Plant Bioactive Molecules

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PREFACE

Plants have always been a source of nourishment and care for living beings. Their dual task as producers of nutrients and drugs played a fundamental role in the evolution (and co-evolution) of herbivorous and omnivorous organisms.

The so-called secondary (or special) metabolites are molecules with well-defined functional roles, aimed primarily at defending plants from abiotic (temperature, light, water availability, etc.) and biotic (attacks of herbivores, fungi, bacteria and viruses) stress. The complexity of the molecular structures produced by plants is only equal to their versatility and biodiversity, while the harmonious interweaving of biosynthetic and metabolic pathways offers a perfect picture of the adaptive plasticity of plants as environmental conditions change.

This book is divided into three units to offer the reader a general, biochemical and biotechnological framework of bioactive plant molecules.

The first unit analyses the concepts of biodiversity and sustainability and the functional roles of bioactive molecules, exploring the sites of synthesis and accumulation, the strategies adopted by plants to defend themselves from stress and the use of bioactive molecules as food supplements and as a source for natural medicines to combat diseases. The first unit also includes chemotaxonomy, where bioactive molecules and other secondary products play a fundamental role in support of the identification of plant species.

The second unit describes plant biochemistry with a detailed discussion on the main biosynthetic pathways leading to the synthesis of aromatic compounds (phenols and flavonoids) and terpenes (from volatile substances to phytosterols, to antioxidant molecules such as carotenoids and astaxanthin) to conclude with the biosynthetic pathways leading to the synthesis of nitrogen-containing bioactive molecules, including alkaloids, glucosinolates and cyanogenic glucosides. In this unit, one chapter is also dedicated to oxylipins, describing the biochemistry of jasmonates and green leaf volatiles, substances typical of plant reactions to biotic stress and mechanical damage.

The third and last unit deals with plant biotechnology and the production of bioactive molecules both *in vivo* and *in vitro*. The main techniques are described, such as cell and tissue cultures and root and shoot cultures, with particular attention to the *in vitro* production of bioactive molecules of industrial interest. In addition to the defining of plant biotechnology, a chapter deals with its technological aspects by describing bioreactors, photobioreactors and cryopreservation techniques. The unit concludes with a chapter dedicated to genetic engineering for the production of bioactive molecules, where in addition to the definition of transgenic plants ethical problems, risks and benefits of using recombinant DNA in genetically modified organisms (GMOs) are discussed. Several examples of terpene, phenolic compound and alkaloid engineering are presented along with methods and techniques for industrial application. Molecular pharming is also described, revealing its peculiarities and potential, with examples of bioactive molecules produced to treat infectious diseases and to improve the quality of human life. Finally, a paragraph is dedicated to food safety issues and bioethical considerations.

I wrote this book for science students of university undergraduate and graduate courses, but the language used (especially in the first and third unit) is simple enough to be understood by all people who are interested in bioactive natural molecules. Writing a book on these issues is always a challenge, especially due to the continuous stream of new notions being published every day across hundreds of international scientific journals. The intent was to collect most of the recent notions, being fully aware of the limits imposed by the vastness of the subject.

I wish you a very good reading.

Massimo Maffei

UNIT I

BIODIVERSITY AND THE SITES OF SYNTHESIS, FUNCTIONAL ROLES, PHYTOCHEMISTRY AND CHEMOTAXONOMY OF BIOACTIVE PLANT MOLECULES

CHAPTER ONE

BIODIVERSITY AND ITS DISTRIBUTION, AND CHARACTERIZATION OF BIOACTIVE PLANT MOLECULES

Biodiversity, or biological diversity, is a global concept of biology that includes the analysis and description of variability in living forms, whether it is related to microbes, plants or animals present in aquatic and terrestrial ecosystems. This concept can be further extended to molecules produced by living organisms, regardless of their function or biosynthetic pathway.

In the biosphere, there are many areas of biodiversity and the most common are insects, ranging from 2 to 5 million species, angiosperms, with more than 275,000 species known, and the broad area of secondary (or specialized) metabolites, which exceeds 100,000 known molecular structures.

Biodiversity is present below ground, where billions of microorganisms live, and above ground, where weeds and spontaneous plants seem to confirm the concept that nature ultimately prevails.

There are about 275,000 plant species on our planet and about 33,000, or 12.5%, are threatened with extinction. This is a sad reality that, alongside 11% of bird species being endangered, shows how biodiversity is imperilled, especially in those areas where human intervention is devastating. Plants, which comprise about 370 families, are distributed all over the world in all its almost 200 countries, but 91% of plant families are concentrated in only one country, linking the potential danger of their extinction to national, social and economic conditions.

1.1. Biodiversity

The concept of biodiversity includes diversity within species, between species and among ecosystems. Molecular plant biodiversity is a topic of great interest because it reflects the impressive diversity in the chemical structures produced by individual species. The concept can be extended to several ecosystems and resized to a smaller scale such as a given nation, a park, a group of plants and even one species.

The term “biodiversity” became popular after the signing by 168 countries of the “Convention on Biological Diversity” (see below). Today, “biodiversity” is a term familiar to many: almost no research programme with an ecological intent can avoid considering biodiversity. Similarly to the term “ecology”, coined more than 60 years ago, the term “biodiversity” has been used by several social groups with different aims and goals.

The most recent interpretations of the term “biodiversity” are not limited to the concept of “species richness”, but rather are also related to varieties, races, life forms and genotypes, as well as types of landscape, habitats and structural elements (e.g., shrubs, stone walls, bushes, ponds).

Biodiversity is assessed by the classification criteria used in taxonomy. Biosystematics, which includes taxonomy, is a powerful tool for studying biodiversity and makes use of biological disciplines such as evolution, phylogeny, genetics and phytogeography.

Another important component in the study of biodiversity is the evaluation of the genetic diversity which, within species, allows a certain individual to evolve under environmental pressures and natural selection. The variability we observe among individuals (the phenotype) is partly the result of the interaction between genetic differences (the genotype) and the surrounding environment. In the specific case of many secondary metabolites such as monoterpenes, the genotypic expression can be influenced by several factors, both biotic (such as herbivore attack) and abiotic (such as environmental changes). Biodiversity is mainly based on speciation – the formation of a new species – which follows three basic steps: (i) it begins with the existence of a species; (ii) is associated with genetic changes; and (iii) closely depends on the ecological context. Taxonomic groups and eco-regions shape the “lenses” with which biodiversity is valued and preserved. According to some authors, the design of effective conservation strategies requires the examination of groups of eco-regional or biome-specific indicators, rather than a tight set of global indicator groups.

Locations of and threats to biodiversity are distributed unevenly, so prioritizing is essential to the minimization of biodiversity loss. To meet this goal, biodiversity conservation organizations have put forward real models of global priority. Most models give priority to heavily irreplaceable regions; some others are reactive (favouring high vulnerability) while others again are proactive (with less priority given to vulnerability).

Plants, as we will discuss in the next paragraph, are not uniformly distributed on our planet and this is primarily due to historical, causal and functional reasons. Historical causes are studied by biogeography, which assesses the nature of events that occurred during the various historical eras. The drift of continents and the impossibility of plants crossing the oceans that formed from the separation of the land that emerged is a compelling example. Physical isolation caused the independent evolution of the various species and greatly contributed to the facilitating of biodiversity. Climatic zones, variable soil nature, altitude and selective pressures imposed by herbivores as well as natural disasters have contributed greatly to the variability of biological forms present on our planet. The formation of new species following spatial separation (allopatric speciation) is particularly common in animals, but as we will see, it also occurs in the plant kingdom.

The loss of genetic variability in a population reduces its ability to respond to the environment and reduces the possibility of rehabilitating a given habitat. The number of species present is therefore directly proportional to the ability of certain ecosystems to withstand environmental adversities.

How does human action affect ecosystems and biodiversity? Humans have been surrounded by biological diversity for millions of years and have made biodiversity one of the main resources by which to nurture, heal, build, gain energy and much more. Optimally, the resources used by humans are renewable, but often the abuse or misuse of these resources can lead to their extinction. It is evident that the expansion of the ecological niche partly occupied by humans some tens of thousands of years ago has inevitably reduced the niche occupied by animals and plants and inevitably reduced biodiversity. Humans are one of the main causes of extinction. For instance, it is estimated that in the past 400 years more than 600 plant species have become extinct due to human intervention.

The extinction of species is also a natural factor, and the most obvious example is the extinction of dinosaurs, which dominated Earth millions of years before the appearance of humans. The extinction of a species can occur because of natural catastrophes, such as volcanic eruptions or tsunamis, or simply because of the genetic inability to adapt to environmental changes, even in the long run. Small populations are more likely to be at risk of extinction, but some of the most significant current causes are environmental degradation, the over-exploitation of natural resources and the introduction of exotic species.

Yet humans rely for most of their activities on biodiversity. For instance, the bioactive compounds of one prescription drug out of four are made from plant extracts and the pharmaceutical and biotechnology industries are increasingly searching for natural areas exhibiting the greatest expression of biodiversity, where thousands of species are still to be discovered or analysed. Some industries are paying property rights in selected countries to preserve seriously endangered areas. However, while there are hundreds of thousands of potentially usable species, the plant kingdom is also characterized by a remarkable biochemical redundancy. However, the increasing population and the continuous search for cultivatable land lead to the progressive and seemingly unstoppable destruction of rainforests, with irreversible consequences for biodiversity and unimaginable losses of unknown resources. The rise of biotechnology has recently led some anthropologists towards the ethically and philosophically stimulating field of bioprospecting, the searching for genetic and biochemical resources of commercial value. It is an innovative arena that can help produce new therapies while preserving traditional medical systems and biological and cultural diversity by showing their medical, economic and social value, and by bringing biotechnology and other benefits to poor countries which are rich in biodiversity but poor in technology.

1.1.1. Distribution of Biodiversity

Medicinal plants are undoubtedly one of the most fascinating categories of plants in large part because they are sources of bioactive molecules. About 80% of the nearly 30,000 known natural products derive from plants, and in addition, some specialized metabolites are unique to the plant kingdom, not being produced by microbes or animals.

The distribution of medicinal plants can be classified geographically based on the centres of origin of certain species:

- **North American**: *Echinacea angustifolia*, *Hamamelis virginiana*, *Sassafras officinale*, *Lobelia inflata*, *Hydrastis canadensis* and *Podophyllum peltatum*;
- **South and Central American**: *Vanilla planifolia*, *Carica papaya*, *Aloe vera*, *Erythroxylon coca*, *Ilex paraguariensis*, *Theobroma cacao*, *Dioscorea composita* and *Echinocactus williamsii*;
- **Mediterranean**: most of the Lamiaceae, *Valeriana officinalis*, *Digitalis purpurea*, *Crocus sativus*, *Laurus nobilis*, *Foeniculum vulgare*, *Glycyrrhiza glabra*, *Colchicum autumnale* and *Atropa belladonna*;
- **African**: *Acacia senegal*, *Ricinus communis*, *Cassia acutifolia*, *Datura stramonium*, *Rauwolfia vomitori* and *Physostigma vevenosum*;
- **Madagascan**: *Eugenia caryophyllata*, *Catharanthus roseus* and *Piper nigrum*;
- **Indian**: *Rauwolfia serpentina*, *Datura* spp., *Cannabis sativa* var. *indica*, *Curcuma longa*, *Strychnos nux-vomica*, *Cinnamomum zeilanicum*, *Cassia angustifolia*, *Zingiber officinale* and *Dioscorea* spp;
- **Asian**: *Papaver somniferum*, *Panax ginseng*, *Rheum* spp., *Cinnamomum camphora*, *Thea sinensis* and *Vaccinium myrtillus*;
- **Indonesian**: *Myristica fragrans*, *Illicium verum*, *Eugenia caryophyllata* and *Piper methysticum*;
- **Australian**: *Eucalyptus* spp. and *Duboisia myoporoides*.

Certainly one of the most important centres of origin of aromatic and medicinal plants is the Mediterranean basin. This area is difficult to define because it does not coincide with any political boundaries and is characterized by nations of different ethnic groups and climates.

According to some authors, the importance of the Mediterranean region derives from a number of considerations, including the high variability of soil and climatic conditions, which have favoured the high biodiversity of plant species, and the fact that it contains high proportions of annual species belonging particularly to the Caryophyllaceae, Brassicaceae, Asteraceae and Apiaceae.

1.1.2. Actions to Sustain Biodiversity

What are humans doing to prevent the progressive depletion of biological diversity? One of the firmest answers to this question was provided by the

Council of Europe's Convention on the Conservation of European Wildlife and Natural Habitats (1979), or the Bern Convention, that was the first international treaty to protect both species and habitats and to get countries together to decide how to act on nature conservation. The Convention aimed to ensure conservation of wild flora and fauna and their habitats. Special attention was given to endangered and vulnerable species, including selected endangered and vulnerable migratory species.

Another important step was the *Convention on Biological Diversity* (CBD), which was signed by a number of nations during the United Nations Environment Conference held in Rio de Janeiro in June 1992 and that became effective on 29 December 1993. The objectives of the Convention are the conservation of biodiversity, the sustainable use of its components and the true sharing of benefits coming from the exploitation of genetic resources, including the access to such resources and the transfer of relevant technologies. The countries that signed the Convention have the sovereign right to exploit the resources of their territory and the duty to make sure that activities within their jurisdiction do not harm the environment of other neighbouring states. The main task of each state will be to identify those components of biodiversity that need to be conserved and used in a sustainable manner and to monitor identified areas by giving priority to those with the greatest need for immediate intervention. An important task that each country will have to carry out is to respect, retain and maintain the knowledge, innovations and practices adopted by indigenous and local communities by promoting those lifestyles inherent to conservation and sustainable use of biodiversity and by promoting the application of such knowledge, always upon the consent of the people who hold the rights. In the case of developing and underdeveloped countries, actions to preserve biodiversity *in situ* will be particularly important. Nevertheless, the *ex situ* conservation of biodiversity components should be likewise favoured, preferably in the country of origin of such resources.

An interesting aspect of the CBD is education and educational programmes. However, these programmes are not aimed at the education of indigenous populations on the use of biodiversity because indigenous peoples have a cultural heritage that needs to be valued. Instead, attention should be paid to educating people scientifically and technically on species identification, on *in situ* and *ex situ* conservation, and on the sustainable use of biodiversity and its components. Biodiversity conservation research should be promoted and encouraged. Only through the conservation of biological complexity will it be possible to obtain the best results in the search for bioactive molecules for medical and pharmaceutical applications.

Priority policies for the countries that undersigned the CBD will be environmental risk assessment and management of potentially biodiversity-threatening practices as well as the immediate reporting of any ecological disturbances to avoid disasters in neighbouring areas.

An important innovation is the concept that the genetic resources of a country remain under its absolute jurisdiction and that these resources are subject to national legislation. At the same time, however, each country will have to provide the countries that contract with it free access to genetic resources to be used for environmental protection purposes. In any case and always, the exploitation of genetic resources by a second country will have to be authorized by the government of the first country. Agreements between research institutes or individuals who are non-representative of their own country will not be sufficient. In many cases, the escape of genetic resources from a country has been caused by personal and non-governmental contacts with universities, research institutes, industries or corporations. Now, with the CBD, member countries can enact biodiversity protection laws that can pursue those who take a free initiative in managing genetic resources. Therefore, member countries will have to monitor ecosystems and habitats that contain high density, high endemic or endangered species of social, economic, cultural and scientific importance, or which are representative, unique or associated with evolutionary or other biological processes.

At present, relatively few countries have set clear and well defined priorities to be applied for biodiversity management. When applied, they have suffered from a lack of population participation and they have often ignored those social, economic and institutional factors that play an important role in deciding how to handle a conservation problem. Economic incentive policies have been followed by many countries, both in the developed and developing economies. Their application has certainly sensitized populations to the problem of biodiversity conservation with the hope of assimilating the concept of sustainability of genetic resources in their minds. However, incentives are not enough to preserve biodiversity. People's activities need to be regulated, especially when biodiversity conservation becomes a social factor. Legislation-related laws and traditions have proven incredibly effective in preserving and managing biodiversity for hundreds of years in some African and Asian countries.

Table 1.1 lists the key terms of the CBD.

Table 1.1 – Glossary of terms used in the Convention on Biological Diversity

Biological diversity – 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 ecosystems.
Biological resources – includes genetic resources, organisms or parts thereof, populations, or any other biotic component of the ecosystems with actual or potential use or value for humanity.
Biotechnology – any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific use.
Country of origin of genetic resources – the country which possesses those genetic resources in *in situ* conditions
Country providing genetic resources – the country supplying genetic resources collected from *in situ* sources, including populations of both wild and domesticated species, or taken from *ex situ* sources, which may or may not have originated in that country.
Domesticated or cultivated species – species in which the evolutionary process has been influenced by humans to meet their needs.
Ecosystem – a dynamic complex of plant, animal and microorganism communities and their non-living environment interacting as a functional unit.
***Ex situ* conservation** – the conservation of components of biological diversity outside their natural habitats.
Genetic material – any material of plant, animal, microbial or other origin containing functional units of heredity.
Genetic resources – genetic material of actual or potential value.
Habitat – the place or type of site where an organism or population naturally occurs
***In situ* conditions** – conditions where genetic resources exist within ecosystems and natural habitats, and in the case of domesticated or cultivated species, in the surroundings where they have developed their distinctive properties.
***In situ* conservation** – the 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.

Protected area – a geographically defined area which is designated or regulated and managed to achieve specific conservation objectives.	
Regional economic integration organization – an organization constituted by sovereign States of a given region, to which its member States have transferred competence in respect of matters governed by this Convention and which has been duly authorized, in accordance with its internal procedures, to sign, ratify, accept, approve or accede to it.	
Sustainable use – 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.	
Technology – includes biotechnology.	

In 1994, the UK Government published “Biodiversity: the UK Action Plan”, and a UK Plant Conservation Strategy was presented along with this action plan. The Strategy is a framework for the conservation of the native flora of Great Britain and Northern Ireland, officially approved by the statutory conservation agencies (including the Joint Nature Conservation Committee, English Nature, the Countryside Council for Wales, Scottish Natural Heritage and the Department of the Environment for Northern Ireland). The aim of the Strategy is to maintain the character and diversity of the natural flora of the UK and to ensure the viability of species.

The *Global Plan of Action* for the Conservation and Sustainable Utilization of Plant Genetic Resources for Food and Agriculture was formally adopted by representatives of 150 countries during the Fourth International Technical Conference on Plant Genetic Resources, which was held in Leipzig, Germany, from 17 to 23 June 1996. The Conference also adopted the Leipzig Declaration, which focuses on the importance of plant genetic resources for world food security, and commits countries to implementing the Plan. The FAO (Food and Agriculture Organization of the United Nations) is committed to carrying out the Global Plan of Action, under the guidance of the intergovernmental Commission on Genetic Resources for Food and Agriculture, as part of the FAO Global System for the Conservation and Utilization of Plant Genetic Resources.

The Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization (ABS, from Access and Benefit Sharing) of the Convention on Biological Diversity is a supplementary agreement to the CBD. It provides a transparent legal framework for the effective implementation of one of the three objectives of the CBD: the fair and equitable sharing of benefits arising out of the utilization of genetic resources. A significant innovation of the Protocol is the specific obligation of the party to support compliance with national legislation – or regulatory requirements – providing genetic resources and mutually agreed contractual obligations. These compliance provisions, as well as the provisions that lay down the most predictable conditions for the access to genetic resources, help to ensure the sharing of benefits when genetic resources are taken up by those who provide them. In addition, the provisions of the Protocol will strengthen the ability of communities to benefit from the use of their knowledge, innovations and practices. By promoting the use of genetic resources and related traditional knowledge, and by strengthening the opportunities for fair and equitable sharing of the benefits of using them, the Protocol aims to create incentives to preserve biodiversity, use its components in a sustainable way and to further improve the contribution of biological diversity to sustainable development and human well-being.

The Conference of Participants to the CBD held its twelfth meeting in Pyeongchang, Republic of Korea, (6–17 October 2014) and its thirteenth meeting in Cancun, Mexico (4–17 December 2016). It was recognized by the majority of participants that the actual trend could not continue and that the post-2016 agenda should support a transformational approach based on consumption and production within the planetary boundaries, integrating biodiversity in all sectors, building synergies and working through "innovative" partnerships with the participation of all ministries and academia, civil society and the private sector for a sustainable future.

The 2011–2020 Strategic Plan for Biodiversity is a decennial framework action brought by all countries and stakeholders to save biodiversity and improve people's benefits. The Strategic Plan is based on a shared vision, mission, strategic goals and 20 ambitious goals still attainable, collectively known as *Aichi's goals*. The Strategic Plan serves as a flexible framework for defining national and regional objectives and promotes the coherent and effective implementation of the three objectives of the CBD. Table 1.2 lists Aichi's goals. (For further information and developments of the CBD link to http://www.cbd.int.)

Table 1.2. The Aichi Biodiversity Targets

Strategic Goal A: Address the underlying causes of biodiversity loss by mainstreaming biodiversity across government and society
1. By 2020, at the latest, people are aware of the values of biodiversity and the steps they can take to conserve and use it sustainably
2. By 2020, at the latest, biodiversity values have been integrated into national and local development and poverty reduction strategies and planning processes and are being incorporated into national accounting, as appropriate, and reporting systems.
3. By 2020, at the latest, incentives, including subsidies, harmful to biodiversity are eliminated, avoid negative impacts, and positive incentives for the conservation and sustainable use of biodiversity are developed and applied, consistent and in harmony with the Convention and other relevant international obligations, taking into account national socio economic conditions
4. By 2020, at the latest, Governments, business and stakeholders at all levels have taken steps to achieve or have implemented plans for sustainable production and consumption and have kept the impacts of use of natural resources well within safe ecological limits.
Strategic Goal B: Reduce the direct pressures on biodiversity and promote sustainable use
5. By 2020, the rate of loss of all natural habitats, including forests, is at least halved and where feasible brought close to zero, and degradation and fragmentation is significantly reduced.
6. By 2020 all fish and invertebrate stocks and aquatic plants are managed and harvested sustainably, legally and applying ecosystem based approaches, so that overfishing is avoided, recovery plans and measures are in place for all depleted species, fisheries have no significant adverse impacts on threatened species and vulnerable ecosystems and the impacts of fisheries on stocks, species and ecosystems are within safe ecological limits.
7. By 2020 areas under agriculture, aquaculture and forestry are managed sustainably, ensuring conservation of biodiversity.
8. By 2020, pollution, including from excess nutrients, has been brought to levels that are not detrimental to ecosystem function and biodiversity.
9. By 2020, invasive alien species and pathways are identified and prioritized, priority species are controlled or eradicated, and measures are in place to manage pathways to prevent their introduction and establishment.

10.	By 2015, the multiple anthropogenic pressures on coral reefs, and other vulnerable ecosystems impacted by climate change or ocean acidification are minimized, so as to maintain their integrity and functioning.
Strategic Goal C: Improve the status of biodiversity by safeguarding ecosystems, species and genetic diversity	
11.	By 2020, at least 17 per cent of terrestrial and inland water, and 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscape and seascapes.
12.	By 2020 the extinction of known threatened species has been prevented and their conservation status, particularly of those most in decline, has been improved and sustained.
13.	By 2020, the genetic diversity of cultivated plants and farmed and domesticated animals and of wild relatives, including other socio-economically as well as culturally valuable species, is maintained, and strategies have been developed and implemented for minimizing genetic erosion and safeguarding their genetic diversity.
Strategic Goal D: Enhance the benefits to all from biodiversity and ecosystem services	
14.	By 2020, ecosystems that provide essential services, including services related to water, and contribute to health, livelihoods and wellbeing, are restored and safeguarded, taking into account the needs of women, indigenous and local communities, and the poor and vulnerable.
15.	By 2020, ecosystem resilience and the contribution of biodiversity to carbon stocks has been enhanced, through conservation and restoration, including restoration of at least 15 per cent of degraded ecosystems, thereby contributing to climate change mitigation and adaptation and to combating desertification.
16.	By 2015, the Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization is in force and operational, consistent with national legislation.
Strategic Goal E: Enhance implementation through participatory planning, knowledge management and capacity building	
17.	By 2015 each Party has developed, adopted as a policy instrument, and has commenced implementing an effective, participatory and updated national biodiversity strategy and action plan.

18.	By 2020, the traditional knowledge, innovations and practices of indigenous and local communities relevant for the conservation and sustainable use of biodiversity, and their customary use of biological resources, are respected, subject to national legislation and relevant international obligations, and fully integrated and reflected in the implementation of the Convention with the full and effective participation of indigenous and local communities, at all relevant levels.
19.	By 2020, knowledge, the science base and technologies relating to biodiversity, its values, functioning, status and trends, and the consequences of its loss, are improved, widely shared and transferred, and applied.
20.	By 2020, at the latest, the mobilization of financial resources for effectively implementing the Strategic Plan 2011–2020 from all sources and in accordance with the consolidated and agreed process in the Strategy for Resource Mobilization should increase substantially from the current levels. This target will be subject to changes contingent to resources needs assessments to be developed and reported by Parties

A new concept emerging from the conferences dedicated to the study of methods and strategies for the conservation of biodiversity is sustainability. We will discuss this concept in the next section.

1.2. Sustainability

Sustainability is a general concept applicable to social, economic, environmental and agricultural considerations. Although these four categories have many common points, the greatest overlap is between economic, environmental and agricultural sustainability. In very general terms, the term sustainability encompasses the use of components of biological diversity in a way and at a rate that does not lead to the long-term decline of natural resources, thereby maintaining its potential to meet the needs and aspirations of present and future generations.

From a social point of view, the main objective of sustainability is to reduce poverty, and some social scientists place social sustainability above any other sustainability. The reduction of poverty can only be achieved through qualitative development, fair distribution of wealth and community strength, rather than demographic growth control. Countries that fully and successfully adopt the criteria of social sustainability are those with a more “peaceful” lifestyle, compared to nations suffering from economic and social insecurity. Once social sustainability is achieved, populations can easily move towards commitment to environmental sustainability, thus achieving a sustainable development. Sustainable development integrates all four categories of sustainability mentioned above and is defined by the WWF as “the enhancement of the quality of human life combined with the ability to support ecosystems”. Sustainable environmental development implies in any case more sustainability for production and consumption than for the growth of a sustainable economy. It follows that a priority for sustainable development is the increase of human well-being in terms of reduction of poverty, illiteracy, hunger, disease and inequality. The key task of environmental sustainability is to sustain global life-support systems indefinitely (this referring principally to those systems maintaining human life). Protecting human life is the main anthropocentric reason humans seek environmental sustainability. Human life depends on species for food, shelter, breathable air, plant pollination, waste assimilation and other environmental life-support services. It is difficult to predict what choices will be required to sustainably maintain the environment, but surely we will not be able to sustain less than what remains of the existing environment. In other words, we can define environmental sustainability as “maintenance of Nature capital”. The fundamental point is that environmental sustainability is a natural science concept and obeys biophysical laws. This general definition seems to be robust irrespective of country, sector or future epoch.

While, on the one hand, the application of sustainability principles to intensively cultivated areas in countries with high industrial and socio-economic development is aimed at improving living conditions and controlling the environmental impact of humans, on the other hand, it serves to increase the long-term biological potential in those marginal lands that suffer from poor fertility and depletion of organic matter. Sustainable development of agriculture requires an in-depth study of some key themes that include the knowledge and management of the rhizosphere (the space around the roots of plants), the evaluation of the benefits and risks of modifying these processes and the contribution and the limits of biotechnology to improve the productivity of transgenic plants (see also Chapter 12).

Farmers who practice sustainable agriculture must rely on a continuous network of information, new technologies and innovations that are instrumental to succeeding in the management of their farmland. However, it remains to be determined whether the current agricultural extension scheme is capable of achieving sustainable farming. The role of the agricultural extension is to facilitate the learning process. This involves facilitating:

- the process of community development and innovation;
- the process of collective and individual learning of innovation (technical and social) to improve the community's ability to innovate; and
- the management of rural knowledge.

Sustainable agricultural production is necessary to ensure both global food safety and environmental safety. Conservation agriculture is gaining popularity around the world for such sustainable strategies as permanent soil cover, soil low-sturgeon, crop rotation and integrated pest management. The control of weeds is the biggest challenge in the adoption of conservation agriculture.

Systems with a high sustainability make the best use of environmental resources and services. The key principles for sustainability are:

- integrating biological and ecological processes such as nutrient cycling, nitrogen fixation, soil regeneration, allelopathy, competition, predation and parasitism into food production processes;
- minimizing the use of non-renewable inputs that cause harm to the environment or to the health of farmers and consumers;
- making productive use of the knowledge and skills of farmers, thus improving their self-reliance and substituting human capital for costly external inputs; and
- making productive use of people's collective capacities to work together to solve common agricultural and natural resource problems, such as for pest, watershed, irrigation, forest and credit management.

What is the meaning of sustainability with regard to natural resources? What is to be sustained, for how long and for whom? Many difficulties arising when trying to define sustainability become more apparent if we consider the concept of unsustainability, which is the complementary side of sustainability. However, in this way only the limits of uncertainty are seen and this does not contribute to the development of models and