar & Shah, 2016).

3.8 Population Growth and Socio-Economic Factors

In recent decades, rapid population growth poses severe threats to our biodiversity by encroaching on the natural environments to fulfill increasing basic demands (e.g., food, house, medications, job, etc.) (Marques et al., 2019). For instance, rapid population growth, unplanned urbanization, and intense poverty cause severe

pressures on habitats of wilds through deforestation, conversion of agricultural lands, and unsustainable resource exploitation for creating dwelling facilities, expanding municipalities, and producing foods for all (Upreti & Upreti, 2002). The complex combination of environment, socio-culture, and economic factors affect agro-biodiversity in a region (Rana et al., 2007; Paudel et al., 2012). For example, educated farmers tended to have more diverse yields because of better awareness than illiterate farmers (Winters et al., 2006). The changes in socio-economic and demographic characteristics result in higher opportunities for non-agricultural jobs, which create pressure in agricultural production systems by increasing the density of farming throughputs. The natural patterns of organic matter cycling in the agro-ecosystem can no longer be maintained for fossil energy inputs and monoculture (Giampietro, 1997). Thus, agrobiodiversity can be negatively influenced because of the changes in socio-economic and demographic characteristics (Kahane et al., 2013; Marques et al., 2019).

3.9 Overexploitation

Overexploitation is considered one of the most devastating factors that cause a significant decline in the species diversity of different animals (Rosser & Mainka, 2002). For example, bushmeat hunting (Ripple et al., 2016), wildlife poaching and trafficking (Gray et al., 2018), and commercial overfishing (Klautau et al., 2016) put enormous pressure on wild species to be declined. In a study, Rosser and Mainka (2002) showed that overhunting of different species of birds for food and body parts was ranked as the second most threatening factors following habitat loss. Thus, overexploitation, overharvesting, or overhunting of any species must be stopped to keep them protected and thereby ensure the biodiversity to be functioning well.

4 Sustainable Use of Agro-Biodiversity and Food Chain

Sustainability is a complex idea in respect of agro-biodiversity that includes economic, social, and environmental issues. Rotating crops to embrace diversity, planting cover crops, reducing or eliminating tillage, applying integrated pest management, integrating livestock and crops, adopting agroforestry practices etc. are considered as the sustainable approaches. Agro-biodiversity is fundamentally different from other approaches to sustainable development where innovations are based on the co-creation of knowledge, combining science with the traditional, practical, and local experience of producers (FAO, 2018d). The ways followed in agro-biodiversity to empower the producers and communities as critical agents for making a sustainable change have been discussed as follows-

4.1 Managing an Environment Free from Pollution

Pollution is the introduction of contaminants into the natural environment that causes an adverse change (Merriam-Webster, 2020). Our surrounding environment is getting polluted due to human interventions, either industrially and agriculturally, or due to infrastructural developments. Energy conservation should be emphasized, and renewable resources should be encouraged to combat the adverse effects of global pollution and maximum protection of public health (Owusu & Asumadu-Sarkodie, 2016). Measures should be formulated and implemented to reduce pollution and protect surface water, groundwater, and drinking water. To reduce Reuse and recycling of solid and hazardous wastes should be promoted too to ensure maximum protection of public health and safety and preservation of the environment (Lumen Learning, 2020). Increasing concerns about global environmental change and food security have focused attention on the need for environmentally sustainable agriculture. One aspect of this ‘sustainability’ is environmental sustainability (Dicks et al., 2013), which includes efficient use of natural resources and does not degrade the ecological systems that underpin it or deplete natural capital stocks (Dobermann & Nelson, 2013).

4.2 Integrated Management of Land and Water

Water Resources Management is one of the pillars of sustainable ecosystems (Turton et al., 2007). It is related to various sectors like agriculture, industry, domestic water supply, and sanitation, hydropower, health, and environment. Agriculture is the largest water user worldwide but is also a significant polluter; large scale land-use changes impact the hydrology of river basins resulting in the downstream water availability and flood risks (ITT, 2019).

Integrated water resources management (IWRM) is a widely used framework, but water efficiency in agriculture does not figure prominently in many IWRM plans (Calder, 2005; Lenton, 2011). In response to the decreasing availability of water in many regions, a need for a better water management strategy to achieve water productivity in rain-fed agriculture is especially urgent (Duda, 2003). Effective water management is essential for sustainable agriculture, both to produce food crops and for the sustainable production of biofuels and energy. Concepts like “more crop per drop” need to be added in information technologies for controlling irrigation water flow (Rosegrant et al., 2009; Monaghan et al., 2013).

Soil conservation measures are essential for land conservation and rehabilitation (Jahangir et al., 2019). The participation of women in decision-making processes, as the managers of water and land resources, is also essential to ensure the sustainable use of land and water resources (UN Chronicle, 2020).