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Partnership on Sustainable Agriculture and Mitigation to Climate Change

REPORT ON THE EU INSTITUTIONAL FRAMEWORK REGARDING POLICIES AND REGULATIONS ON AGRICULTURAL BIODIVERSITY, ORGANIC AND "CLIMATE-SMART" AGRICULTURE

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1. Introduction to Biodiversity

1.1. Biodiversity: Importance, Definition(s) and Meaning(s)

Biodiversity, abbreviated from the terms 'biological' and 'diversity', encompasses the variety of life-forms found at all scales of biological organisation, ranging from genes to species to ecosystems [1].

According to [2], the term "biodiversity" is quite a recent term, that was coined in the USA during the "National Forum on Biodiversity," which took place in September 1986 under the patronage of the National Academy of Science and the Smithsonian Institute in Washington DC. This forum was conceived by Dr. Rosen who introduced the term **biodiversity**, which aptly represents, as well as any term can, the vast array of topics and perspectives covered during the Washington forum [3].

The term Biodiversity should serve as a keyword, which connects impartial scientific realisations and conceptions of moral values, in order to clarify the decrease of biological diversity as central problem of mankind [2].

Greater biodiversity in ecosystems, species, and individuals leads to greater stability [4]. For example, species with high genetic diversity and many populations that are adapted to a wide variety of conditions are more likely to be able to weather disturbances, disease, and climate change. Greater biodiversity also enriches us with more varieties of foods and medicines.

Biodiversity does encompass a significant component of scientific inquiry, of course [5]. Scientists define biodiversity as the variety of all living organisms on Earth and at all levels of organization (Figure 1). It incorporates living things from all parts of the globe, including land, sea and fresh waters. It constitutes all forms of life – bacteria, viruses, plants, fungi, invertebrate animals, animals with backbones – and not just the things we can see or prey upon. Biodiversity includes human beings too.

Biodiversity is increased by genetic change and evolutionary processes and reduced by habitat destruction, population decline and extinction [1]. There is a growing recognition that the level of biodiversity is an important factor in influencing the resilience of ecosystems to disturbance.

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Recognizing that the appropriateness of a particular definition depends on the audience, DeLong [6] suggested several possible definitions for Biodiversity that are consistent with his findings. The DeLong's general/comprehensive definition for Biodiversity is presented below.

Biodiversity is a state or attribute of a site or area and specifically refers to the variety within and among living organisms, assemblages of living organisms, biotic communities, and biotic processes, whether naturally occurring or modified by humans. Biodiversity can be measured in terms of genetic diversity and the identity and number of different types of species, assemblages of species, biotic communities, and biotic processes, and the amount (e.g., abundance, biomass, cover, rate) and structure of each. It can be observed and measured at any spatial scale ranging from microsites and habitat patches to the entire biosphere.

This definition is consistent with the meanings of the terms from which biodiversity was derived, i.e., diversity and biological [6] and allows for modification according to the context in which it is used [7].

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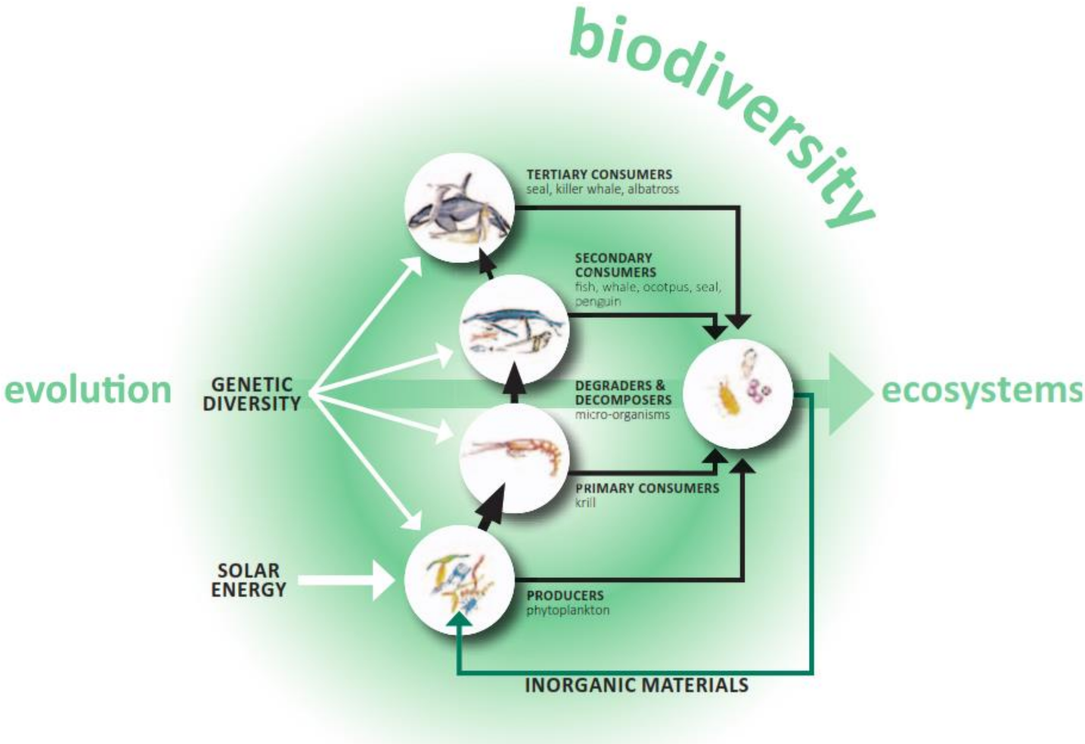
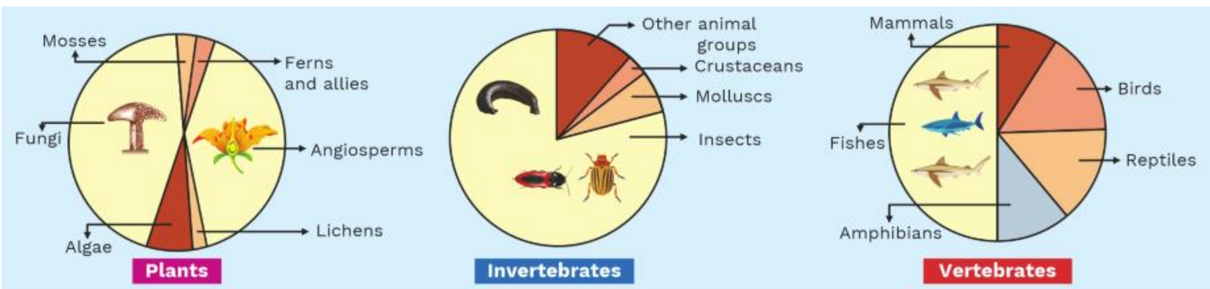


Figure 1 [5]: Biodiversity is the web of life
This pictorial representation begins on the left with the evolutionary processes giving rise to the genetic diversity of living organisms, showing the organisation of the species carrying genetic diversity into food chains of producers (driven by energy from the sun), consumers and decomposers, and the ecosystems that the organisms make up. The diagram depicts a marine food chain.

“Biological diversity” means the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems [8], Figure 2 [9].

Biodiversity [10] includes not only the world's species with their unique evolutionary history (it is 4.5 billion years of evolution, embodied [11]), but also genetic variability within and among populations

Figure 2 [9]: Representation of global biodiversity of major taxa of plants, invertebrates and vertebrates.



of species and the distribution of species across local habitats, ecosystems, landscapes, and whole continents or oceans.

Biodiversity refers to the infinite variety of life forms; genetic diversity – variation of genes within individual species, species diversity – variety of species in flora and fauna, and ecosystem diversity – variety of ecosystems, such as rainforests, coral reefs and deserts, that exist on our planet [12].

1.2. Levels of biodiversity

Biodiversity is a complex term that includes not only the variety of different animals (species diversity) but also the difference between animals of the same species (genetic diversity) and between ecosystems (ecosystem diversity) [1].

According to Convention on Biological Diversity [8], biodiversity is usually explored at three levels: genetic diversity, species diversity and ecosystem diversity (Figure 3 [13]). These three levels work together to create the complexity of life on Earth [14].

1.2.1. Genetic diversity

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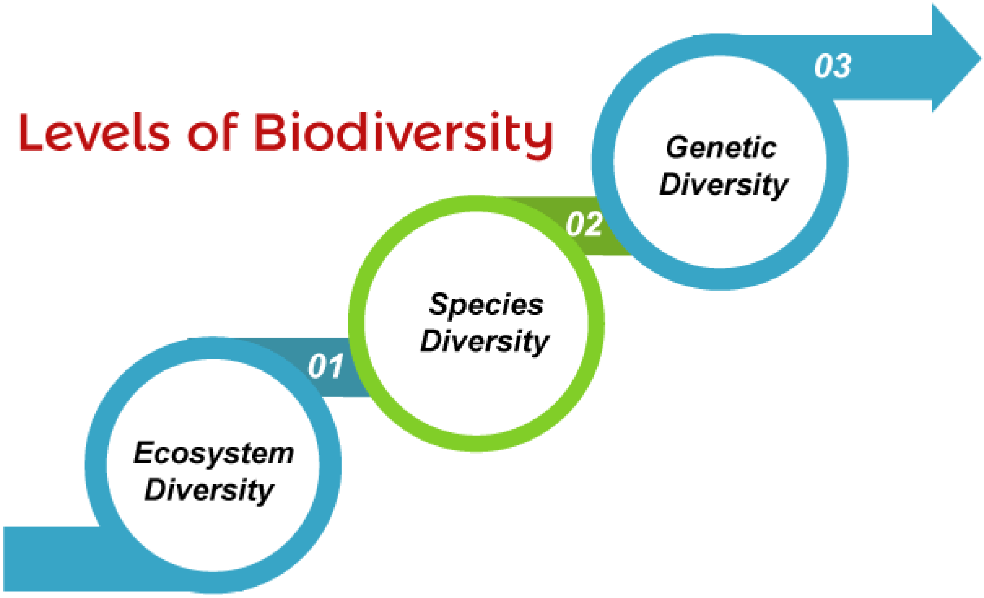

Figure 3 [13]: The three levels of biodiversity

Genetic Diversity: within a species, genetic diversity refers to the number of genes present; **Species Diversity**: the diversity of species observed within a habitat or region is referred to as species diversity; **Ecosystem Diversity**: the diversity of habitats in a specific location is referred to as ecosystem diversity.

Genes are the basic units of all life forms on Earth. They are responsible for both the similarities and the differences between organisms [14].

Genetic diversity refers to the variation in the genetic composition of individuals within or among species [15]. Genetic diversity enables the population to adapt to its environment and respond to natural selection. The amount of genetic variation is the basis of speciation. Genetic diversity occurs at several levels of organization, such as among higher taxonomic categories such as kingdoms, phyla and families, among species and among populations (Figure 4 [16]).

To conserve genetic diversity, different populations of a species must be conserved [14].

Failure to maintain genetic diversity limits the capacity for a population to adapt, making it vulnerable

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to even small changes in the environment and increasing the likelihood of extinction [1].

1.2.2. Species diversity

Historically, species are the fundamental descriptive units of the living world and this is why biodiversity is very commonly, and incorrectly, used as a synonym of species diversity, in particular of "species richness" [7].

According to the *biological species concept*, species are groups of actually or potentially interbreeding natural populations, which are reproductively isolated from other such groups [15, 17]. Species diversity refers to the variety of species within a habitat [14] or a region [14, 15], i.e., species richness [15].

In the broad sense, species diversity includes *species richness* (the number of species in a community) as well as *species evenness* (the relative abundance of each species), Figure 5 [15]. Some habitats, such as rainforests and coral reefs, have many species [14]. Others, such as salt flats or a polluted stream,

Figure 4 [16]: The four Genetic Essential Biodiversity Variables (EBVs; bullet points) are indicated below each level of biological organization (Species, Populations, Individuals) for which they can be calculated. The species level corresponds to the combined genetic diversity for the species. The population level pie charts reflect the relative population sizes and the proportion of genotypes in each population (i.e. population genetic structure resulting from gene flow and migration). The smallest circles represent unique individuals with the colors depicting their genotypes.

have fewer.

Diversity in species is important for economic, biological, social and cultural reasons [1]. Major threats to species diversity are loss of habitat and fragmentation, over exploitations (fishing, hunting, extraction), pollution, the introduction of invasive species (e.g., Asian Green Mussels) and global climate change. In order to conserve species diversity, natural resource management and habitat protection are vital.

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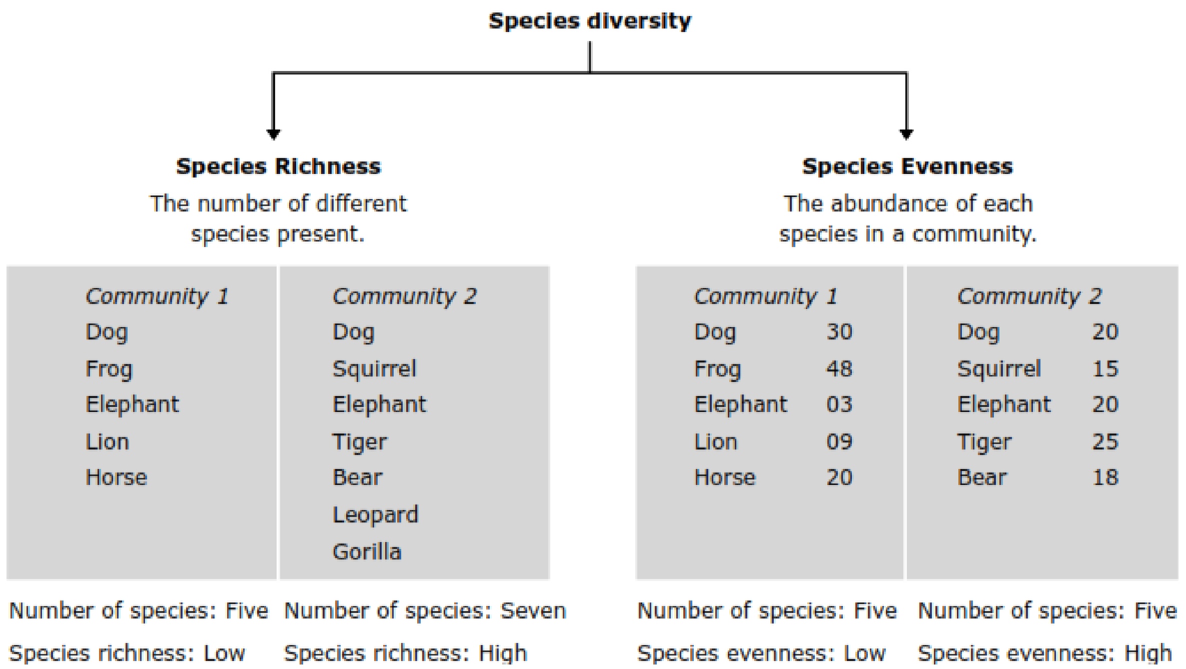


Figure 5 [15]: Species diversity for two communities.

1.2.3. Ecosystem diversity

An ecosystem is a community of organisms and their physical environment (namely biotic and abiotic factors [18]) interacting together [14]. An ecosystem can cover a large area, such as a whole forest, or a small area, such as a pond [14].

Ecosystems include all the species, plus all the abiotic factors characteristic of a region [15]. For example, a desert ecosystem has soil, temperature, rainfall patterns, and solar radiation that affect not only what species occur there, but also the morphology, behaviour and the interactions among those species.

Ecosystem diversity describes the number of niches, trophic levels and various ecological processes that sustain energy flow, food webs and the recycling of nutrients [15].

Keith et al. [19] developed a conceptual model (Figure 6) to inform the construction of the Global

Ecosystem Typology, consistent with the six design principles, and to serve as a template for describing the units of classification.

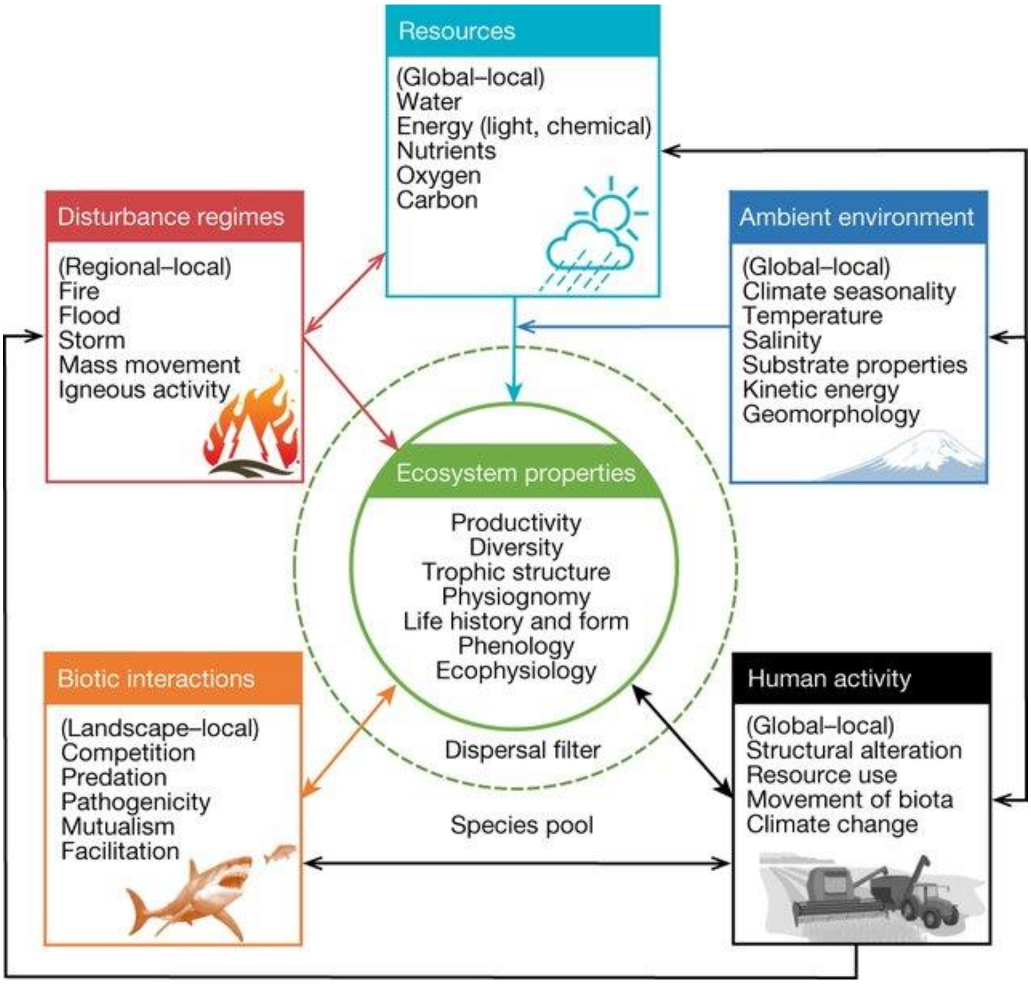
1.3. Changes in Biodiversity

Biodiversity is the result of billions of years of evolution [20], and, in this respect, current biodiversity is the product of past evolution, just as future biodiversity will be a product of contemporary evolution [21]. Most changes occur slowly enough to allow species to adapt, either through emphasis of differrent traits or movement to a new, more hospitable environment [22].

Biodiversity is diminished or destroyed in a number of ways either by natural changes or by human disruption [23]. Nowadays, through human activity, we are faced with many threats to which would lead to a loss of biodiversity [20].

Figure 6 [19]: The generic model of ecosystem assembly
underlying the Global Ecosystem Typology.

The 5 boxes represent abiotic (resources, the ambient environment and disturbance regimes) and biotic (biotic interactions and human activity) drivers that filter assemblages and form evolutionary pressures that in turn, shape ecosystem-level properties (inner green circle).



Depletion of natural resources, global climate change, biodiversity loss, degradation and destruction off ecosystems, air, water pollution are the challenging aspects of anthropogenic activities and directly related with environmental ethics and human values [18].

There are two global-scale environmental impacts to be anticipated from the forestry projections [24]. First is a potential impact on the world's climate. Second is a significant reduction in the number of plant and animal species on the planet. The second impact concerns Changes in Biological Diversity

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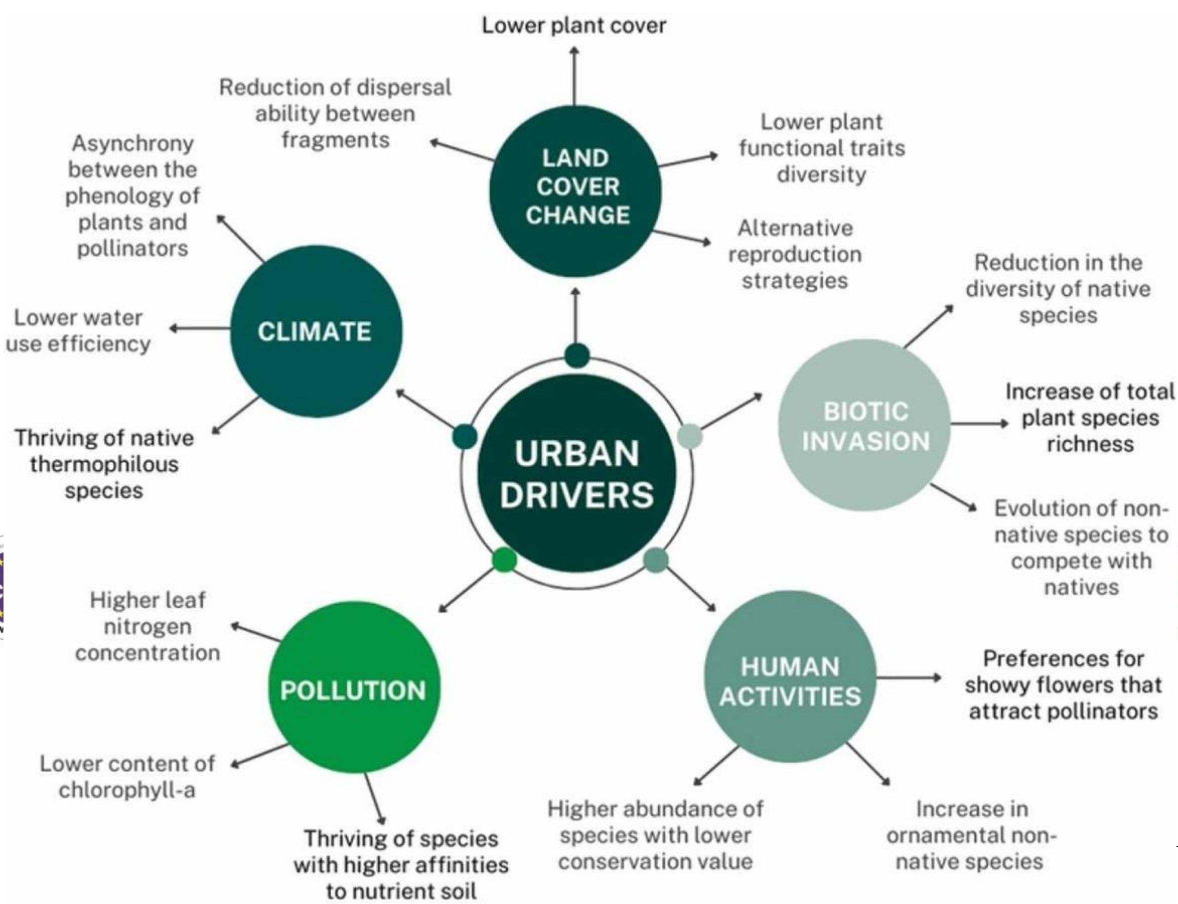
that is implied by the forestry projections, and their major effect is a significant reduction in biotic diversity [24]. The extent to which the diversity of the flora and fauna is maintained provides a basic index to the ecological health of the planet.

Climate change and biodiversity are interconnected: climate change is causing biodiversity loss, and biodiversity loss is causing climate change: destroying and degrading ecosystems releases more carbon dioxide into the atmosphere than burning fossil fuels [11].

There is no doubt that human civilization has had a negative impact on biodiversity, particularly since the industrial revolution [25]. Humanity impacts the planet's biodiversity in multiple ways, both deliberate and accidental [26].

Human activities are responsible for the degradation, fragmentation, and destruction of ecosystems and their biodiversity contributing to the disappearance of 60% of the world species since 1970 [27]. Not only because of industrial, economic or urban activities but also because of how they all together contribute to climate change and its extreme events.

De Barros Ruas and co-workers [28], after undertaking a broad systematic review of peer-reviewed articles reporting data about the effects of urbanization in two ecological levels (species and communities) in vascular plants worldwide, have found that the responses of plant species and



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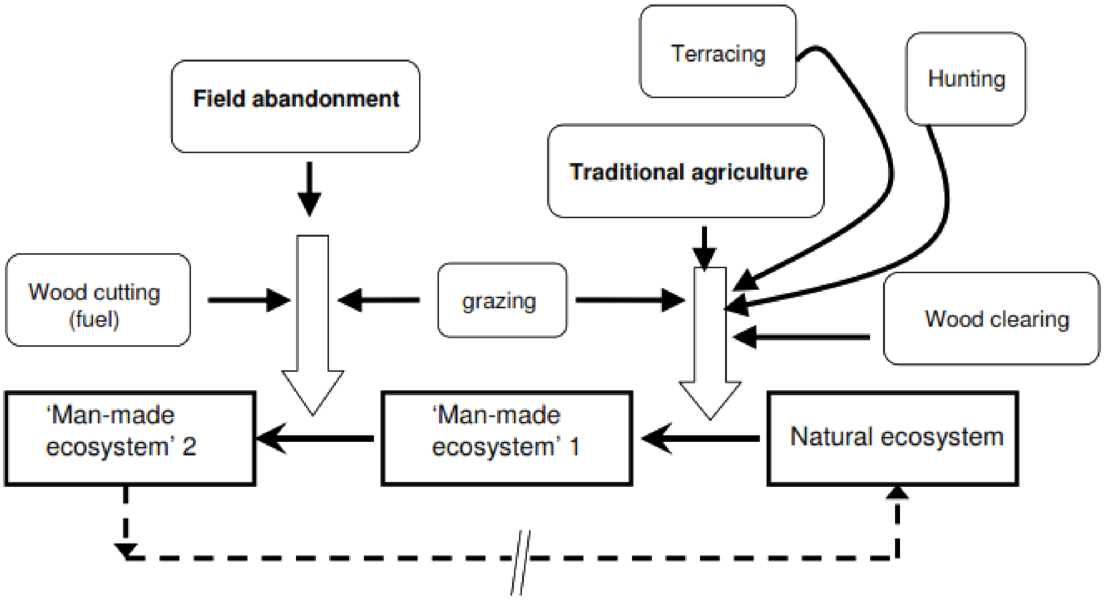

Figure 8 [30]: The creation of "man-made ecosystem" via various channels of human impact on the Mediterranean environment.

communities to urbanization could be categorized according to the following five Urban Drivers: biotic invasion, climate, human activities, land cover change, and pollution, Figure 7 [28,29].

The biggest threat to biodiversity to date has been the way humans have reshaped natural habitats to make way for farmland, or to obtain natural resources, but as climate change worsens it will have a growing impact on ecosystems [26].

For the Old World Mediterranean-type ecosystems [30], the human impact on the environment has led to the emergence of "man-made ecosystems" composed of natural components (Figure 8).

The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) estimates that about 77% of the land and 87% of the ocean have been altered by humans, which has led to a loss of 83% of wild mammal biomass, and half of the world's plant biomass [31]. The IPBES also suggests that more than a million plant and animal species are currently threatened with extinction, potentially putting us on a path to what has been dubbed Earth's sixth mass extinction.

Since ecosystems are not static in nature, getting changed over time [32], this Earth's sixth mass extinction should be seen and understood historically and naturally: there have been five big mass extinctions in Earth's history – these are called the "Big Five", Figure 9 [33]. Extinctions are a normal part of evolution: they occur naturally and periodically over time. Understanding the reasons and timelines of these events is important to understand the speed and scale of species extinctions today.

1.4. Nature and Biodiversity for Humans

Human society relies on natural habitats for a variety of services, including productivity, recycling of nutrients, breakdown of wastes, and maintenance of clean air, water, and soil [34].

Virtually no place remains untouched chemically, physically, or biologically-by the curious and

Figure 9 [33]: The "Big Five" mass extinctions in Earth's history.

determined hand of humanity [35]. Although much more by accident than by design, humanity now controls conditions over the entire biosphere.

Humans have been a natural component of many ecosystems for thousands of years and human activities (Figure 10) have an increasing impact on virtually all the processes that govern ecosystem properties influencing interactively the resources availability, disturbance regime, and biotic diversity [36].

Figure 10 [36]: The relationship between state factors (outside the circle), interactive controls (inside the circle), and ecosystem processes.

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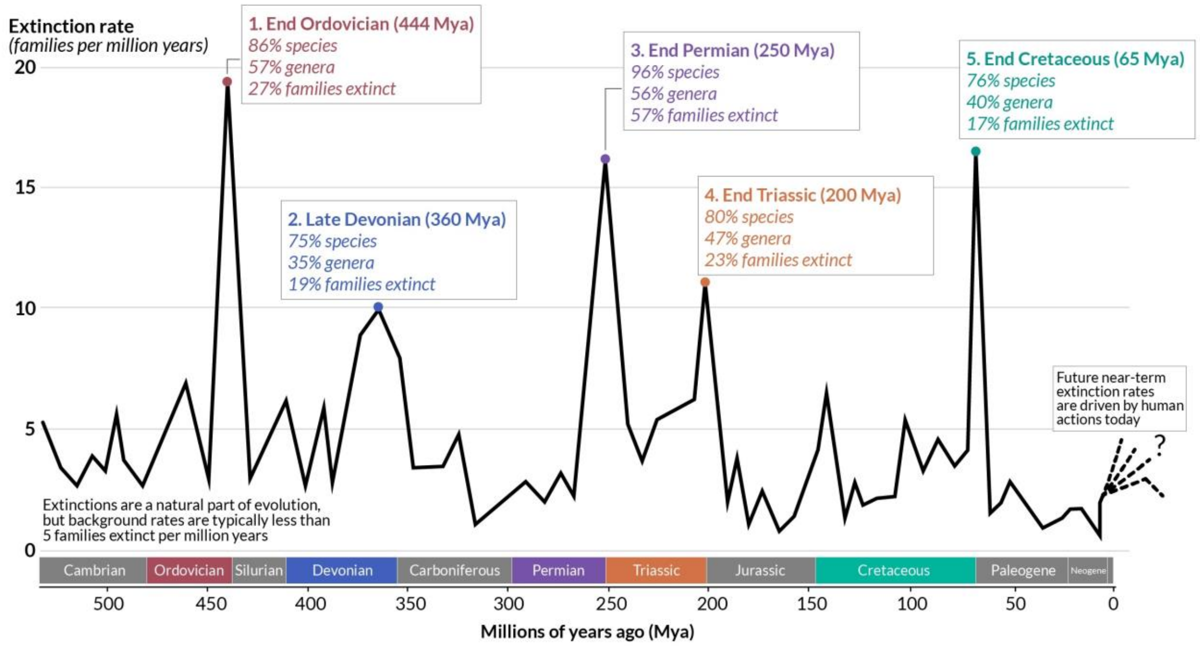


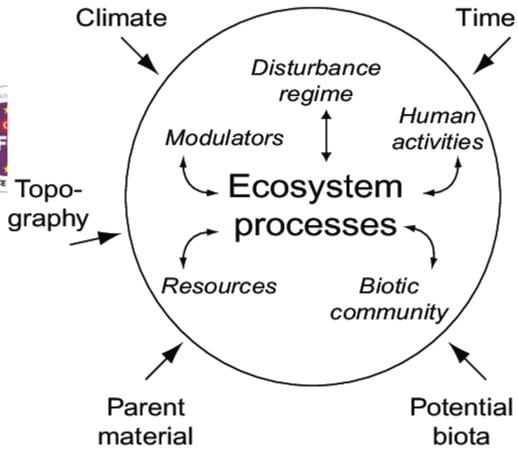
From the human ecological perspective [37], biodiversity can serve as an indicator of human influence on ecosystem conditions (Figure 11). Following this approach, it becomes evident that the identification of human impact on ecosystem biodiversity turns into a key factor in describing its state and dynamics.

1.4.1. Food Chains and Food Webs in Ecosystems

For ***food,*** shelter, growth and development, all life systems interact with the environment [38].

In this respect, the purpose of this section is to reveal how humans do interact with the other biotic components existing in their ecosystem in providing their food according to their food needs and diet.

Ecosystems are the planet's life-support systems for the human species and all other forms of life [39].



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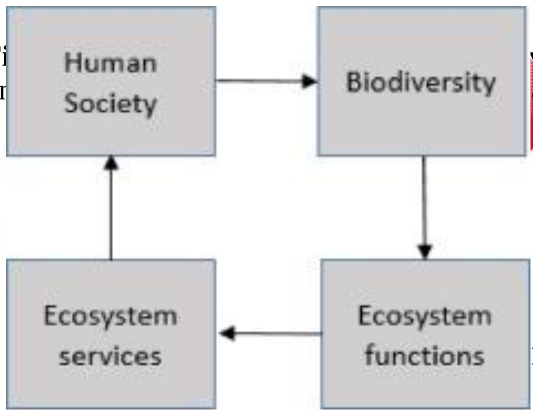

The biotic component of any ecosystem may be thought of as the functional kingdom of nature, since they are based on the type of nutrition and the energy source used [40]. The trophic structure of an ecosystem is one kind of producer-consumer arrangement [40], organized in an orderly manner [32].

In a trophic structure, the producers and consumers are arranged together in various levels in accordance with their inter-relationships (or simply their food-relationship) in an ecosystem [32]. Each food level in this structure is known as a trophic level [32,40,41].

The Biotic (living) component is the trophic structure of an ecosystem, where the living organisms are distinguished on the basis of their nutritional relationships [40], Figure 12 [42,43].

The biotic components, which include the living entities in an ecosystem, i.e., all the microbes, animals, plants and their products [32], can be categorized as (Figure 12):

* **Producers** or **autotrophs** make their own food [32,38,41,44]. Producers, such as plants, make food through a process called photosynthesis. This food is used by the plant for its own energy or may be eaten by consumers [38].

In ecosystems, generally, it is considered that only green plants as producers as they manufacture their food by using energy from the sun [32].

* **Consumers** [32,38,41] or heterotrophs [32,38] need to eat food that producers/autotrophs have produced [32,38] or food that comes from other organisms [38,43,44]. Even if the organism being consumed is another animal, it traces its stored energy back to autotrophs and the process of photosynthesis [44], i.e., the basic food is the food coming from producers/autotrophs.

Depending upon their food habits, consumers are classified into primary, secondary and tertiary consumers [32,38,43], and, even, quaternary consumers [43,45].

Omnivores (Biophages [38]) feed at several levels of the trophic structure [46] eating both plants and animals [38], resulting in non-integer trophic positions [47].

Empirical research and logic have shown that the vast majority of consumers on this planet are very omnivorous, feeding on many types of food throughout the entire food web [48].

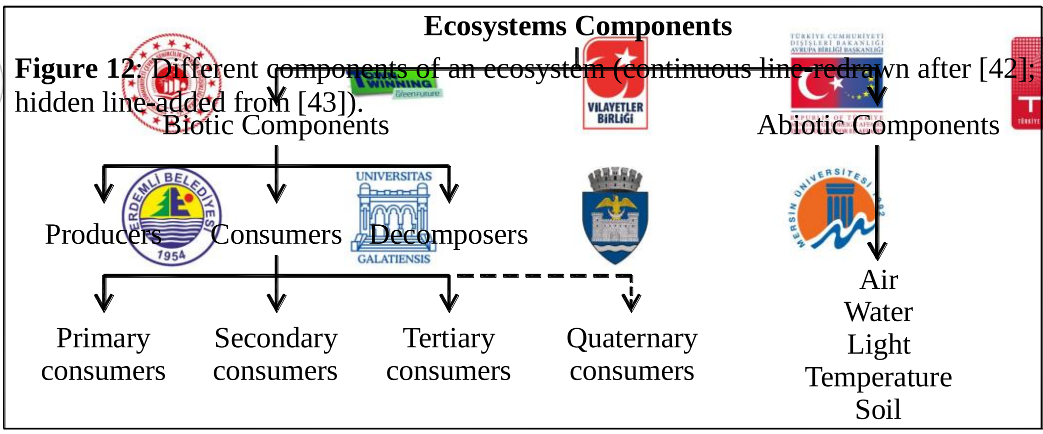

Figure 12: Different components of an ecosystem (continuous line-redrawn after [42]; hidden line-added from [43]).

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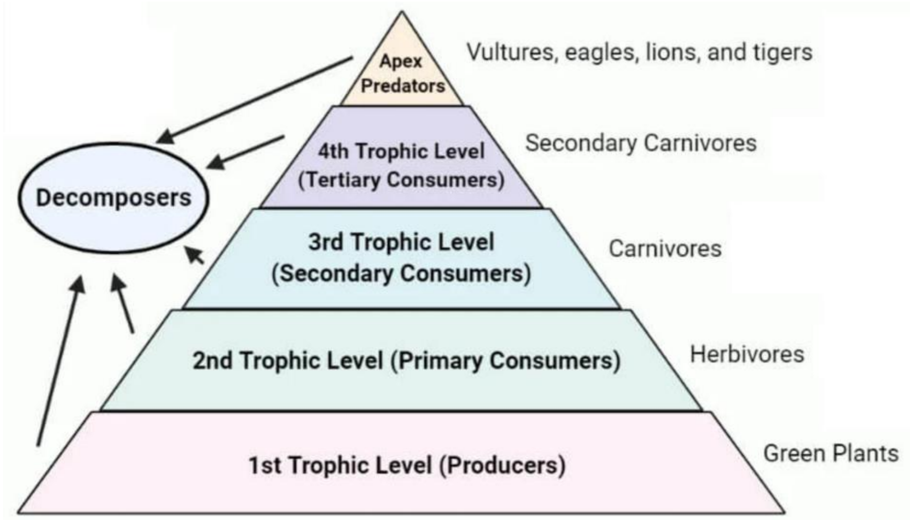


Figure 13 [49]: Decomposers/Micro-consumers are present and act at all trophic levels processes of an ecosystem.

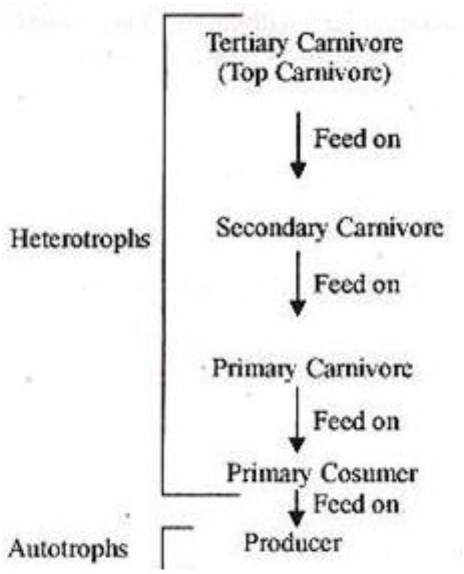
* **Decomposers** or **Micro-consumers** [32,38,41,43] or **Detritivores** [49,50] or **Transformers** [49] are heterotrophs that break down the dead tissue and waste products [32,38,43]. They play a very important role in the ecosystem because they recycle the nutrients [38] converting organic matter into energy and nutrients [49]. Bacteria and fungi are the main decomposers [38,43,49].

According to Biotic Components branches from Figure 12 (and other similar figures in literature), it seems that Decomposers/Micro-consumers act separately from Producers and Consumers. In fact, these (micro-)organisms are present and act at all trophic levels [49,51], Figure 13 [49].

Figure 14 [52]: A representation of a food chain in an ecosystem.

A trophic level refers to the position of organisms in the food chain, autotrophs being at the base of chain [50], Figure 14 [52]. According to Huxel and Polis [48], a **food chain** is a representation of the links between consumers and their resources, for example, nutrients→plant→herbivore→carnivore.

A **food chain** is composed of species that are connected by the flow of energy and material from producers to consumers [53], Figure 15 [50].



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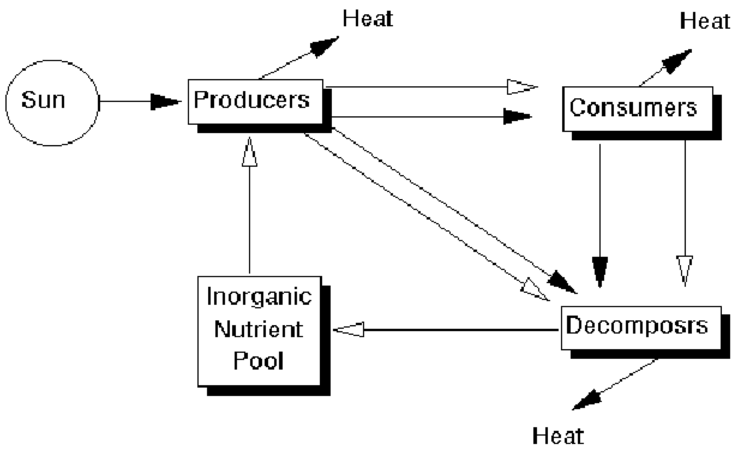


Figure 15 [50]: Flow of energy and inorganic nutrients through the ecosystem.

The diagram from Figure 15 shows how both energy and inorganic nutrients flow through the ecosystem [50]. The dark arrows represent the movement of this energy, and the movement of the inorganic nutrients is represented by the white arrows. It can be note that all energy comes from the sun, and that the ultimate fate of all energy in ecosystems is to be lost as heat. Autotrophs obtain the inorganic nutrients from the inorganic nutrient pool, which is usually the soil or water surrounding the plants or algae. These inorganic nutrients are passed from organism to organism as one organism is consumed by another. Ultimately, all organisms die and become detritus, food for the decomposers.

Comparing figures 12, 14 and 15. one may note that if the food chain refers to:

- material flow, then the food chain is a closed loop, the inorganic nutrients are returned to the soil or water to be taken up again, which means that the inorganic nutrients are recycled [50], Figure 16 – the round cycle [54];
- energy flow, then the food chain is in a linear fashion [48], which means that the energy does not recycle [50], Figure 16 – the linear cycle [54].

Virtually, all ecosystems depend on a continual input and output of energy to maintain their internal structure and function, and, therefore, the ecosystems are classified as thermodynamically open systems [54].

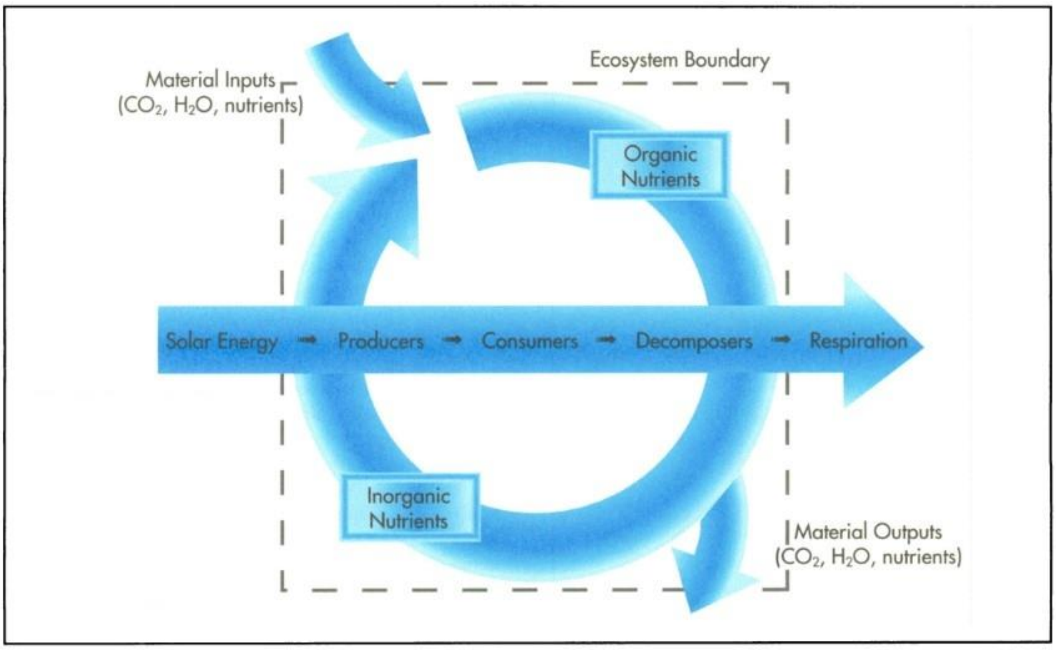
In most ecosystems, the input of solar energy (Figures 15 and 16) acts as the "fuel" for photosynthesis (to build sugars from carbon dioxide and water [46]), and the feeding relationships and efficiencies of energy flow among trophic levels establish the rates of energy flux [54].

Empirical research indicates that food chain length is important, but also that the processes governing propagation of the effects between trophic levels depend on a wide range of other factors, like behavioural interactions, disease and parasite transmission, species richness, competition for space and interference between individuals [55].

Many species of producers and consumers are usually interconnected and some may be interdependent [53]. **Food webs** are diagrams that can function as ‘‘flow maps’’ to document which species interact with other species, either directly or indirectly, as energy flows through the community and determines

Figure 16 [54]: A conceptual model of an ecosystem illustrating the one-way flow of energy and the recycling of nutrients.

the movement of nutrients and other materials.

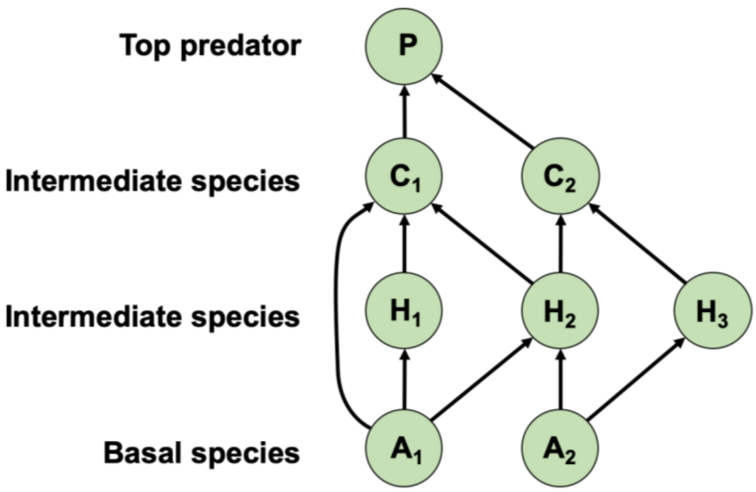


Food web is a connection of multiple food chains: food chain follows a single path, whereas food web follows multiple paths [56], Figure 17 [57].

Humans are consumers and thus are ranked above the producers in any food chain [58]. They rank at the top of any food chain, above the tertiary consumers, because they consume both plants (vegetables) and meat (other consumers), but are not eaten consistently by any animals.

1.4.2. Ecosystem Services

The purpose of this section is to present the interactions between humans and nature/biodiversity.



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At the first glance, this term “ecosystem services” would suggest that nature/biodiversity, through its ecosystems, would provide some service to humans/human societies.

In general, and normally, all organisms living on Earth, starting with the one-cell ones and ending with top predators and/or humans, are part of different ecosystems and all of them must find resources to subsist. This complex term of “find resources to subsist” is, in fact, the reason for keeping nature and biodiversity in continuous movement and change, based on the trade-off between the organism do need to subsist and what their ecosystems could provide them.

On the other hand, according to the information presented within the section ***1.4.1. Food Chains and Food Webs in Ecosystems***, it could be seen how the organisms living in an ecosystem contribute to their ecosystem re-start (in a cycling process, obviously) by providing the(ir) “raw material” to Decomposers.

However, all information presented so far was a general one, suitable for all organisms that do not have the mind, means, and power of humans!

Starting from here, we may realize that we could provide to us almost everything we need (and what we do not basically need), even against nature, causing biodiversity loss, pollution, climate change, landscape degradation.

To add some optimism to this dark-light picture, we, humans and our human societies, do have the mind, means, and power to reduce, to a large extent, the adverse effects of human activity on our ecosystem environment.

In the following, there will be presented some aspects regarding the ecosystem contribution to human well-being in the form of ecosystem services.

Biodiversity is essential for sustaining the natural ecosystems on which humans, and all life, depend [59].

Human biology has a fundamental need for food, water, clean air, shelter and relative climatic constancy [39], and according to the ecosystem approach, nature provides humans with benefits including food, clean water and opportunities for recreation [60]. Using this approach helps maintain and enhance these benefits, whilst enabling prosperous communities to develop.

The future of the world's human societies still depends upon natural resources [61]. In fact, water, croplands, forests, and grasslands underpin the world's economy. Except for fossil fuels and minerals, they supply all of the raw materials for industry. Moreover, natural, vegetated landscapes reduce erosion and filter pollutants from air and runoff water. They reduce extremes of flooding and provide food and fiber – all for "free" because these natural systems are powered by the sun [61] (Figures 15 and 16).

Ecosystem components represent the basic building blocks of complex food webs, of which humans are a part, and ecosystem processes provide many services upon which humans rely [54] linking natural resources with people's well-being [62].

Ecosystem services are the benefits people obtain from ecosystems [63] and they are often the result of human management of natural resources [62].

Ecosystem services can be grouped under the following four headings [62,63,64]:

- **Provisioning services**: such as food, water, timber, fiber and genetic material;
- **Supporting system and services**: necessary for the production of all other ecosystem services, such as soil formation, nutrients cycling and primary production/photosynthesis;
- **Regulating services**: such as regulation of climate, water purification, biological control mechanisms, carbon sequestration, pollination of commercially valuable crops, floods, diseases, wastes;
- **Cultural services**: providing a source of aesthetic enjoyment, spiritual/religious fulfillment, recreational or scientific enrichment.

The human species, while buffered against environmental changes by culture and technology, is fundamentally dependent on the flow of ecosystem services [63].

A more comprehensive classification of ecosystem services is presented in [65]. The authors, Daily and Dasgupta, stated that, based on available scientific evidence, it is certain that:

- Ecosystem services are essential to civilization.
- Ecosystem services operate on such a grand scale and in such intricate and little-explored ways that most could not be replaced by technology.
- Human activities are already impairing the flow of ecosystem services on a large scale.
- If current trends continue, humanity will dramatically alter virtually all of Earth's remaining natural ecosystems within a few decades.

The Millennium Ecosystem Assessment [64] considers human well-being to consist of five main components: the basic material needs for a good life, health, good social relations, security, and freedom of choice and action. Human well-being is the result of many factors, many directly or indirectly linked to biodiversity and ecosystem services while others are independent of these (Figure 18).

In [66] it is proposed a conceptual framework for ecosystem assessments: The conceptual framework links socio-economic systems with ecosystems via the flow of ecosystem services and through the drivers of change that affect ecosystems either as consequence of using the services or as indirect impacts due to human activities in general (Figure 19). The flow of "ecosystem services" to socio-economic systems to ensure human well-being needs an adequate response of socio-economic systems to maintain biodiversity and ecosystem functions in a healthy condition and productivity.

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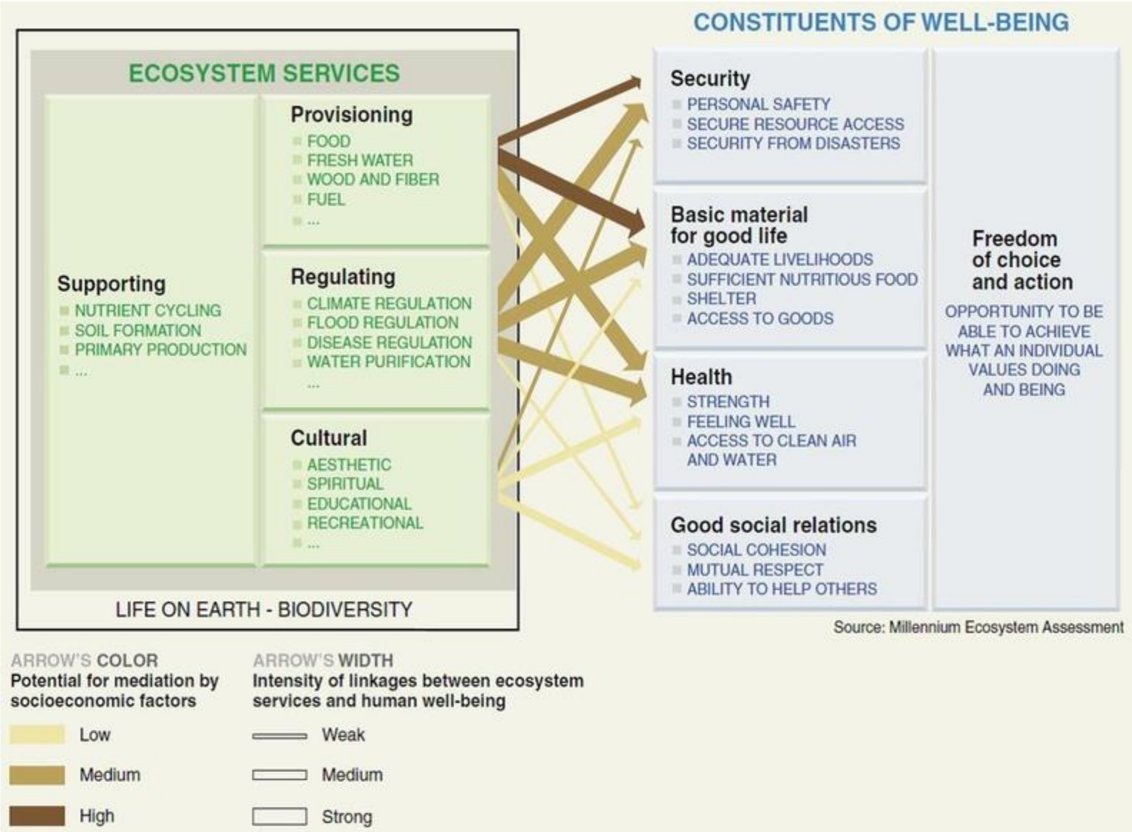


Figure 18 [64]: Linkages among Biodiversity, Ecosystem Services, and Human Well-being.

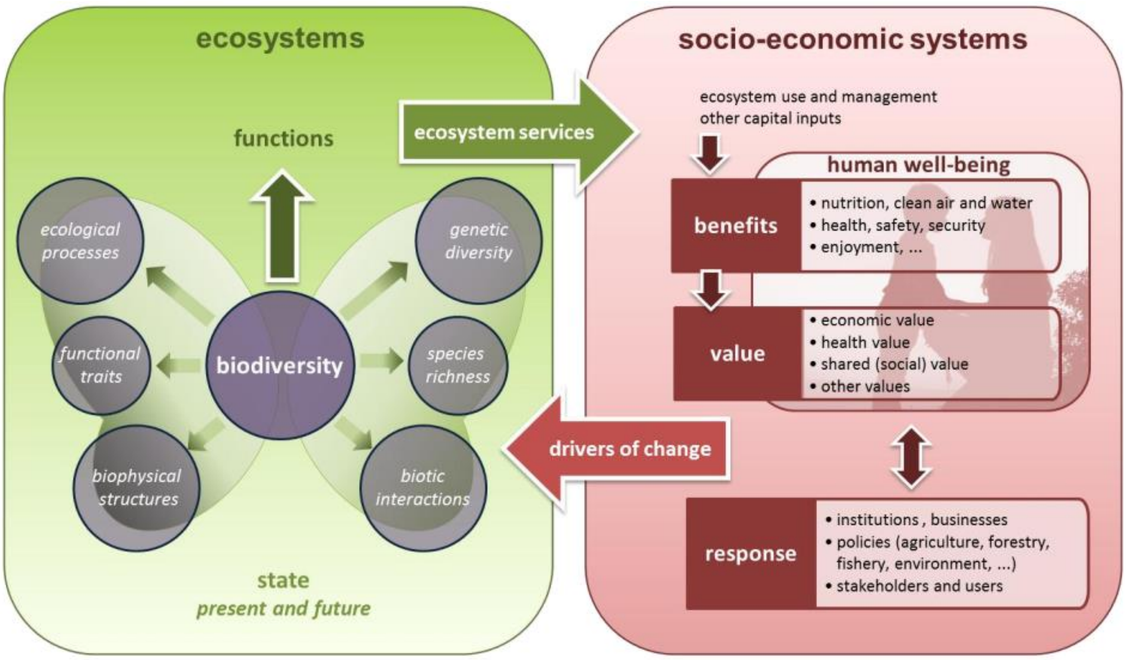


Figure 19 [66]: Conceptual framework for EU wide ecosystem assessments.

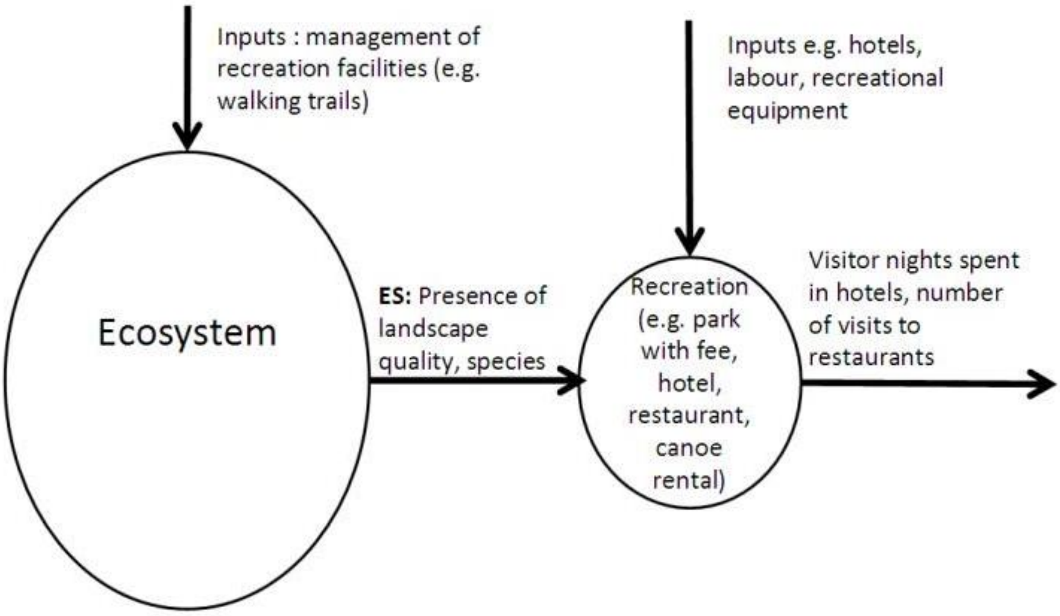
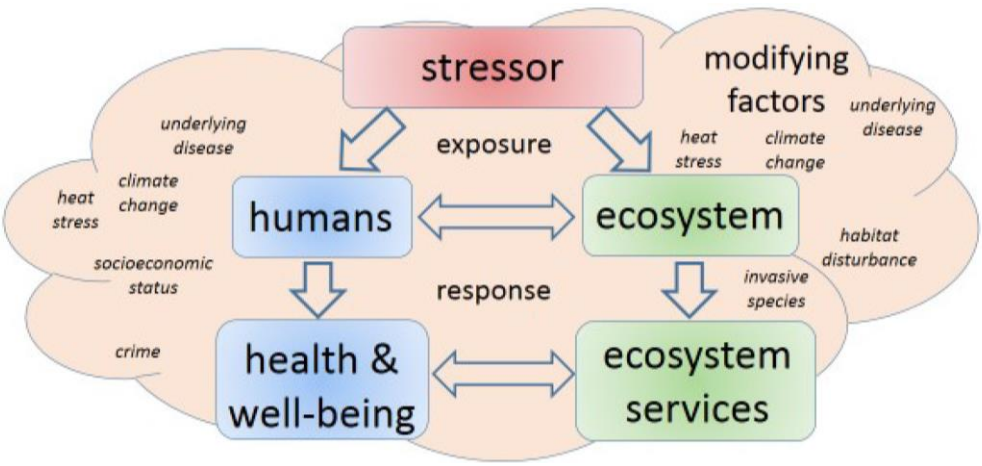


Figure 20 [67]: Creating walking trails in an ecosystem, enhances the cultural/recreational service of that ecosystem.

On the other hand, human societies could create/implement different facilities into ecosystems to improve or to diversify the services provided by the ecosystems. For example, creating walking trails in an ecosystem with additional facilities as hotels, restaurants, and recreational equipment would lead to the increase of number of people enjoying this ecosystem cultural service [67], Figure 20.

Many communities and their supporting ecosystems face high pollutant exposures and risks [68]. Human exposure and effects can be exacerbated by nonchemical stressors (also known as modifying factors) such as poverty, limited access to services, pre-existing health conditions, and aging infrastructure that undermines pollution-control efforts. Nonchemical stressors that may intensify



ecosystem exposures and effects include, for instance, habitat disturbance and destruction, life-stage-specific vulnerabilities and invasive species in addition to aging infrastructure. Figure 21 illustrates a conceptual model for how environmental stressors, ecosystem services, and human health and well-being are inter-related and influence one another.

In many respects, human health is a bottom-line (or integrating) component of well-being, since changes in economic, social, political, residential, psychological and behavioural circumstances all have health consequences [39]. Basic determinants of human well-being may be defined in terms of: security; an adequate supply of basic materials for livelihood (e.g., food, shelter, clothing, energy, etc.); personal freedoms; good social relations; and physical health. By influencing patterns of livelihoods, income, local migration and political conflict, ecosystem services impact the determinants of human well-being. The ways in which health status may

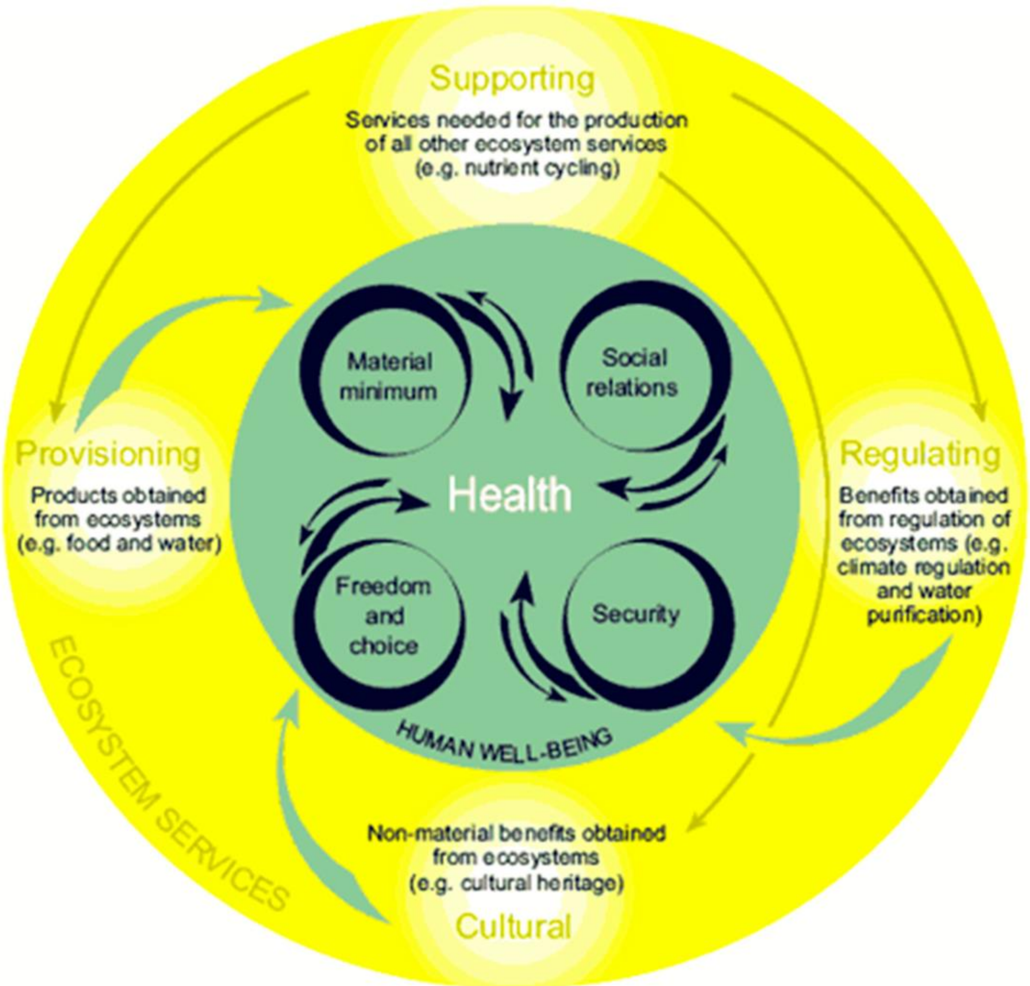


Figure 22 [39]: Associations between health, other aspects of human well-being and ecosystem services.

both reflect and influence human well-being are illustrated in Figure 22.

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2. **Agricultural Biodiversity**

"Food is the moral right of all who are born into this world."

Norman Borlaug [69]

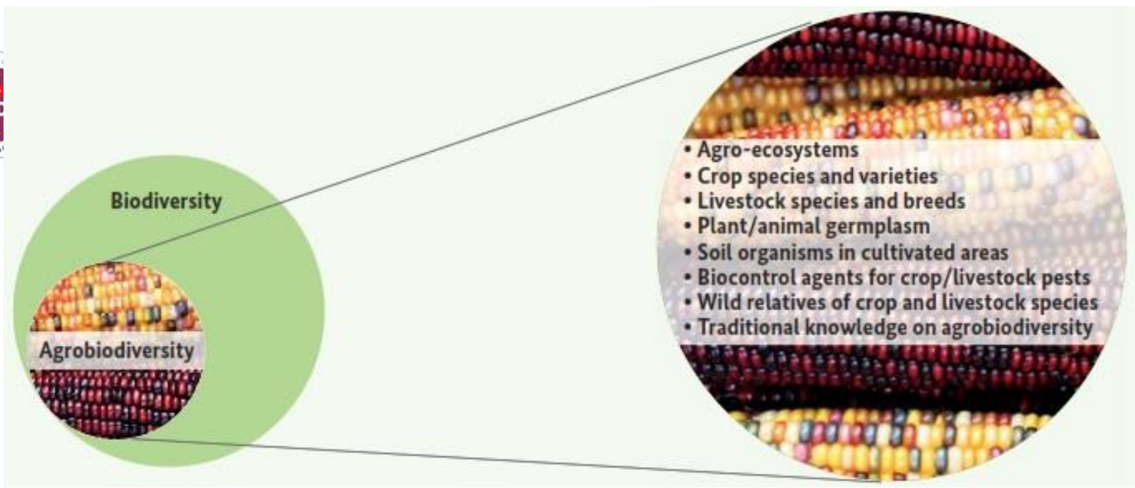
Agricultural biodiversity provides humans with food, raw materials for goods such as: cotton and wool for clothing; wood for shelter and fuel; plants and roots for medicines; and materials for biofuels [70]. In accordance with annex I of decision III/11 of the Conference of the Parties to the Convention on Biological Diversity [71], **Agricultural Biodiversity** is a broad term that includes all components of biological diversity (Figure 23 [72]) of relevance to food and agriculture, and all components of biological diversity that constitute the agro-ecosystem: the variety and variability of animals, plants and micro-organisms, at the genetic, species and ecosystem levels, which are necessary to sustain key functions of the agro-ecosystem, its structure and processes.

Agrobiodiversity is the outcome of the interactions among genetic resources, the environment and the management systems and practices used by farmers and herders [72]. It has developed over millennia, as a result of both natural selection and human interventions.

Agricultural biodiversity is essential to the world for the following functions [73]:

- sustainable production of food and other agricultural products, including providing the building blocks for the evolution or deliberate breeding of useful new crop varieties;
- biological support to production via, for example, soil biota, pollinators and predators;
- wider ecological services provided by agro-ecosystems, such as landscape protection, soil protection and health, water cycle and quality, and air quality.

Agrobiodiversity, or agricultural biodiversity, is the part of biodiversity recognized as a resource by farmers for agricultural production [74]. It corresponds to the diversity of living organisms consciously managed by the farmer. Like biodiversity, agrobiodiversity is divided into three levels



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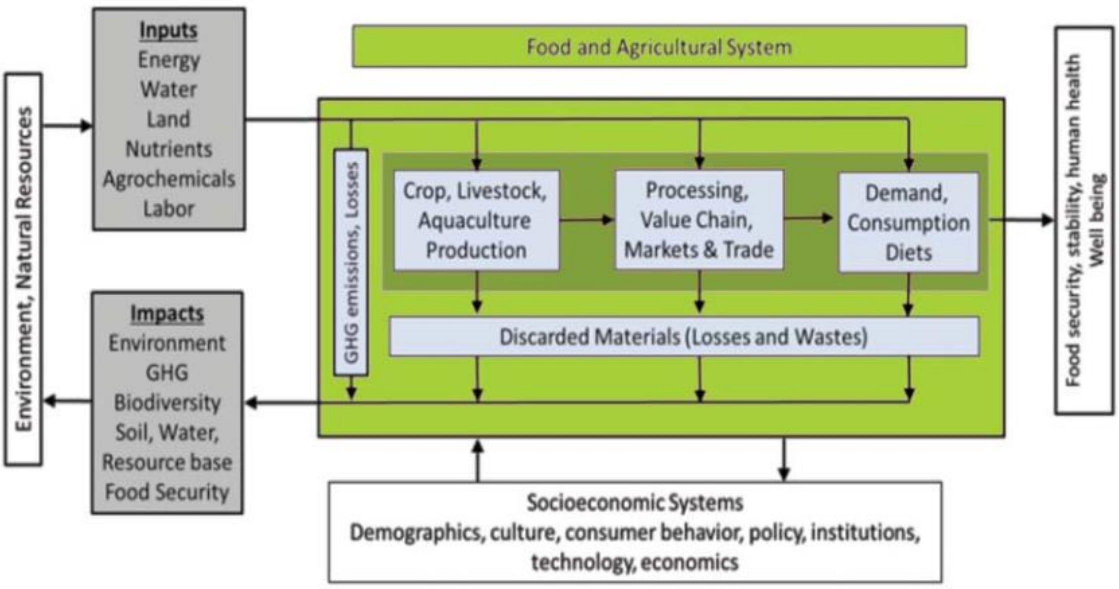
which interact with one another: genetic diversity, specific diversity and agro-ecosystem diversity.

Agricultural biodiversity includes those components of biological diversity relevant to food and agriculture as well as the components of biological diversity that constitute the agro-ecosystem [75]. It exists at several levels, from the different ecosystems in which people raise crops and livestock, through the different varieties and breeds of the species, to the genetic variability within each variety or breed. While part of this biodiversity is directly managed to supply the goods and services that people need, much is not directly intended for production but remains important as a source of materials and for its contributions to ecosystem services such as pollination, control of greenhouse gas emissions and soil dynamics.

More than agrobiodiversity, in respect of providing food, feed, fiber, energy, and other products, Food and Agricultural Systems (FAS) are intricately interwoven with human society [76]. FAS are often misunderstood as simply farming systems. In reality, FAS are much more complex because they encompass a wide range of activities - including production, processing, transport, marketing, and consumption, as well as management of the byproducts. In the U.S., FAS constitute more than 22% of the national GDP (Gross Domestic Product) , employ more than 28% of the national workforce, and are critical to national security.

However, as is evident in the FAS schematic in Figure 24, different decision-makers control the various activities along the FAS value chain, and there are no public or private infra- structures for recovering unwanted outputs, which are lost or discarded as wastes [76]. These wastes include the 30% to 50% loss of produced food that is typically dumped into landfills, along with the valuable resources, such as nitrogen, carbon, and other raw materials, that are contained in discarded food.



2.1. Definition of Agrobiodiversity

Similar to biodiversity, there are many different definitions of agrobiodiversity with different foci and scopes [77].

Agricultural biodiversity is defined as "the variety and variability of animals, plants and micro-organisms that are used directly or indirectly for food and agriculture, including crops, livestock, forestry and fisheries [78]. Table 1 sets out the biological scope of agricultural biodiversity in more detail [79].

Agricultural biodiversity comprises the diversity of genetic resources (varieties, breeds) and species used for food, fodder, fiber, fuel and pharmaceuticals [78]. It also includes the diversity of non-harvested species that support production (soil micro-organisms, predators, pollinators), and those in the wider environment that support agro-ecosystems (agricultural, pastoral, forest and aquatic) as well as the diversity of the agroecosystems" (Figure 25).

According to the Handbook of the Convention on Biological Diversity [80] and summarized in [72], the following four dimensions of agricultural biodiversity can be identified:

1. **Genetic resources for food and agriculture:**
   - Plant genetic resources, including crops, wild plants harvested and managed for food, trees on farms, pasture and rangeland species.
   - Animal genetic resources, including domesticated animals, wild animals hunted for food, wild and farmed fish and other aquatic organisms.
   - Microbial and fungal genetic resources.

These constitute the main units of production in agriculture, and include cultivated and domesticated species, managed wild plants and animals, as well as wild relatives of cultivated and domesticated

Table 1 [79]: Scope of agricultural biodiversity by biological taxa.

Taxa	Scope
Plants	• Crops • Harvested and managed wild plants for food • Trees on farms • Pasture and rangeland species
Higher Animals	• Domestic animals • Wild animals • Wild and farmed fish
Arthropods	• Pollinators (e.g., bees, butterflies) • Pests (e.g., grasshoppers, greenflies) • Predators (e.g., wasps, beetles)
Soil biota	• Organisms (e.g., earthworms) • Microbes (e.g., rhizobia, fungi, disease-producing pathogens)

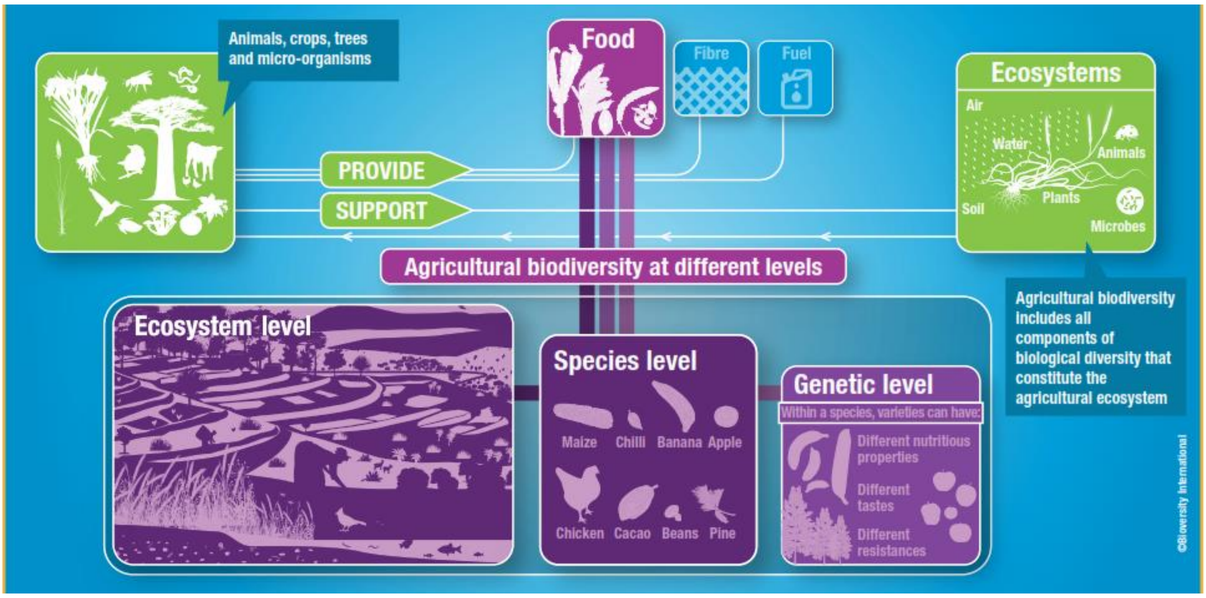


Figure 25 [78]: Components of Agricultural Biodiversity and linkages between them.

species.

2. **Components of biodiversity that support ecosystem services upon which agriculture is based.** These include a diverse range of organisms that contribute to nutrient cycling, pest and disease regulation, pollination, pollution and sediment regulation, maintenance of the hydrological cycle, erosion control, carbon sequestration and climate regulation.
3. **Abiotic factors,** such as local climatic and chemical factors and the physical structure and functioning of ecosystems, which have a determining effect on agrobiodiversity.
4. **Socio-economic and cultural factors.** Agrobiodiversity is largely shaped and maintained by human activities and management practices, and a large number of people depend on agrobiodiversity for sustainable livelihoods**.**

According to [73], the components of Agricultural Biodiversity are as follows:

- ❖ **Crop Diversity**

Of the 27,000 species of higher plants, about 7,000 species are used in agriculture, but only three (wheat, rice and maize) provide half of the world's plant-derived calorie intake.

- **Wild Plant Biodiversity**

In addition to domesticated plants, wild species are important nutritionally and culturally to many people. Foods from wild species form an integral part of the daily diets of many poor rural households. They are an important source of vitamins, minerals and other nutrients, and also represent ready sources of income for cash-poor households.

- **Livestock Diversity**

Of about 50,000 known mammal and bird species, only about 40 have been domesticated. These species provide people not only with food but also clothing, fertilizer and fuel (from manure) and draught power. From these species, farmers and breeders have developed about 5,000 identified breeds to fit local environmental conditions and to meet specific needs.

- **Aquatic Diversity**

Fish and other aquatic species are integral parts of several important farming systems. For example, in the tropical rice-fish systems of Asia, fish from rice paddies may provide as much as of dietary protein. More generally, aquaculture is becoming increasingly important and now supplies about 20% of total fish production.

- **Below-ground Biodiversity**

Roots are responsible for nutrient and water uptake by crops. They physically stabilize soil structure against erosion and soil movement on steep slopes and, in tropical systems, the contribution of roots to soil organic matter is proportionately larger than from above-ground inputs. The effects of roots on soil biophysical properties are particularly critical in impoverished farming systems where crop residues are at a premium for fuel and fodder.

- **Microbial Biodiversity**

Microbes contribute a wealth of gene pools that could be a source of material for transfer to plants to achieve traits such as stress tolerance and pest resistance, and large-scale production of plant metabolites.

- **Arthropod Biodiversity**

Insects, spiders and other arthropods often act as natural enemies of crop pests.

Insects and arthropods are also important pollinators of many crops. Bees and other pollinating insects are essential agents for the production of many crops. Insect pollination is also required for seed production.

2.2. Issues of biodiversity in agriculture

More so than in any other sector of human activity, agriculture is indivisibly linked with biodiversity [81]. It can benefit from biodiversity, modify biodiversity and can contribute to its maintenance (Figure 26 [82]). For agriculture, biodiversity is thus an object of vital and increasing importance at all levels of agricultural policy. Agricultural activity generally implies the management and control of ecosystems in the areas that it exploits. Questions of relationships between agriculture and biodiversity

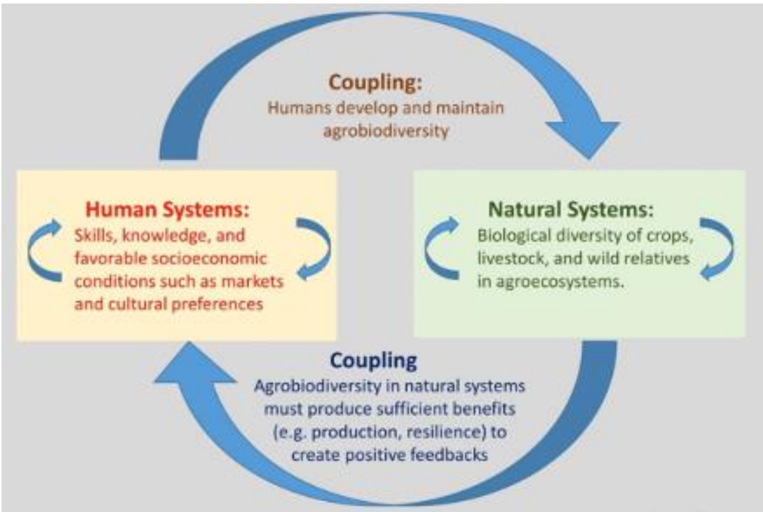


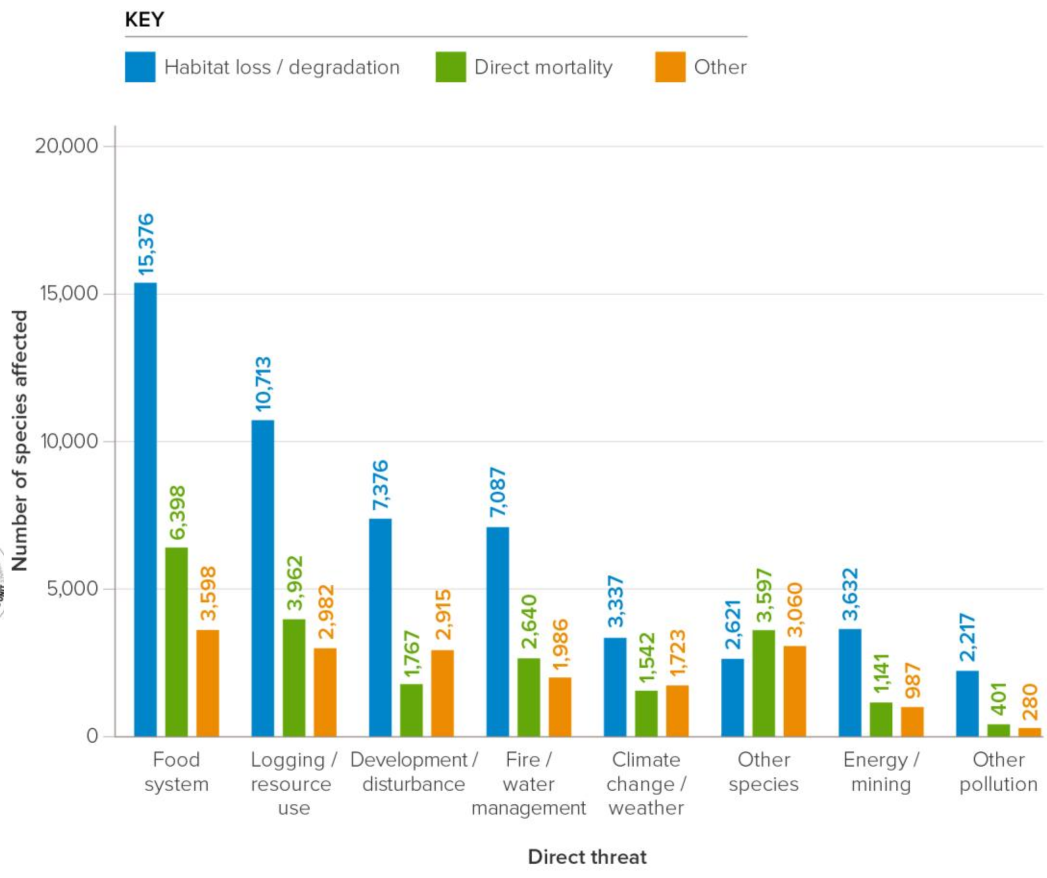
Figure 26 [82]: Agrobiodiversity in coupled Human-Natural food systems. Farmers' selection and management practices, and their use of genetic resources, have played an important role in agrobiodiversity conservation.

are thus often posed in terms of compromises or co-existence. However, agriculture can also have beneficial effects on biodiversity, at different scales and levels of organisation. In addition, the benefits of agriculture for the maintenance of biodiversity can be numerous, for agricultural production is due to, in its largest sense, "ecosystem services" provided within agricultural areas.

The global food system threatens more species than any other area of human endeavour, through habitat destruction to create new farmland; overexploitation of marine and terrestrial species; and agricultural pollution of freshwater and marine ecosystems (Figure 27) [83]. Of the ~25,000 species that the IUCN (International Union for Conservation of Nature) has identified as threatened with extinction, 13,382 are threatened by agricultural land clearing and degradation alone. In addition, some 3,019 species are affected by hunting and fishing, and 3,020 by pollution from the food system.

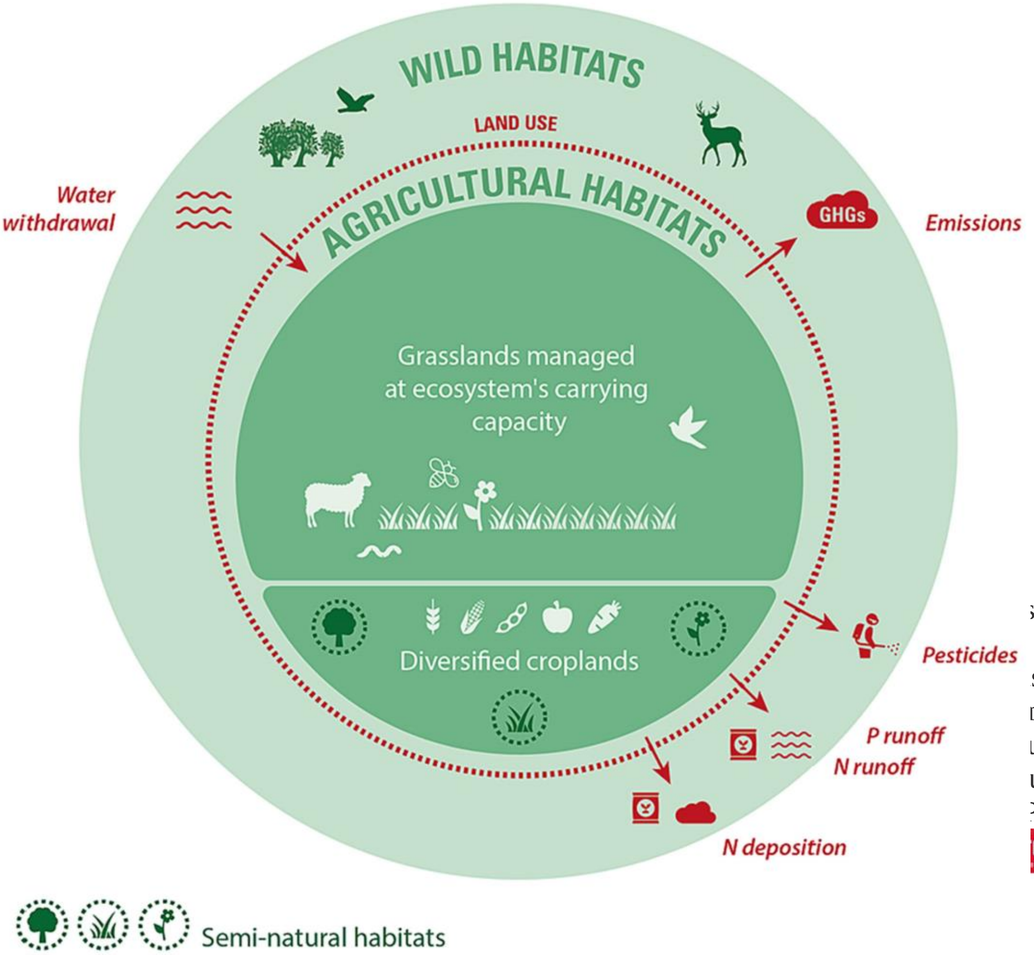
One of society’s most pressing challenges is to slow the rate of global biodiversity loss and extinction [84]. There is now overwhelming evidence that the loss of species impacts the functioning of ecosystems and that many services provided by species have important economic value.

Based on an extensive but not systematic literature review, García-Vega et al. identified the main biodiversity pressures stemming from agriculture and proposed a critical boundary, for each one that would ensure biodiversity conservation [85]. Boundaries include ceilings below which negative



impacts on biodiversity are limited, as well as thresholds at or above which positive effects on biodiversity arise. Depending on the nature of the pressure and its relationship to biodiversity, as well as the evidence available, boundaries may apply to pressures and then translate into agricultural practices, or apply directly to practices. Figure 28 illustrates the resulting agricultural system, constrained by the multiple boundaries that would ensure effective biodiversity conservation.

Biodiversity is an important regulator of agro-ecosystem functions, not only in the strictly biological sense of impact on production, but also in satisfying a variety of needs of the farmer and society at large [86]. In particular, it increases resilience of agro-ecosystems and is as such a means for risk reduction and adaptation to climate change. Agro-ecosystem managers, including farmers, can build upon, enhance and manage the essential ecosystem services provided by biodiversity in order to work towards sustainable agricultural production. This can be achieved though good farming practices



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which follow ecosystem-based approaches designed to improve sustainability of production systems. Good agricultural practice should:

- Maintain a high level of crop-genetic diversity, both on farm level as in seed banks, which will help to increase and sustain production levels and nutritional diversity throughout the full range of different agro-ecological conditions.
- Integrate, through ecosystem approach strategies, the planned biodiversity (crop sequences and associations) that is maintained with the associated diversity (for example, wild pollinators).
- Adopt production system management strategies, such as not disturbing soil, maintaining mulch covers from crop residues and cover crops which increase the biological activity and diversity of the production system.
- Consider the benefits of having fragmented land (riparian areas, forest land within the agricultural landscape) on the agricultural yield, through improved biological processes such as pollination.
- Improve the adaptation of good farming practices (i.e. pest management strategies, etc.) which follow ecosystem-based approaches designed to improve the sustainability and agricultural biodiversity of production systems.
- Aim at producing commodities that meet the consumer needs for products that are of high quality, safe and produced in an environmentally and socially responsible way.

2.3. Agricultural ecosystems or agroecosystems

Agroecosystems are those "ecosystems that are used for agriculture" in similar ways, with similar components, similar interactions and functions [87]. Agroecosystems comprise polycultures, monocultures, and mixed systems, including crop-livestock systems (rice - fish), agroforestry, agro-silvo-pastoral systems, aquaculture as well as rangelands, pastures and fallow lands. Their interactions with human activities, including socio-economic activity and sociocultural diversity, are determinant.

Agroecosystems may be identified at different levels or scales, for instance, a field/crop/ herd/pond, a farming system, a land-use system or a watershed.

The MA (Millennium Ecosystem Assessment) proposed a classification of ecosystem services into four categories, provisioning, regulating, cultural and supporting [63,81]. This classification, which serves as a framework to compare individual studies, has been criticised recently for the lack of precision in the definition of regulating and supporting services. Within the assessment report written by INRA [81], a more operational classification of ecosystem services, with the three following categories, has been used:

1) “Input” services, which contribute to the provision of resources, the maintenance of the physical and-chemical processes supporting agriculture, and which guarantee the regulation of biotic interactions, positive or negative, for example the maintenance of the structure or the fertility of soils, pollination, protection of the health of domestic animals;

2) “Production” services contributing to agricultural productivity. These services concern plant and animal production including levels of production, the stability of production over time and the quality of products themselves;

3) “Output” services not directly contributing to agricultural income, which include, in particular, the control of water quality, climate regulation through carbon sequestration or the aesthetic value of landscapes.

The effects of biodiversity on ecosystem functions contributing to each of these services (Figure 29) can be positive – strictly speaking these benefits constitute services – or negative – consisting of costs to agricultural production and/or society (dis-services in the terminology used in the MA).

A range of benefits, covering all four categories of ecosystem services, have directly or indirectly been

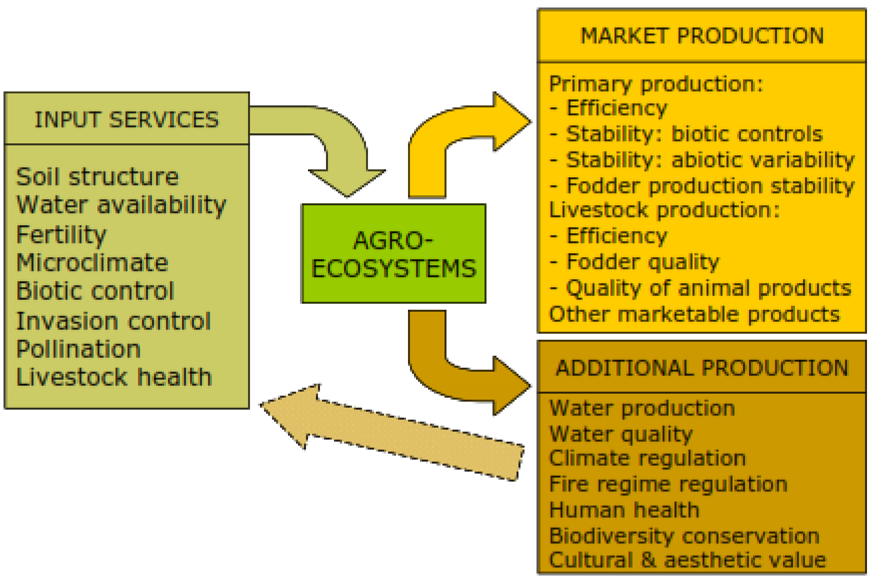

Figure of agro- essment

associated with agrobiodiversity (Table 2), highlighting its importance at all levels of the ecosystem service scheme [77]. Agrobiodiversity comprises diversity at various levels and includes genetic diversity, species diversity, and the diversity of agroecosystems (genetic diversity, for instance, plays a larger role in the provision of some regulating services, while species diversity is of high relevance for the provision of certain cultural services).

2.4. Agricultural biodiversity as a circular system

Circular systems are not a new idea, they are based on nature [76]. Waste does not occur in nature, one organism's waste is another organism's food, and nutrients and energy flow in closed-loop cycles of growth, decay, and reuse.

In this respect, as it was mentioned in Chapter 1, Decomposers or Micro-consumers [32,38,41,43] or Detritivores [49,50] or Transformers [49] break down the dead tissue and waste products [32,38,43]. They play a very important role in the ecosystem because they recycle the nutrients [38] converting organic matter into energy and nutrients [49], Figures 15 and 16. According to Biotic Components branches from Figure 12, it seems that Decomposers act separately from Producers and Consumers. In fact, these (micro-)organisms are present and act at all trophic levels [49,51], Figures 13 and 15.

Table 2 [77]: Overview of ecosystem services that have been directly or indirectly associated with agrobiodiversity.

Ecosystem services		
Category	**Description**	**Service**
Provisioning Services	Products obtained from ecosystems	• Food and other agricultural products • Plant genetic resources
Regulating Services	Services that contribute to the regulation of ecosystem processes	• Disease- and pest regulation • Pollination
Cultural Services	Non-material services provided by ecosystems	• Traditional, local knowledge • Cultural identity • Aesthetic and spiritual values
Supporting services	Services that allow for the presence of other ecosystem services	• Primary production • Nutrient- and water cycle • Carbon sequestration

In contrast to natural circular systems (Figures 15 and 16), our current linear FAS do not include mechanisms for waste recovery and productive reuse [76]. This linear arrangement of human food chain (Figure 12-Biotic components, Figure 14 and Figure 16-central arrow) could be understood according to the mention of Günther et al. in their report [88]: The EU's current economy is still largely linear, based on the assumption that natural resources are abundantly available and cheap to dispose of.

The circular economy aims to transform our economy from the current, mostly linear, take-make-waste model towards a closed-loop model [89], Figure 30 [76]. This transformation can minimise the use of materials and energy while reducing environmental pressures linked to resource extraction, emissions and waste. In this way, the circular economy principles provide solutions that achieve more sustainable production and consumption patterns, which in turn benefit biodiversity and nature through reduced resource extraction and waste.

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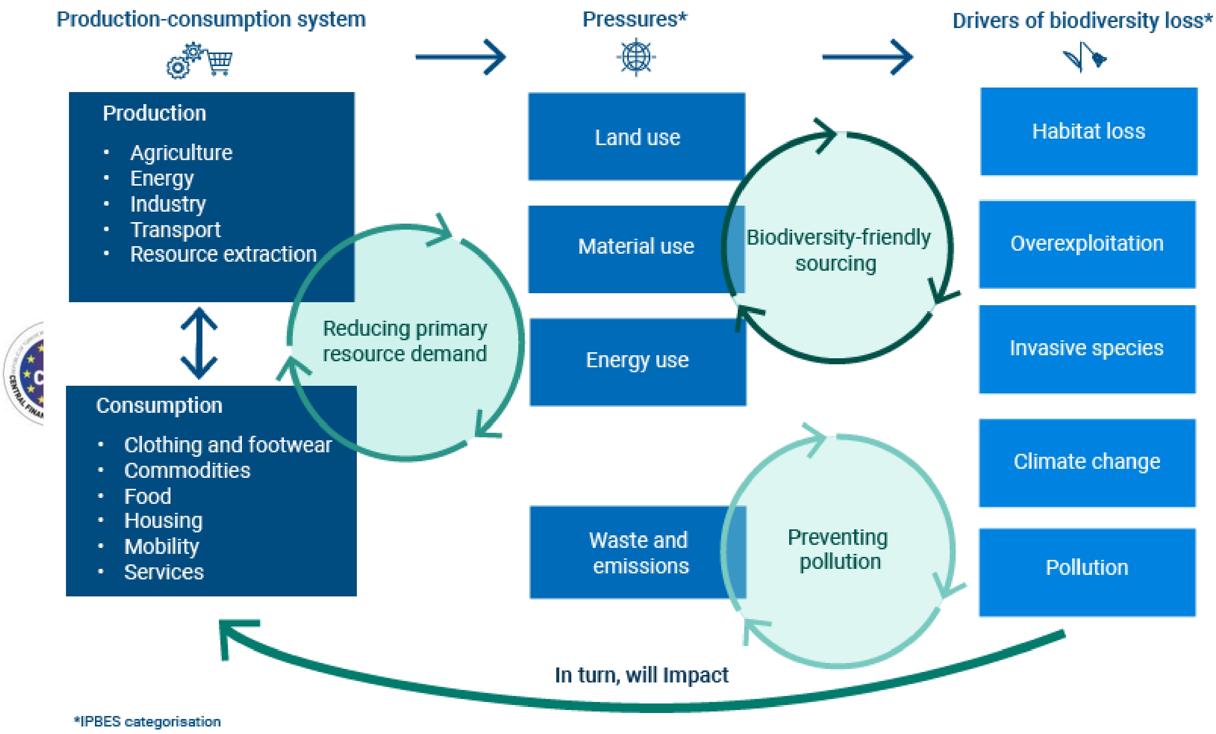
Circular economy has the potential to reduce the impact of our production and consumption systems on biodiversity through three key areas of intersection (Figure 31) [89]:

1. **Reduce primary resource demand** can be achieved by changing consumption patterns, extending product lifespans, recycling materials and adopting circular business models. Lower demand for primary resources decreases the demand for excavation activities and for converting natural habitats into cropland or monocrop plantations. As a result, key drivers of biodiversity loss, including habitat loss, overexploitation and the introduction of invasive species, will be eased.
2. **Preventing pollution** can be achieved by phasing out hazardous substances, reducing emissions and other forms of leakage, and promoting closed and clean loops. This, in turn, reduces the impacts on biodiversity of pollution, such as air pollution, fertiliser run-off, or leakage of toxic chemicals, but also contributes to climate change mitigation by lowering greenhouse gas emissions from waste decomposition.
3. **Biodiversity-friendly supply** relates to the sourcing and cultivation of raw materials. It can be achieved by reducing the negative impact of resource extraction, e.g., by improving environmental practices in the forestry sector. This, in turn, contributes to more resilient production and consumption systems.

The introduction of a Circular Economy in agriculture means the utilization of minimal amounts of external inputs in the production of agricultural commodities [90]. It also means closing the nutrient loops in agri-food production, from livestock to cropland farming; reducing negative discharges, such



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as waste and emissions in the environment; and valorizing agri-food waste.

Circularity in agriculture entails developing farming methods and systems that reflect natural cycles, lessen reliance on finite resources, and support sustainable and regenerative practices (according to FAO, around one-third of all food produced for human consumption is lost or wasted globally, amounting to approximately 1.3 billion metric tonnes per year) [91].

Examples of circular agricultural approaches which integrate a regenerative dimension include shifting from synthetic to organic fertilisers, employing crop rotation, and using greater crop variation to promote biodiversity [92]. Other examples include regenerative agricultural approaches such as agroecology, agroforestry, and managed grazing sequester carbon in the soil and improve its health; they increase biodiversity in surrounding ecosystems and enable agricultural lands to remain productive instead of degrading over time, thereby reducing pressure to expand them.

2.5. Agriculture and biodiversity conservation

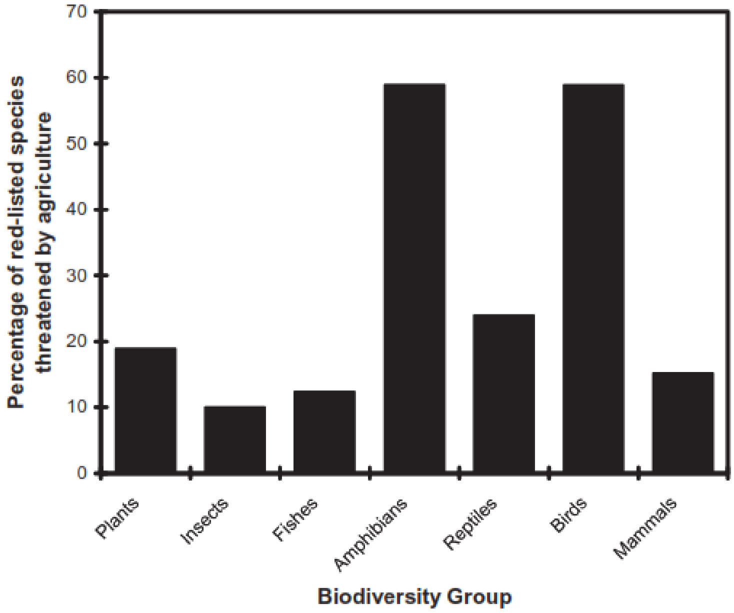

Figure 32 [93]: The percentage of red-listed species threatened by agriculture in a range of biodiversity groups. Data are from the World Conservation Union (IUCN) Red List database.

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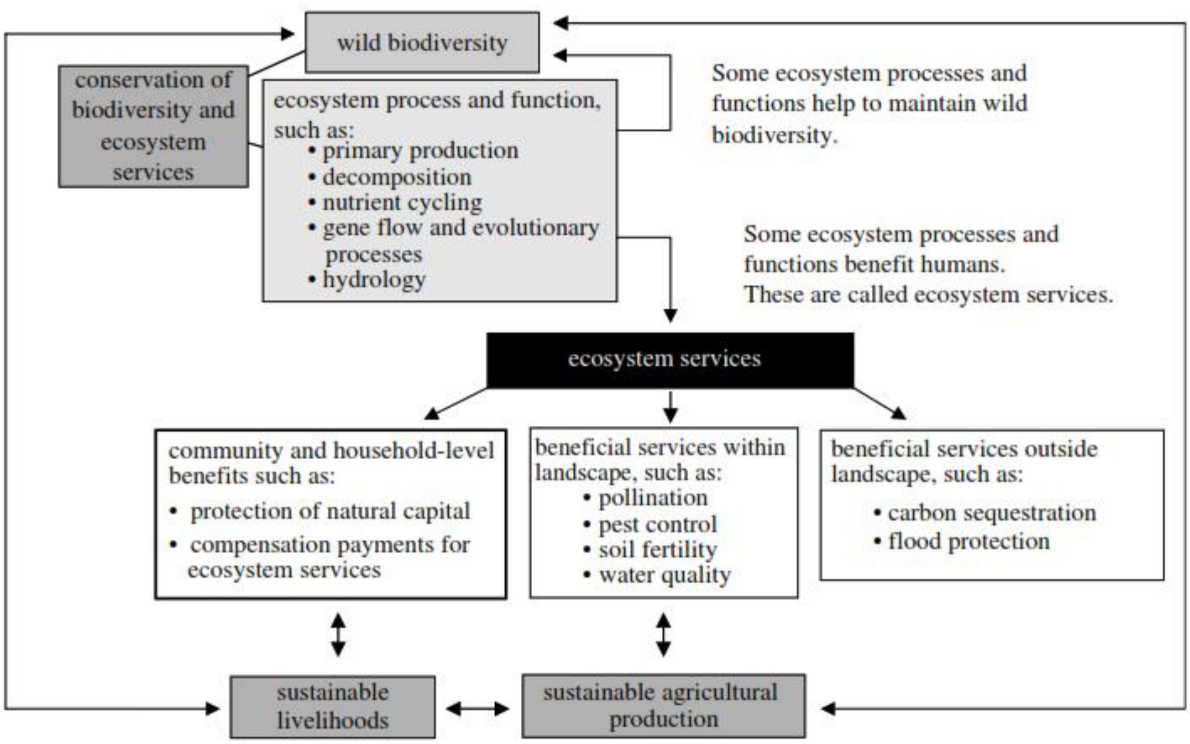
The expansion and intensification of agriculture during the 20th century contributed to poverty alleviation and improved food security globally, but these benefits came at a cost to the environment [93]. Natural ecosystems have been destroyed or damaged, and the ecosystem services they provide to man degraded or lost (MEA 2005). Not surprisingly, these ecosystem changes have been accompanied by losses of biodiversity locally and by an increased risk of extinction globally. According to IUCN data, agriculture is a major cause of global endangerment (Figure 32), and recent analyses have shown that endangerment is closely linked with agricultural land-use.

Conservation of wild biodiversity (genes, species and ecosystems) is considered by many to be an ethical imperative [94]. At the same time, conservation also supports "ecosystem services - ecological processes and functions that sustain and improve human well-being. Historically, Provisioning Services have been seen as the highest priority services provided by agricultural landscapes. But it is now recognized that even the "bread baskets" and "rice bowls" of the world also provide other ecosystem services, such as water supply and quality, or pest and disease control (Figure 33), that are also important. The conservation community is moving towards an "ecosystem approach" to conserving biodiversity (Figure 33), in light of the dependence of protected areas on a supportive matrix of land and water use [94].

DeClerck et al. [95] presented five critical challenges to agriculture in relation to biodiversity that suggests that this interaction can be conceived as an **AR^{3}T** "mitigation hierarchy" with targets aligned with the forthcoming CBD Kunming objectives (Figure 34):

- **Avoid** continued land expansion into intact nature to secure nature's essential contribution to



climate mitigation, aiming for levels of 30% protected and >50% intact;

- **Restore** intact nature where possible, prioritizing those areas that have been degraded, have high climate mitigation or have biodiversity conservation potential in line with no net loss as of 2020, restoration in 2030, and full recovery by 2050, contributing to biodiversity conservation, climate mitigation and regional hydrological flow regulation;
- **Reduce** the impacts of agriculture on biodiversity, notably by halting the losses of nutrients, biocides and other pollutants to air, soil and water;
- **Regenerate** the ecosystem services provided by biodiversity in all agricultural lands everywhere retaining a *minimum* 10% of habitat within agriculture;
- **Transform** the food system by creating the policy instruments, demand and incentives for food production systems that leverage biodiversity's capacity to contribute to climate, environmental, food and nutritional securities.

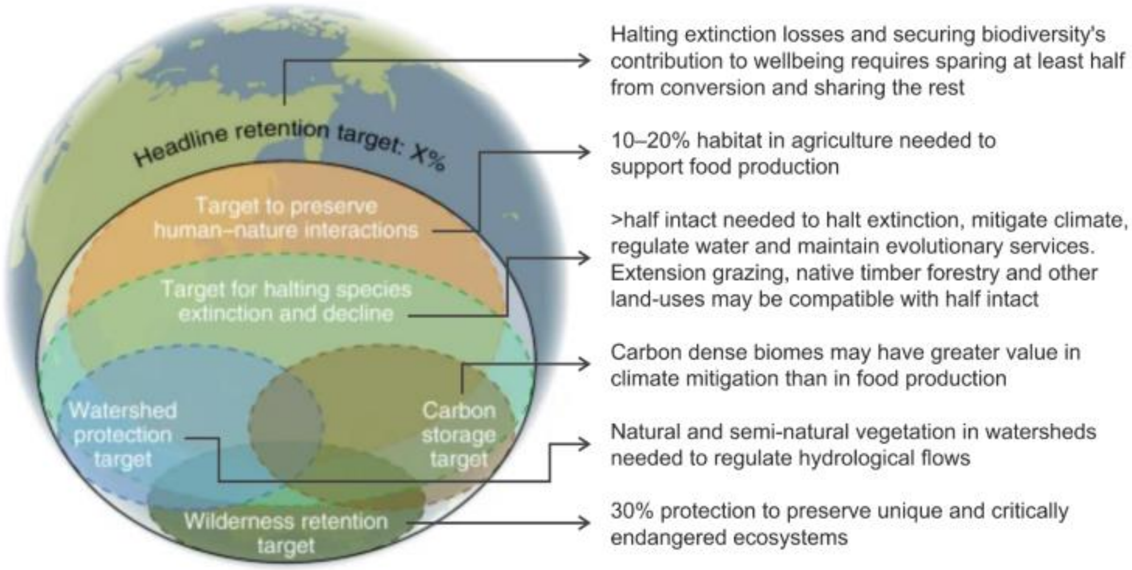


Figure 34 [95]: Bold biodiversity targets are required to halt the loss of biodiversity and secure biodiversity's contributions to Earth system and ecosystem processes. Today, approximately half the Earth's land surface remains intact, making "half intact" the equivalent of a no net loss target. Combined actions to avoid loss, restore intact nature, reduce impacts of human activities on nature, regenerate ecosystem service production through nature-positive production, and transform agricultural policies and actions are needed to maintain a safe environmental space for humanity.

García-Vega et al. [85] considered five key dimensions of biodiversity conservation, which we understand as requirements for effective conservation of global biodiversity, including both natural and agricultural biodiversity (Table 3). Two dimensions are important for the conservation of agrobiodiversity: providing habitat and resources for species inhabiting agricultural landscapes, as well as conserving functional groups that provide critical ecosystem services at the field level (i.e., pollinators, natural enemies, and soil biota). Key dimensions for natural biodiversity are the conservation of natural habitats for wildlife, the connectivity across landscapes, and limiting the

Table 3 [85]: The key dimensions of agricultural and natural biodiversity conservation, and their associated pressures stemming from agriculture.

Type of biodiversity	Dimension of biodiversity conservation	Pressures from agriculture
Agricultural biodiversity	Habitats and resources across agricultural landscapes	Landscape and farm-scale simplification
	Ecosystem service providers within agroecosystems	Landscape and farm-scale simplification, pesticide pollution
Natural biodiversity	Natural habitats and resources	Agricultural expansion and fragmentation of natural habitats
	Landscape connectivity	Landscape and farm-scale simplification
	Changes to the abiotic environment	N (Nitrogen) and P (Phosphorus) pollution, pesticide pollution, GHG emissions, water withdrawal

external impacts of farmland management across the globe (i.e., pesticide and nutrient pollution, GHG emissions, and water withdrawal).

Restoring and regenerating damaged land and finding compromise between biodiversity and production within commodity production and agricultural patches, can further contribute to improved environmental outcomes [96]. Current challenges with agricultural productivity already encourage use of hybrid crop varieties, bred for yield, harvest or pest and disease resistance.

The adoption of biodiversity-based practices for agriculture it is up to individual farmers who are ultimately the agents who decide how much natural capital to conserve and utilize, and will do that based on their own objectives and needs, and the social, economic (e.g., markets and policies), and environmental conditions in which they operate [97]. The multiple interactions between farmers and the natural resources they use, and between farmers and the institutional environment, create different farming practices and styles, which result in local specificity and regional heterogeneity of the natural and social environments which may either enhance or reduce agrobiodiversity. The private and social values of biodiversity often differ widely (Figure 35).

Figure 35 [97]: Ecosystem Linkages between social and individual or private values of biodiversity conservation. When the social value outweighs the individual value, then biodiversity is underprovided by the direct land users. Policies are needed to correct for such market failure.

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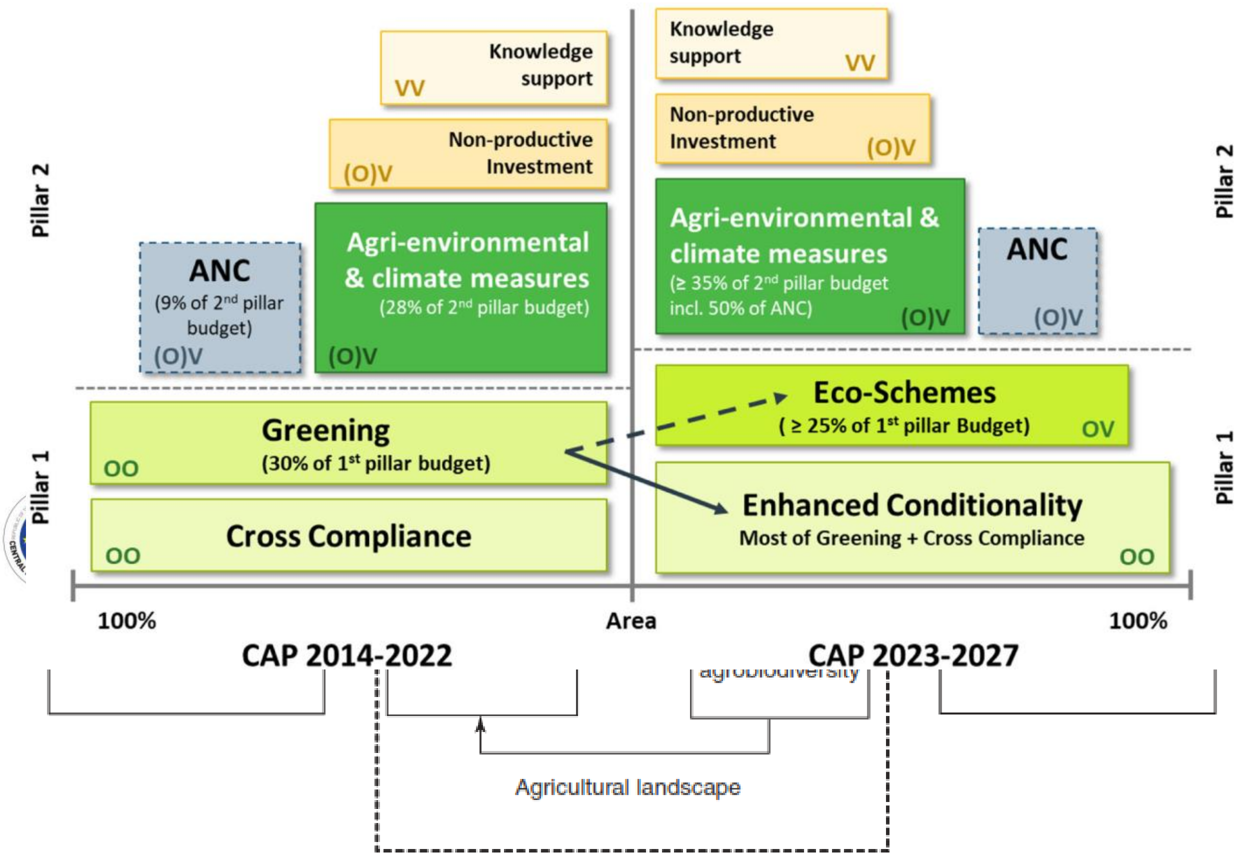
Individual farmers tend to react to the private use-value of biodiversity when reflected in the marketplace and thus typically ignore the ‘‘external’’ benefits of conservation that accrue to the wider society [97]. This currently implies an overexploitation of biodiversity, thus imposing excessive costs on society at large. Institutional intervention through incentives is therefore needed to ensure that agrobiodiversity will be used and conserved to its full potential of functional benefits.

To address the weaknesses of CAP (Common Agricultural Policy) 2014-2022 (Figure 36), the CAP post-2023 proposes a new ‘‘Green Architecture’’ around three area-related environmental instruments: ‘‘enhanced conditionality’’; AECM in Pillar 2; and new ‘‘Eco-schemes’’ in Pillar 1 [98]. Similar to AECM, Eco-schemes are voluntary for farmers, but Member States (MS) have much more freedom in their design. MS are required to invest at least 20% of Pillar 1 payments in Eco-schemes in 2023–2024 and at least 25% after 2025. The minimum share of Pillar 2 payments for environmental instruments increases from 30% currently to 35% after 2023. A new delivery model will also focus more on outcomes than prescriptions, granting MS more flexibility regarding how they intend to achieve the CAP’s objectives.

In parallel to the CAP reform, the European Commission introduced the Green Deal, the Farm to Fork Strategy and an updated Biodiversity Strategy and adopted a Climate Law in June 2021 [98]. Major agri-environmental targets by 2030 include reduced use of chemical pesticides (−50%), antibiotics



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(−50%), and fertilizers (−20%); expanding the land share of organic farming to 25%; maintaining or restoring landscape features on at least 10% of farmland; and reducing net GHG emissions by 55%. These ambitious goals require improved environmental performance of European agriculture, with many implications for the CAP.

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