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COURSE SUPPORT

Biodiversity and Climate Change

Level: Master 1 Biodiversity and Plant Physiology

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LIST OF FIGURES

LIST OF TABLES

SUMMARY

Chapiter III. Climate change and plant biodiversity

Chapiter IV. Climate Change in Algeria

Introduction

Biological diversity, the name given to the entire variety of life on Earth, provides the products and services that sustain our livelihoods through the ecosystems it forms. The pressures exerted by human beings on ecosystems are leading to a depletion and alteration of biological diversity at an unprecedented rate. The current populations are altering ecosystems more rapidly and significantly than at any other time in human history. Climate change adds additional pressure to our ecosystems.

The **Millennium Ecosystem Assessment**, a comprehensive evaluation of the connections between ecosystem health and human well-being, reveals that climate change could become the most significant factor directly responsible for the depletion of biological diversity by the end of the century.

The relationship between biodiversity and climate change is complex and reciprocal. On one hand, climate change is a major driver of biodiversity loss. As temperatures rise and weather patterns become more erratic, species are forced to migrate, adapt, or face extinction. Many species, particularly those with limited mobility or specific habitat requirements, are unable to adapt quickly enough, leading to a decline in biodiversity. Habitats such as coral reefs, wetlands, and polar regions are particularly vulnerable, and their degradation further exacerbates the loss of biodiversity.

On the other hand, biodiversity plays a critical role in mitigating and adapting to climate change. Ecosystems rich in biodiversity are more resilient to environmental changes and can better withstand and recover from climate-related disturbances. Forests, wetlands, and other natural habitats act as carbon sinks, absorbing CO_2 from the atmosphere and helping to regulate the global climate. The loss of these ecosystems not only releases stored carbon but also reduces the Earth's capacity to sequester carbon in the future.

Moreover, biodiversity contributes to human adaptation strategies. Diverse agricultural systems, for example, are more resilient to climate variability and extremes, ensuring food security in a changing climate. Traditional knowledge, often rooted in biodiversity-rich environments, offers valuable insights into sustainable resource management and climate adaptation.

In summary, the preservation of biodiversity is not just a conservation issue but a fundamental component of global efforts to address climate change. Protecting and restoring ecosystems can mitigate the impacts of climate change while simultaneously enhancing the resilience of both natural and human systems. As the world grapples with the dual crises of biodiversity loss and climate change, integrated approaches that address both challenges are crucial for achieving long-term sustainability and resilience.

Chapiters I: Biodiversity

I.1. The term biodiversity

Biodiversity is the variation of life forms within a given ecosystem, biome, or for the entire Earth. Biodiversity is often used as a measure of the health of biological systems. The biodiversity found on Earth today consists of many millions of distinct biological species, which is the product of nearly 3.5 billion years of evolution.

I.1.1. Evolution and meaning

Biodiversity is a portmanteau word, from biology and diversity, originating from and used interchangeably with "biological diversity." This term was used first by wildlife scientist and conservationist Raymond F. Dasmann in a lay book advocating nature conservation. It was not widely adopted for more than a decade, when in the 1980s it and "biodiversity" came into common usage in science and environmental policy. Use of the term by Thomas Lovejoy in the Forward to the book credited with launching the field of conservation biology introduced the term along with "conservation biology" to the scientific community. Until then the term "natural diversity" was used in conservation science circles, including by The Science Division of The Nature Conservancy in an important 1975 study, "The Preservation of Natural Diversity." By the early 1980s TNC's Science program and its head Robert E. Jenkins, Lovejoy, and other leading conservation scientists at the time in America advocated the use of "biological diversity" to embrace the object of biological conservation. (Wilson,1998).

Its contracted form biodiversity may have been coined by W.G. Rosen in 1985 while planning the National Forum on Biological Diversity organized by the National Research Council (NRC) which was to be held in 1986, and first appeared in a publication in 1988 when entomologist E. O. Wilson used it as the title of the proceedings of that forum.

Since this period both terms and the concept have achieved widespread use among biologists, environmentalists, political leaders, and concerned citizens worldwide. It is generally used to equate to a concern for the natural environment and nature conservation. This use has coincided with the expansion of concern over extinction observed in the last decades of the 20th century. A similar concept in use in the United States, besides natural diversity, is the term "natural heritage." It pre-dates both terms though it is a less scientific term and more easily comprehended in some ways by the wider audience interested in conservation. "Natural

Heritage" was used when Jimmy Carter set up the Georgia Heritage Trust while he was governor of Georgia; Carter's trust dealt with both natural and cultural heritage. It would appear that Carter picked the term up from Lyndon Johnson, who used it in a 1966 Message to Congress. "Natural Heritage" was picked up by the Science Division of the US Nature Conservancy when, under Jenkins, it launched in 1974 the network of State Natural Heritage Programs. When this network was extended outside the USA, the term "Conservation Data Center" was suggested by Guillermo Mann and came to be preferred. **(UNEP,1995).**

I.1.2 Definitions

Biologists most often define "biological diversity" or "biodiversity" as the "totality of genes, species, and ecosystems of a region". An advantage of this definition is that it seems to describe most circumstances and present a unified view of the traditional three levels at which biological variety has been identified:

- genetic diversity
- species diversity
- ecosystem diversity

This multilevel conception is consistent with the early use of "biological diversity" in Washington. D.C. and international conservation organizations in the late 1960s through 1970's, by Raymond F. Dasmann who apparently coined the term and Thomas E. Lovejoy who later introduced it to the wider conservation and science communities. An explicit definition consistent with this interpretation was first given in a paper by Bruce A. Wilcox commissioned by the International Union for the Conservation of Nature and Natural Resources (IUCN) for the 1982 World National Parks Conference

in Bali The definition Wilcox gave is "Biological diversity is the variety of life forms...at all levels of biological systems (i.e., molecular, organismic, population, species and ecosystem)..." Subsequently, the 1992 United Nations Earth Summit in Rio de Janeiro defined "biological diversity" as "the variability among living organisms from all sources, including, 'inter alia', terrestrial, marine, and other aquatic ecosystems, and the ecological complexes of which they are part: this includes diversity within species, between species and of ecosystems". This is, in fact, the closest thing to a single legally accepted definition of biodiversity, since it is the definition adopted by the United Nations Convention on Biological Diversity.

The current textbook definition of "biodiversity" is "variation of life at all levels of biological organization".(Gaston and John;2004).

If the gene is the fundamental unit of natural selection, according to E. O. Wilson, the real biodiversity is genetic diversity. For geneticists, biodiversity is the diversity of genes and organisms. They study processes such as mutations, gene exchanges, and genome dynamics that occur at the DNA level and generate evolution. Consistent with this, along with the above definition the Wilcox paper stated genes are the ultimate source of biological organization at all levels of biological systems..."

I.1.3 Measurement

Biodiversity is a broad concept, so a variety of objective measures have been created in order to empirically measure biodiversity. Each measure of biodiversity relates to a particular use of the data. For practical conservationists, this measure should quantify a value that is broadly shared among locally affected people. For others, a more economically defensible definition should allow the ensuring of continued possibilities for both adaptation and future use by people, assuring environmental sustainability.

As a consequence, biologists argue that this measure is likely to be associated with the variety of genes. Since it cannot always be said which genes are more likely to prove beneficial, the best choice for conservation is to assure the persistence of as many genes as possible. For ecologists, this latter approach is sometimes considered too restrictive, as it prohibits ecological succession.

Biodiversity is usually plotted as taxonomic richness of a geographic area, with some reference to a temporal scale. Whittaker described three common metrics used to measure species-level biodiversity, encompassing attention to species richness or species evenness:

- Species richness - the least sophisticated of the indices available.
- Simpson index
- Shannon-Wiener index

There are three other indices which are used by ecologists:

- Alpha diversity refers to diversity within a particular area, community or ecosystem, and is measured by counting the number of taxa within the ecosystem (usually species)
- Beta diversity is species diversity between ecosystems; this involves comparing the number of taxa that are unique to each of the ecosystems.
- Gamma diversity is a measurement of the overall diversity for different ecosystems within a region. (Whittaker,1972).

I.2.Fauna and flora

I.2.1 Fauna

Fauna is all of the animal life present in a particular region or time. The corresponding term for plants is flora. Flora, fauna and other forms of life such as fungi are collectively referred to as biota.

I.2.1.1. Subdivisions on the basis of region

- ✓ **Cryofauna**

Cryofauna refers to the animals that live in, or very close to, cold areas.(Fig.1)



Orcinus orca ***Aptenodytes forsteri*** ***Thalassarche melanophris***

Figure 1: Cryofauna diversity shown by 3 examples.
https://joysquared8.wordpress.com/subdivisions-of-fauna/cryofauna/

- ✓ ***Epifauna***

Epifauna, also called epibenthos, are aquatic animals that live on the bottom substratum as opposed to within it, that is, the benthic fauna that live on top of the sediment surface at the seafloor.(Fig.2)




Echinoderm ***Mollusca*** ***Crustacean*** ***Littoraria angulifera***

Figure 2 : *Epifauna* diversity shown by 4 examples. https://www.jaxshells.org/anqu.htm

- ✓ **Infauna**

Infauna are benthic organisms that live within the bottom substratum of a water body, especially within the bottom-most oceanic sediments, the layer of small particles at the bottom of a body of water, rather than on its surface. Bacteria and microalgae may also live in the interstices of bottom sediments. In general, infaunal animals become progressively smaller and less abundant with increasing water depth and distance from shore, whereas bacteria show more constancy in abundance, tending toward one million cells per milliliter of interstitial seawater. Such creatures are found in the fossil record and include lingulata, trilobites and worms. They made burrows in the sediment as protection and may also have fed upon detritus or the mat of microbes which tended to grow on the surface of the sediment. (Uribe ,2023)

Today, a variety of organisms live in and disturb the sediment. The deepest burrowers are the ghost shrimps (*Thalassinidea*), which go as deep as 3 metres (10 ft) into the sediment at the bottom of the ocean.(Fig.3)

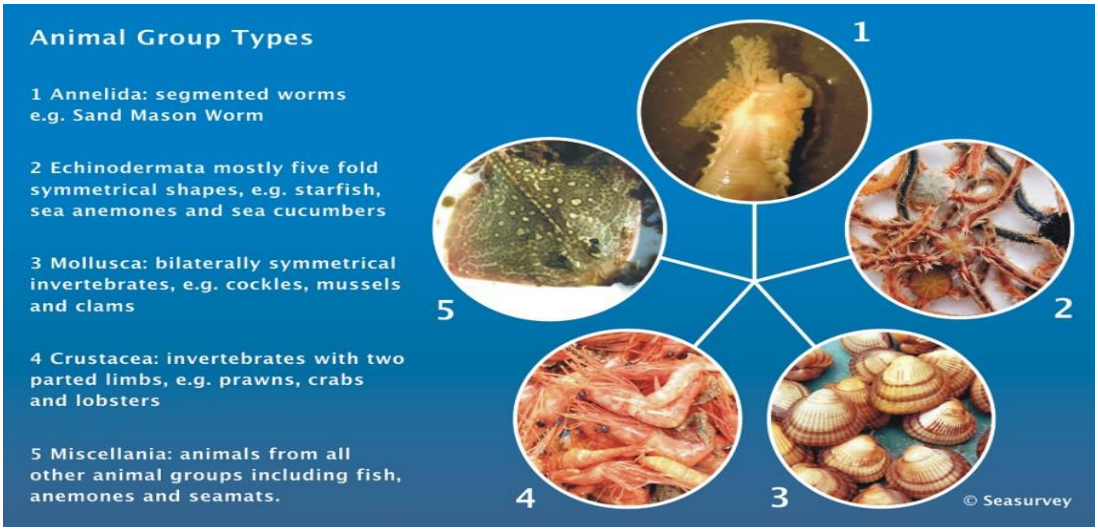


Figure 3: ***Infauna*** diversity shown by 5 examples. https://ets.wessexarch.co.uk/recs/how-we-study-the-seafloor/ecological-methods/

- ✓ **Limnofauna**

Limnofauna refers to the animals that live in fresh water.(Fig.4)

Figure 4: *Limnofauna* diversity shown by different examples.

https://visualdictionary.org/freshwater-animals/

- ✓ **Macrofauna**

Macrofauna are benthic or soil organisms which are retained on a 0.5 mm sieve. Studies in the deep sea define macrofauna as animals retained on a 0.3 mm sieve to account for the small size of many of the taxa.(Fig.5)

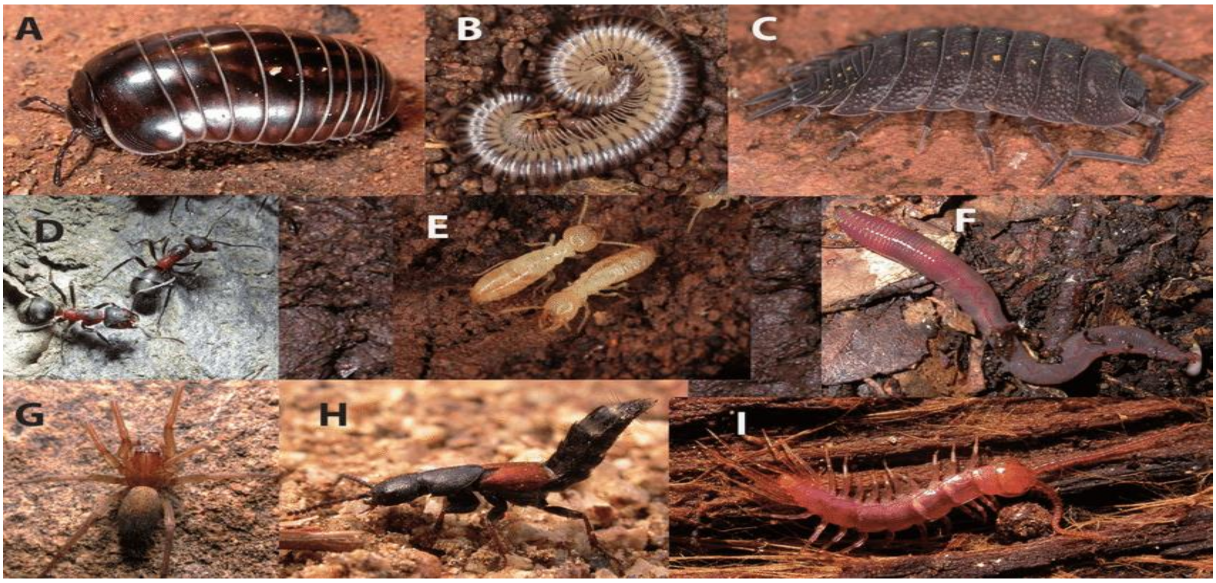


Figure 5: *Macrofauna* diversity shown by different examples

Diversos representats de la macrofauna. Sapròfags: A, diplòpode (Glomeridae, 10 mm de llargària); B, diplòpode (Julidae, 25 mm); C, isòpode (Porcellionidae, 12 mm). Enginyers: D, formigues (Formicidae, 7 mm); E, tèrmits (Rhinotermitidae, 5 mm); F, cuc de terra (Lumbricidae, 90 mm). Depredadors: G, araneid (Agelenidae, 10 mm); H, coleòpter (Staphylinidae, 12 mm); I, quilòpode (Lithobiidae, 35 mm). Fotografies d'Eduardo Mateos.

- ✓ **Megafauna**

Megafauna are large animals of any particular region or time. For example, African megafauna.(Fig.6)

Figure 6: Rhino facts; *Ceratotherium simum (Megafauna animals).*

https://www.bioexpedition.com/black-rhinoceros/

- ✓ **Meiofauna**

Meiofauna are small benthic invertebrates that live in both marine and freshwater environments. The term *meiofauna* loosely defines a group of organisms by their size, larger than microfauna but smaller than macrofauna, rather than a taxonomic grouping. One environment for meiofauna is between grains of damp sand (see Mystacocarida).

In practice these are metazoan animals that can pass unharmed through a 0.5 1 mm mesh but will be retained by a 30–45 μm mesh, but the exact dimensions will vary from researcher to researcher. Whether an organism passes through a 1 mm mesh also depends upon whether it is alive or dead at the time of sorting.(Fig.7)

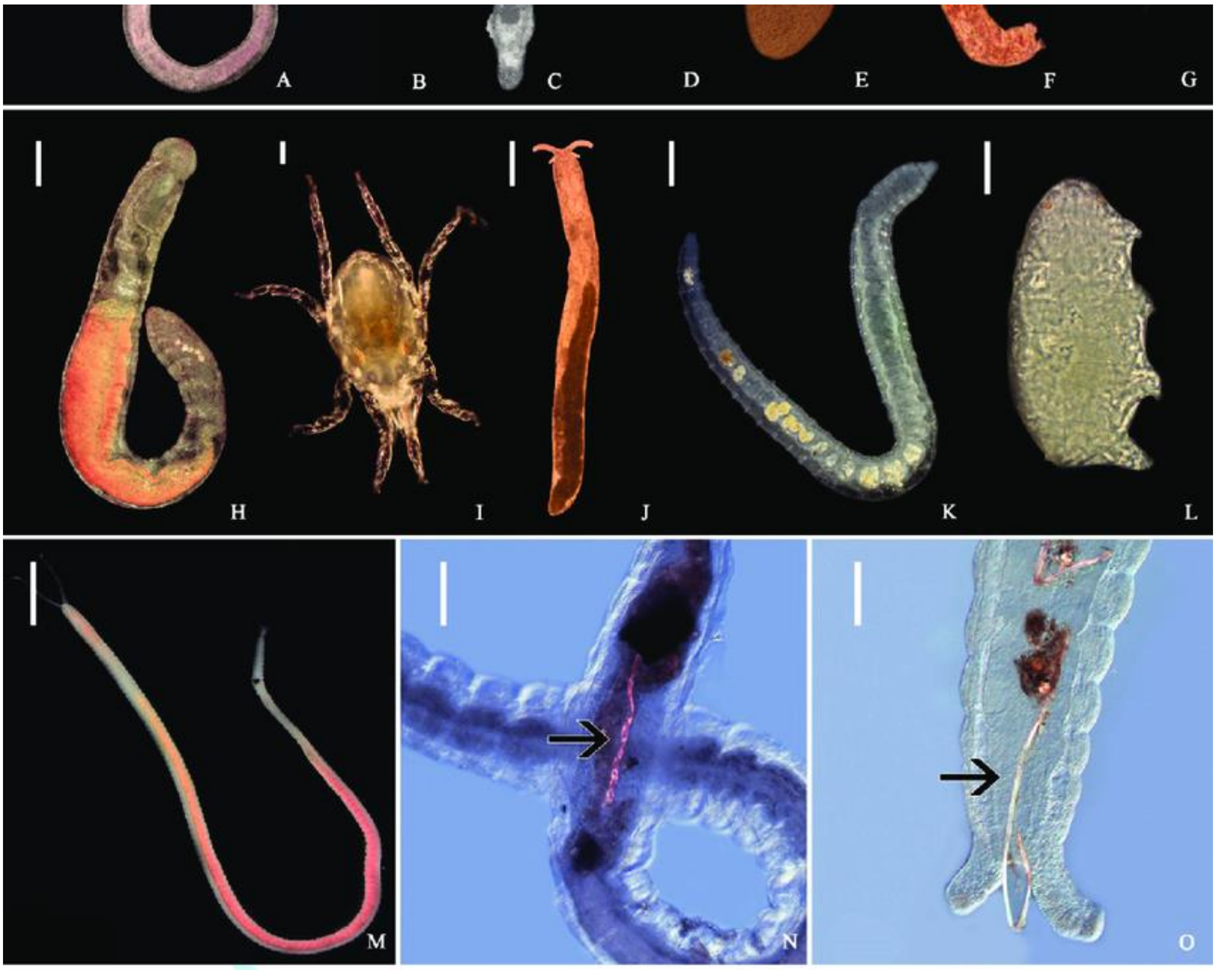


Figure 7: Meiofauna diversity shown by examples from a variety of higher taxa.

A. Nematoda, Enoplida; B. Nematoda, Epsilonematidae; C. Platyhelminthes, Proseriata; D. Platyhelminthes, Dalyelliidae; E. Platyhelminthes, Polycladida; F. Gastrotricha, Macrodasyidae; G. Gastrotricha, Chaetonotida; H. Annelida, Sedentaria, Ctenodrilus sp.; I. Arthropoda, Chelicerata, Acari; J. Mollusca, Gastropoda, Microhedyle sp; K. Annelida, Clitellata, Olygochaeta, L. Tardigrada, Heterotardigrada, Echiniscoididae; M. Annelida, Sedentaria, Saccocirrus cf. pussicus; N.-O. Saccocirrus cf. pussicus collected from the Santa Marta region that exhibit microfibers inside their gut. Scales in A., E., H., J., K., M. 200 µm; in C., D., N., O. 100 µm; and in B., F., G., I., L., 50 µm.

- ✓ **Mesofauna**

Mesofauna are macroscopic soil animals such as arthropods or nematodes. Mesofauna (Fig.8), are extremely diverse; considering just the springtails (Collembola), as of 1998, approximately 6,500 species had been identified. (Rusek ,1998)

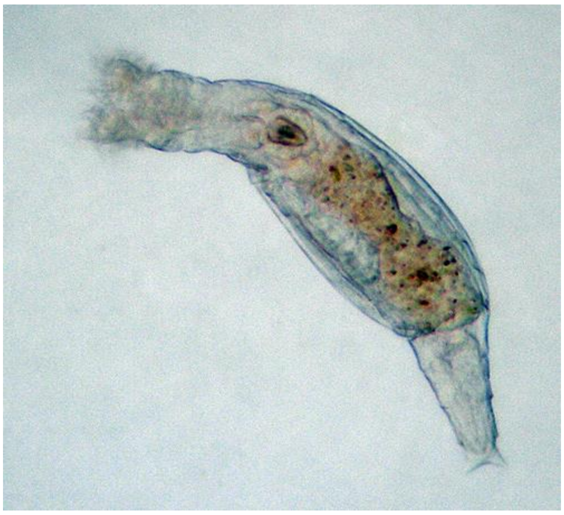
Springtails (Collembola) **mites (*Trombidium holosericeum*)**

Figure 8: Mesofauna diversity shown by 2examples.

https://elevagro.com/blog/biodiversidade-do-solo-organismos-a-servico-do-sistema-produtivo/

- ✓ **Microfauna**

Microfauna are microscopic or very small animals (usually including protozoans and very small animals such as rotifers). To qualify as microfauna, an organism must exhibit animal-like characteristics, as opposed to microflora, which are more plant-like.(Fig.9)



Arachnid *(Lorryia formosa)* ***Rotifera*** *(Habrotrocha rosa)*

Figure 9: Microfauna diversity shown by 2examples.

https://en.wikipedia.org/wiki/Habrotrocha_rosa

✓ **Stygofauna**

Stygofauna is any fauna that lives in groundwater systems or aquifers, such as caves, fissures and vugs. Stygofauna and troglofaunaare the two types of subterranean fauna (based on life-history). Both are associated with subterranean environments – stygofauna is associated with water, and troglofauna with caves and spaces above the water table. Stygofauna can live within freshwater aquifersand within the pore spaces of limestone, calcrete or laterite, whilst larger animals can be found in cave waters and wells. Stygofaunal animals, like troglofauna, are divided into three groups based on their life history - stygophiles, stygoxenes, and stygobites (Fig. 10) (Rubens and al, 1999).

Figure 10 : Stygofauna (Subterranean Fauna).

https://www.bennelongia.com.au/services/subterranean-fauna/stygofauna/

Troglofauna

Troglofauna are small cave-dwelling animals that have adapted to their dark surroundings. Troglofauna and stygofauna are the two types of subterranean fauna (based on life-history). Both are associated with subterranean environments – troglofauna is associated with caves and spaces above the water table and stygofauna with water. Troglofaunal species (Fig.11),include spiders, insects,myriapods and others.

Some troglofauna lives permanently underground and cannot survive outside the cave environment. Troglofauna adaptations and characteristics include a heightened sense of hearing, touch and smell. Loss of under-used senses is apparent in the lack of pigmentation as well as eyesight in most troglofauna. Troglofauna insects may exhibit a lack of wings and longerappendages.(Chapman ,1982)

figure11: Troglofauna (Subterranean Fauna).
https://www.bennelongia.com.au/services/subterranean-fauna/troglofauna/

- ✓ **Xenofauna**

Xenofauna, theoretically, are alien organisms that can be described as animal analogues. While no alien life forms, animal-like or otherwise, are known definitively, the concept of alien life remains a subject of great interest in fields like astronomy, astrobiology, biochemistry, evolutionary biology,science fiction, and philosophy. (Fig.12)

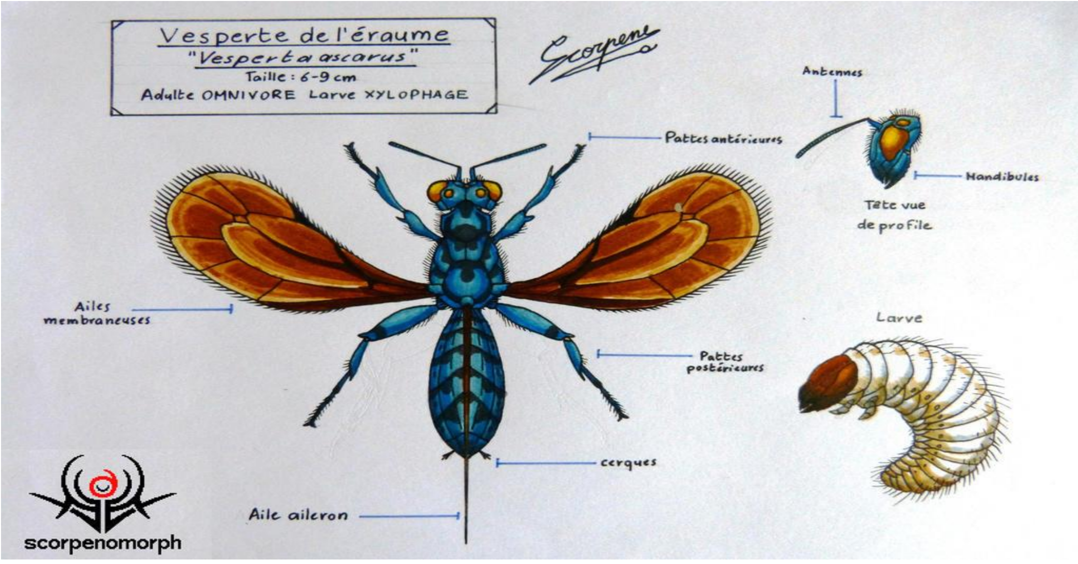


Figure 12 : hydra 3 xenofauna https://www.deviantart.com/scorpenomorph/art/hydra-3-xenofauna-vesperte-de-l-eraume-478044775

- ✓ **Other**

Other terms include *avifauna*, which means "bird fauna" and *piscifauna* (or *ichthyofauna*), which means "fish fauna" (Fig.13).

Common ostrich ***Apricaphanius saourensis***

Figure 13: *Avifauna* and *ichthyofauna* diversity shown by 2examples(bird and fish)**.**

I.2.1.2. Algeria animals (fauna)

Algeria, a country in North Africa, is a land of varied landscapes, home to a rich and diverse wildlife. The northern part of the country, with its Atlas Mountains, plains, and Mediterranean forests, serves as a refuge for many species such as the Barbary macaque, the only primate native to North Africa, as well as the golden jackal, the fennec fox, and the Atlas leopard, although the latter has become extremely rare. Algerian forests, particularly those in the Aurès and Kabylie regions, are teeming with birdlife, including species like the golden eagle, the Eurasian eagle-owl, and the white stork. (Fig.14)

Moving southwards, the vast desert expanses of the Sahara cover more than three-quarters of Algeria's territory. Despite the extreme climatic conditions, the desert is far from lifeless. The fennec fox, a symbol of the desert, is a small fox with large ears adapted to the heat. The desert is also home to the dromedary, essential for the nomadic populations, as well as the ocellated lizard and the desert monitor. The Sahara is also the last stronghold of the Saharan cheetah, an extremely endangered subspecies. The wetter areas of the country, such as the oases and chotts (salt lakes), are habitats for aquatic species, including various amphibians, as well as flamingos.

The diversity of habitats in Algeria, from Mediterranean mountains to Saharan deserts, allows for a rich fauna, but it is threatened by deforestation, desertification, and poaching. Conservation efforts are underway to protect this natural heritage, with the creation of national parks and nature reserves aimed at preserving Algeria's unique biodiversity.

I.2.1.3. Estimation and number of Algeria fauna

✓ **Mammals**

- **Total Number of Mammal Species**: Algeria is home to around 107 species of mammals.
- **Endemic Species**: The Barbary macaque (*Macaca sylvanus*), found in the forests of the Atlas Mountains, is one of the few primates living outside of Asia and is unique to North Africa.

✓ **Birds**

- **Total Number of Bird Species**: Approximately 430 species of birds have been recorded in Algeria, including both resident and migratory species.
- **Endemic and Notable Species**: The Algerian nuthatch (*Sitta ledanti*) is an endemic bird species found only in a few mountain ranges in Algeria.

✓ **Reptiles and Amphibians**

- **Reptiles**: Algeria has around 120 species of reptiles. The Sahara is particularly rich in lizard species, including geckos and skinks.
- **Amphibians**: There are about 16 species of amphibians, most of which are found in the northern, more temperate regions of the country.

✓ **Fish**

- **Freshwater Fish**: Algeria has a relatively low diversity of freshwater fish, with around 35 species, many of which are found in the few permanent rivers and lakes in the northern part of the country.
- **Marine Fish**: The Mediterranean coast of Algeria hosts a variety of marine life, including hundreds of fish species.

✓ **Invertebrates**

- **Insects**: Algeria is home to a vast number of insect species, particularly in the desert regions. This includes various species of beetles, butterflies, and ants.
- **Arachnids**: Scorpions are common in the desert, with several species such as *Androctonus australis* being highly venomous.

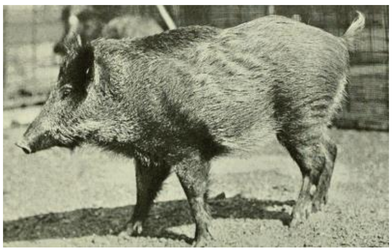
Conservation Status

- **Endangered Species**: Several species in Algeria are considered endangered or vulnerable. The addax antelope (*Addax nasomaculatus*) is critically endangered, and the population of Barbary macaques is declining due to habitat loss.
- **Protected Areas**: Algeria has established several national parks and reserves, such as Tassili n'Ajjer and Ahaggar National Park, to protect its biodiversity.(*Amori,2016)*



Vulpes zerda ***Addax nasomaculatus*** **Macaca sylvanus**





Struthio camelus camelus ***Gazella cuvieri*** ***Sus scrofa algira***

Figure 14: Photographs of a few Algeria animals. https://a-z-animals.com/animals/location/africa/algeria/

I.2.2. Flora

I.2.2.1 The Meaning of Flora

The term Flora usually refers to the natural vegetation of a particular geographic region or a scientific work that catalogues such vegetation. These meanings have evolved from a metonymy of the Roman goddess Flora. It was previously assumed that this metonymic use began in the seventeenth century and was initially limited to book titles. However, the present article challenges these assumptions and demonstrates that the metonymic use of Flora was employed much earlier, and not in book titles, but in poetry and letters.

According to the Oxford English Dictionary [henceforth OED], in modern times the term Flora often denotes "a descriptive catalogue of the plants of any geographical area, geological period, etc." or "the plants or plant life of any particular region or epoch", that is either a certain type of scientific literature or the content of such a scientific work.

The term is, of course, derived from the Roman goddess Flora, but its use in the Aforementioned sense is likely a neologism of sense coined in the early modern period.3In this article, I firstly give an overview of how the term was used in the seventeenth century and how it got the meanings it has today. Secondly, I discuss three texts – two letters and a liminary poem – from the end of the sixteenth and the beginning of the seventeenth century, which seem to have been largely overlooked for the historical etymology of Flora, but challenge the current state of research.(Lovaniensia,2019).

I.2.2.2. Flora in the world

There are an estimated 400,000 species of vascular plants and bryophytes on Earth, with perhaps an additional 10% yetto be discovered. The majority are flowering plants (calcula-tions centre around 352,000 to 370,000 accepted species; Nic Lughadha & al., 2016), whereas gymnosperms amount to 1090 species ,and there are roughly13,300 species of ferns and fern allies, 12,800mosses, and 7500 hornworts and liver-worts. These plants constitute the basis of most terrestrial ecosystems and hold answers to many of the world's health, social, environmental and economic problems. The completion of a full inventory of plant life is vital for protecting threatened species of all kinds of organ-isms and realizing their full potential to support human needs before many of them become extinct. (Crosby & al., 2000)

The classification of plants is currently in transition from a classification based mainly on comparative morphology (morpho-species) to the implementation of the results of phylogenetic analyses and evolution-based taxon circumscriptions. While a more-or-less stable classification has been achieved at the level of order sand families ,advances in knowledge have led to significant changes in generic and supra generic classifications. Changes at the generic level affect the naming of organisms following the rules of nomenclature, and thus directly influence the linking of distribution, molecular or morphological data to scientific names. This is also true for ongoing changes in species cir-cumscriptions (hence a change in a taxon concept) that occur as a consequence of new collections, new information sources and the application of new analytical methods in systematics. In addition, significant numbers of species are still being discovered and described as new to science every year (on average 2000 species of vascular plants per year in the last two decades), so there is a con-stant need for the incorporation of taxa into the Taxonomic Backbone. Verification of names and identities of species by taxonomic experts has been shown to have a significant effect on the estimation of biodiversity overall (Cardoso & al.,2017), making it imperative that the global taxonomic community is involved in such efforts.

I.2.2.3. Estimating the Size of the World's Threatened Flora

The most commonly cited figure for the fraction of the global flora threatened with extinction—13%—is known to be a serious underestimate, because it does not include a reliable tally of species at risk in the tropical latitudes where most of the world's plants grow (Bramwell,2002). Here we estimate the missing tropical data from global patterns of plant endemism. The results suggest that as many as half of the world's plant species may qualify as threatened with extinction under the World Conservation Union (IUCN) classification scheme.

Comprehensive Red Lists for plants are available for only a scattering of tropical countries, making it difficult to assess the true scale of the global conservation crisis for plants. We have approximated the missing tropical data by observing that the number of plant species endemic to a country is a reasonable proxy for the number of globally threatened plant species in that country. 83% of plant species endemic to the South American country of Ecuador qualify as globally threatened under IUCN criteria . At the global scale, 91% of the species in the most comprehensive list of threatened plant taxa to date are endemic to a single country .(Walter and Gillett, *1997)*

Species endemic to a single country represent 46 to 62% of the world flora. That is likely an overestimate of the global proportion of threatened species, because (i) many temperate countries have accurate tallies of their threatened floras, which are in some cases substantially smaller than their endemic floras (e.g., Australia), (ii) endemics in "biodiversity hot spots" are more likely to qualify as threatened than those elsewhere, and (iii) species endemic to small countries are more likely to be threatened than species endemic to large countries. Four other calculations of the proportions of threatened plant species are described in Table 1. The results fall in the range 22 to 47%, considerably higher than previous estimates .

The vast proportion of potentially threatened tropical taxa (;121,000 species) are endemic to countries in biodiversity hot spots where high floristic diversity and massive habitat loss coincide . Evaluating the conservation status of these species, adding deserving taxa to the IUCN Red List, and updating their status regularly would provide a relatively inexpensive yardstick to measure the success or failure of conservation efforts in hot spots, while at the same time essentially completing the global database of threatened plants. On the basis of our experience in recent checklist and red book projects in megadiverse Ecuador , we estimate the cost of such a project at ,$100 per species per year, for an annual budget of ,$12.1 million for all hot spots. This would require only 2.4% of the annual hot spots budget proposed by Myers *et al,2000*. Only with the species-by-species information generated by such an undertaking will conservationists be able to monitor and prevent the large-scale plant extinctions foreseen to occur in the tropics in this century.

Table 1: Five estimates of the number and proportion of plant species threatened with extinction worldwide. The percentages are calculated by dividing the estimated number of threatened plant species by global floras of 422,000 and 310,000 species,respectively.(prince and al,2000)

Estimate	Number of threatened species in each country calculated as:	Number of plant species threatened (proportion of total)
I	The number of species endemic to that country	193,513 (46 to 62%)
II	For tropical countries, the number of endemic species; for temperate countries, the number of currently threatened species	144,282 (34 to 47%)
III	For tropical hot spot countries, the number of endemic species; for other tropical countries, 50% of endemic species; for temperate countries, the number of currently threatened species	141,555 (34 to 46%)
IV	For tropical countries measuring <300,000 km², the number of endemic species; for other tropical countries, 50% of endemics; for temperate countries, the number of currently threatened species	94,052 (22 to 30%)
V	For tropical countries in hot spots or measuring <300,000 km², number of endemic species; for other tropical countries, 50% of endemics; for temperate countries, number of currently threatened species	141,974 (34 to 45%)

I.2.2.4. flora in Algeria (in the different bioclimatic levels)

Algeria, with its diverse geography ranging from the Mediterranean coast to the Sahara Desert, hosts a wide range of flora distributed across its various bioclimatic zones. These zones range from humid coastal areas to arid desert landscapes. Below is a detailed overview of the flora found in Algeria across its different bioclimatic levels (fig.15)

1. Humid and Sub-Humid Zones (Tellian Atlas and Coastal Areas)

- **Location:** Northern Algeria, including the coastal plains and Tellian Atlas.
- **Climate:** Mediterranean climate with mild, wet winters and hot, dry summers.
- **Flora:**
  - ➢ **Forests:** Dominated by broadleaf trees like cork oak (*Quercus suber*), Algerian oak (*Quercus canariensis*), and holm oak (*Quercus ilex*). In the more

humid areas, you can also find Aleppo pine (*Pinus halepensis*) and maritime pine (*Pinus pinaster*).

- **Understory:** Rich in shrubs like myrtle (*Myrtus communis*), mastic tree (*Pistacia lentiscus*), and laurel (*Laurus nobilis*).
- **Herbaceous Plants:** Diverse, including species such as wild asparagus (*Asparagus acutifolius*) and cyclamen (*Cyclamen africanum*).

2. Semi-Arid Zones (High Plateaus)

- **Location:** The interior high plateaus between the Tellian Atlas and the Saharan Atlas.
- **Climate:** Semi-arid with lower rainfall and more extreme temperatures.
- **Flora:**
  - **Shrublands:** Dominated by steppe vegetation such as alfa grass (*Stipa tenacissima*), sagebrush (*Artemisia herba-alba*), and esparto grass (*Lygeum spartum*).
  - **Forests:** Scattered, with juniper (*Juniperus phoenicea*) and Aleppo pine being common.
  - **Halophytic Vegetation:** Found in saline soils, including species like saltwort (*Salsola spp.*) and glasswort (*Salicornia spp.*).

3. Arid Zones (Saharan Atlas and Northern Sahara)

- **Location:** The transition zone between the High Plateaus and the Sahara Desert.
- **Climate:** Arid with very low rainfall and high temperature variations.
- **Flora:**
  - **Desert Shrublands:** Dominated by drought-resistant shrubs like Retama (*Retama raetam*), tamarisk (*Tamarix aphylla*), and Acacia species.
  - **Ephemeral Plants:** After rare rainfalls, the landscape briefly blooms with annuals like *Astragalus* and *Erodium* species.
  - **Palms:** The date palm (*Phoenix dactylifera*) is prominent in oases.

4. Hyper-Arid Zones (Sahara Desert)

- **Location:** Southern Algeria, encompassing much of the Sahara Desert.
- **Climate:** Extremely arid with very little rainfall, extreme temperatures, and vast expanses of sand.
- **Flora:**

- ➢ **Desert Adapted Plants:** Includes xerophytes like the Sahara mustard (*Brassica tournefortii*), *Fagonia* species, and *Zygophyllum* species.
- ➢ **Oases Vegetation:** Inhabited by date palms and associated species like tamarisk and desert gourds (*Citrullus colocynthis*).
- ➢ **Endemic Plants:** Rare and highly specialized species like the Saharan cypress (*Cupressus dupreziana*) found in the Tassili n'Ajjer region.

5. Montane Zones (Aures and Kabylie Mountains)

- **Location:** High altitude areas within the Atlas Mountain ranges, including the Aures and Kabylie Mountains.
- **Climate:** Cooler with more precipitation than surrounding areas.

- **Flora:**
  - ➢ **Mountain Forests:** Dominated by Atlas cedar (*Cedrus atlantica*), Algerian fir (*Abies numidica*), and other conifers.
  - ➢ **Deciduous Trees:** Such as maple (*Acer spp.*) and ash (*Fraxinus spp.*).
  - ➢ **Alpine Flora:** Including species like rockrose (*Cistus spp.*), thyme (*Thymus spp.*), and junipers.

6. Oasis Zones

- **Location:** Scattered throughout the Sahara, particularly in regions like the M'Zab Valley.
- **Climate:** Oases within hyper-arid environments, with localized water sources.
- **Flora:**
  - ➢ **Cultivated Crops:** Date palms are the primary agricultural product.
  - ➢ **Associated Vegetation:** Includes oleander (*Nerium oleander*), pomegranate (*Punica granatum*), and various vegetable crops in irrigated gardens.
  - ➢ **Riparian Species:** Such as reeds (*Phragmites australis*) and tamarisk, which thrive near water sources.

7. Wetlands and Coastal Areas

- **Location:** Coastal lagoons, estuaries, and other wetland areas near the Mediterranean coast.
- **Climate:** Influenced by Mediterranean conditions, with more moisture and moderate temperatures.
- **Flora:**

- **Aquatic Plants:** Species like reedmace (*Typha spp.*), common reed (*Phragmites australis*), and bulrush (*Scirpus spp.*).
- **Coastal Vegetation:** Includes salt-tolerant species like sea lavender (*Limonium spp.*) and glasswort (*Salicornia spp.*).

Algeria's diverse landscapes and climates support a wide range of plant species adapted to various bioclimatic conditions. From the humid forests of the coastal regions to the sparse vegetation of the Sahara, the country's flora is as varied as its geography.

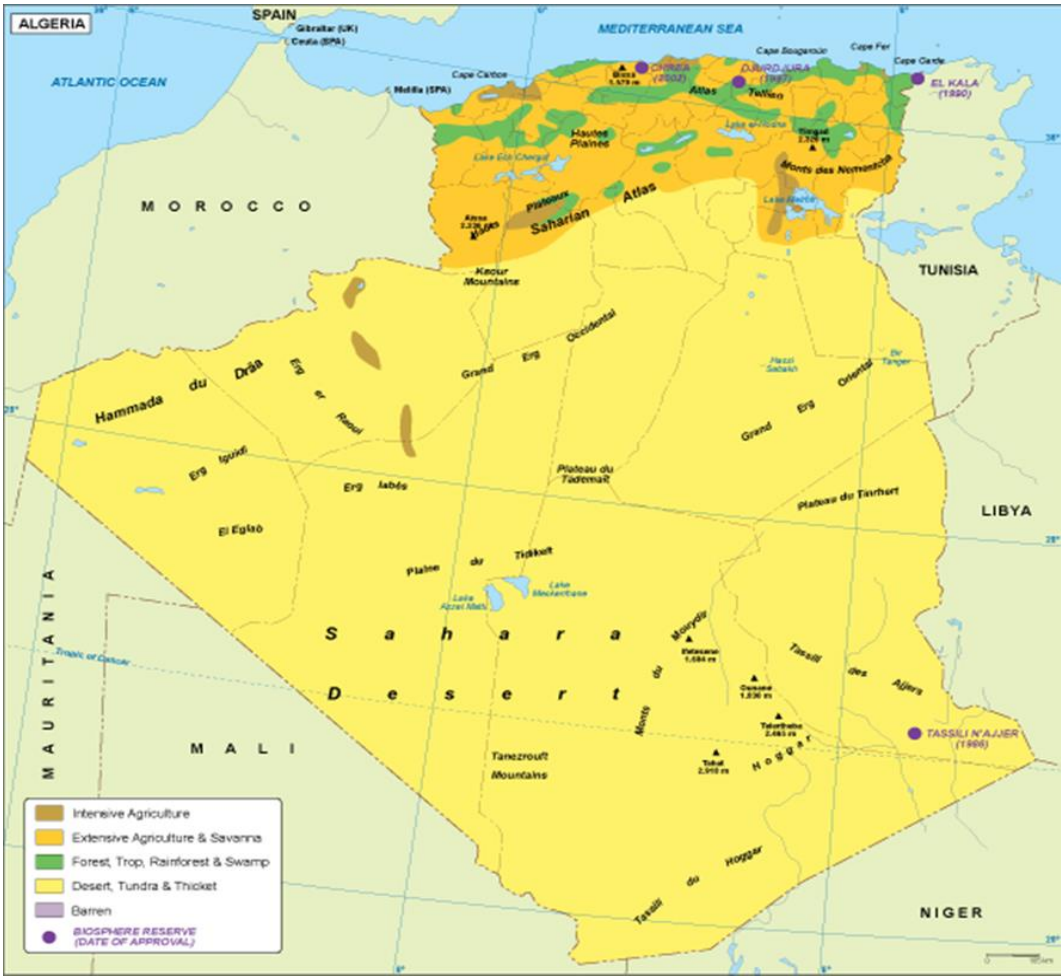


Figure 15 : Algeria vegetation map . https://www.digitalmaps.co.uk/netmaps/algeria-vegetation-map/

I.2.2.5. The endemic vascular plants of Algeria and their diversity

The Algerian endemic vascular flora includes 248 taxa (distributed among 174 species, 72 subspecies and 2 varieties) , representing almost 6.3% of the native flora of Algeria. They belong to a large number of 128 genera and 41 families.

The distribution of endemic species in Algeria is uneven according to the 41 families . Twenty families, containing three or more endemic taxa each, collectively contribute 90% of the endemic taxa in Algeria: *Asteraceae* (20% of endemics), *Fabaceae* (10%), *Caryophyllaceae* (9%) and *Lamiaceae* (8%) are the best-represented families, followed by *Brassicaceae* (7%), *Papaveraceae* (7%) and *Poaceae* (6%). Then, four families include two taxa each, and the remaining 17 families are represented by only one endemic taxon each. Otherwise, there is a weak correspondence between species-rich plant families and endemism. Some larger families contribute more endemic species to the flora of Algeria, while others contribute few endemics, relative to their dominance in the flora. The case of the *Poaceae,* which is the second most species-rich plant family, illustrates this fact; it occupies only the seventh position in terms of number of endemics. Besides, certain families are significantly over-represented, such as *Papaveraceae*, contributing a high proportion of endemics relative to their contribution to the overall flora .(Fig.16)

Endemism appears to be particularly dispersed within the genera present in Algeria (Table 2). Indeed, out of 128 genera containing endemic taxa in Algeria, only 15 of them have four or more taxa each, 11 genera (*Anthemis* L., *Centaurea* L., *Crepis* L., *Festuca* L., *Fumaria* L., *Genista* L., *Ononis* L., *Rupicapnos* Pomel, *Salsola* L., *Silene* L. and *Teucrium* L.) have five endemic taxa or more and only two of these genera have more than ten (*Rupicapnos* and *Silene*). The genus *Silene* is by far the richest in the Algerian endemic flora, with 12 strict-endemic species. Algeria is therefore identified as a centre of endemism for these two genera. The greater part of the genera (103 genera, 81%) are represented by only one or two endemic taxa each. In addition, generic endemism is shown in Algeria by the presence of two exclusively Algerian genera, namely *Agropyropsis* (Batt. & Trab.) A. Camus (*Poaceae*) and *Otocarpus* Durieu (*Brassicaceae*).(Meddour et al ;2023).

Table 2: List of taxa previously considered as Algerian endemics (Dobignard & Chatelain 2010–2013) but now no longer considered as Algerian endemics, with reasons for their exclusion.

Excluded endemic taxa	Reasons for exclusion
Armeria mauritanica Wallr.	Reported from Morocco (APD 2022)
Brassica fruticulosa subsp. *radicata* (Desf.) Batt.	Reported from Morocco (APD 2022; Euro+Med 2022)
Bufonia duvaljouvei Batt. & Trab. subsp. *duvaljouvei*	Reported from Morocco (Euro+Med 2022)
Cenchrus rogeri (Stapf & C. E. Hubb.) F. Verloove	Synonym of *Cenchrus violaceus* (Lam.) Morrone widely present from Sahara to Sahel (POWO 2022)
Crotalaria vialattei Batt.	Reported from Morocco (APD 2022)
Dianthus cintranus subsp. *mauritanicus* (Pomel) Greuter & Burdet	Reported from Morocco (APD 2022)
Fedia graciliflora subsp. *diana* Mathez & Xena (syn. *Valeriana graciliflora* (Fisch. & C. A. Mey.) Byng & Christenh.)	Subspecies previously distinguished no longer recognized and species widely present in W Mediterranean region (POWO 2022)
Fumaria munbyi Boiss. & Reut.	Reported from Morocco (APD 2022)
Gagea mauritanica Durieu	Reported from Balearic Islands (Euro+Med 2022)
Lathyrus allardii Batt.	Battandier (1895) already considered it a weed in Algeria; perhaps only a form of *Lathyrus gorgoni* Parl., native farther east and occasionally introduced (Domina & al. 2015; POWO 2022)
Limonium ramosissimum (Poir.) Maire	Widely distributed in W Mediterranean region (Euro+Med 2022)
Linaria tristis subsp. *marginata* (Desf.) Maire	Reported from Morocco (APD 2022)
Myrtus nivellei Batt. & Trab. subsp. *nivellei*	Reported from Chad and presence questionable in Libya (APD 2022)
Odontites lapiei Batt.	Reported from Morocco (APD 2022)
Odontites purpureus (Desf.) G. Don subsp. *purpureus* (syn. *Odontites purpureus* (Desf.) G. Don)	Reported from Morocco (APD 2022) and Morocco, Tunisia and Spain (Euro+Med 2022); autonym not used (APD 2022)
Odontites rigidifolius (Biv. ex Spreng.) Benth.	Reported from Sicily (Euro+Med 2022)
Odontites triboutii Gren. & Paill.	Reported from Tunisia (APD 2022)
Odontites violaceus Pomel	Reported from Morocco (Euro+Med 2022)
Olea europaea subsp. *laperrinei* (Batt. & Trab.) Cif.	Reported from Niger, Chad and South Sudan (APD 2022)
Ophrys pectus Mutel (syn. *O. pallida* Raf.)	Reported from Sicily (APD 2022)
Ophrys sphegodes subsp. *moesziana* Soó	Synonym of *Ophrys fusca* Link subsp. *fusca* widely distributed in Mediterranean region (Euro+Med 2022)
Opophytum gaussenii (Leredde) Greuter & Burdet	Synonym of *Mesembryanthemum cryptanthum* Hook. f. reported from several countries (Namibia, Morocco, Canary Islands, Libya, Egypt and Palestine) (APD 2022)
Orobanche ducellieri Maire	Synonym of *Phelipanche mutelii* (F. W. Schultz) Pomel widely distributed in Mediterranean region (APD 2022; Euro+Med 2022)
Pentzia monodiana Maire	Reported from Chad (APD 2022)
Potamogeton hoggarensis Dandy	Reported from Chad (APD 2022)
Pulicaria volkonskyana Maire	Reported from Niger (Carvalho & Gillet 1960) and Chad (POWO 2022)
Roegneria marginata subsp. *kabylica* (Maire & Weiller) Dobignard (syn. *Pseudoroegneria marginata* (H. Lindb.) V. Lucía & al.)	Subspecies previously distinguished no longer recognized and species also reported from Morocco (APD 2022)

Continued

Excluded endemic taxa	Reasons for exclusion
Romulea battandieri Bég.	Synonym of *Romulea columnae* Sebast. & Mauri subsp. *columnae* widely present in W Europe and Mediterranean region (Euro+Med 2022)
Salicornia deserticola A. Chev.	Synonym of *Sarcocornia fruticosa* (L.) A. J. Scott distributed in circum-Mediterranean region (Euro+Med 2022)
Saxifraga trabutiana Engl. & Irmsch.	Reported from Morocco (APD 2022) and Spain (Euro+Med 2022)
Scorzoneroides muelleri subsp. *reboudiana* (Pomel) Greuter	Reported from Morocco and Tunisia (APD 2022)
Senecio perralderianus Coss. & Durieu subsp. *perralderianus* (syn. *S. perralderianus* Coss. & Durieu)	Subspecies previously distinguished under *S. perralderianus* no longer recognized and species also reported from Morocco (APD 2022)
Senecio squalidus subsp. *aurasiacus* (Batt. & Trab.) C. Alexander	Reported from Sicily (APD 2022; Euro+Med 2022)
Sideritis incana subsp. *atlantica* (Pomel) Dobignard	Reported from Morocco and Tunisia (APD 2022)
Stipagrostis pungens subsp. *pubescens* (Henrard) H. Scholz (syn. S. *pungens* (Desf.) De Winter)	Subspecies previously distinguished under *S. pungens* no longer recognized and species widely distributed from Sahara to Afghanistan (POWO 2022)
Stipagrostis pungens subsp. *transiens* (Maire) H. Scholz (syn. S. *pungens* (Desf.) De Winter)	Subspecies previously distinguished under *S. pungens* no longer recognized and species widely distributed from Sahara to Afghanistan (POWO 2022)
Thymus dreatensis Batt.	Reported from Morocco (Euro+Med 2022)

Figure 16: Photographs of a few endemic and subendemic tree species in Algeria.

A. *Argania spinosa*, introduced at Chlef, 16 Oct. 2013. **B**. *Lonicera kabylica*, Tikjda at Djurdjura National Park, 27 Jan. 2013. **C**. *Abies numidica*, introduced in Chréa National Park, 8 May 2016. **D**. *Pinus nigra* subsp. *mauretanica*, Tigounatine at Djurdjura National Park, 10 Nov. 2009. **E**. *Fraxinus dimorpha*, Aurès, 9 Dec. 2015. **F**. *Quercus afares*, Guerrouch forest at Taza National Park, 12 Jun. 2019. **G**. *Cupressus* *dupreziana*, Tassili n'Ajjer, 13 May 2007. **H**. *Pinus pinaster* subsp. *renoui*, Jijel, 12 Jun. 2019. **I**. *Cedrus atlantica*, Tikjda at Djurdjura National Park, 10 May 2014. **J**. *Juniperus thurifera* subsp. *aurasiaca*, djebel Chélia at Aurès, 29 Nov. 2018. All photos by Rachid Meddour.

I.2.2.6. Location of endemic species according to the floristic regions

There is considerable variation in the number of endemics within the floristic regions (from zero to 63 taxa) (Fig.17,18). Out of the 20 floristic regions in Algeria, ten regions harbour at least 20 endemic taxa and five regions (K2, K1, AS3, C1+C2, O1) include more than 30 endemics each. The highest endemism richness (number of endemic taxa per floristic region) is recorded in the Small Kabylia (K2), with 63 endemic taxa (25% of all endemics), followed by Great Kabylia (K1), with 49 endemic taxa (20%), E Saharan Atlas, including the Aurès massif (AS3: 42 taxa, 17%), the Hills of Constantine and Bibans-Hodna-Belezma mountains (C1+C2: 40 endemic taxa, 16%) and the Oran coast (O1: 39 taxa, 16%). The outstanding richness of these floristic regions can be explained by the presence of the highest peaks among mountain ranges in the country (K1: Djurdjura, 2308 m; K2: Babors, 2004 m; AS3: Aurès, 2328 m; C1+C2: Belezma, 2178 m) in direct contact with the influence of the Mediterranean Sea. In addition, the C Sahara (SC) is worth mentioning for its endemic richness: this mountainous area in the Algerian Sahara (Ahaggar, 2918 m; Tassili n'Ajjer) hosts 18 strict-endemics (7%).

Altogether, a high number of Algerian endemics (147 or 59%) are range-restricted, i.e. narrowly localized and known from only one floristic region. These endemics are observed especially on the hills of Oran (O1: 24 taxa), the forests of Small Kabylia (K2: 20), the summits of the C Sahara (SC: 15), the Aurès massif (AS3: 12) and the mountains of the W Tell (O3: 11). In all these floristic regions, a large portion of the endemic flora is constituted of these range-restricted taxa, which greatly individualize them phytogeographically.

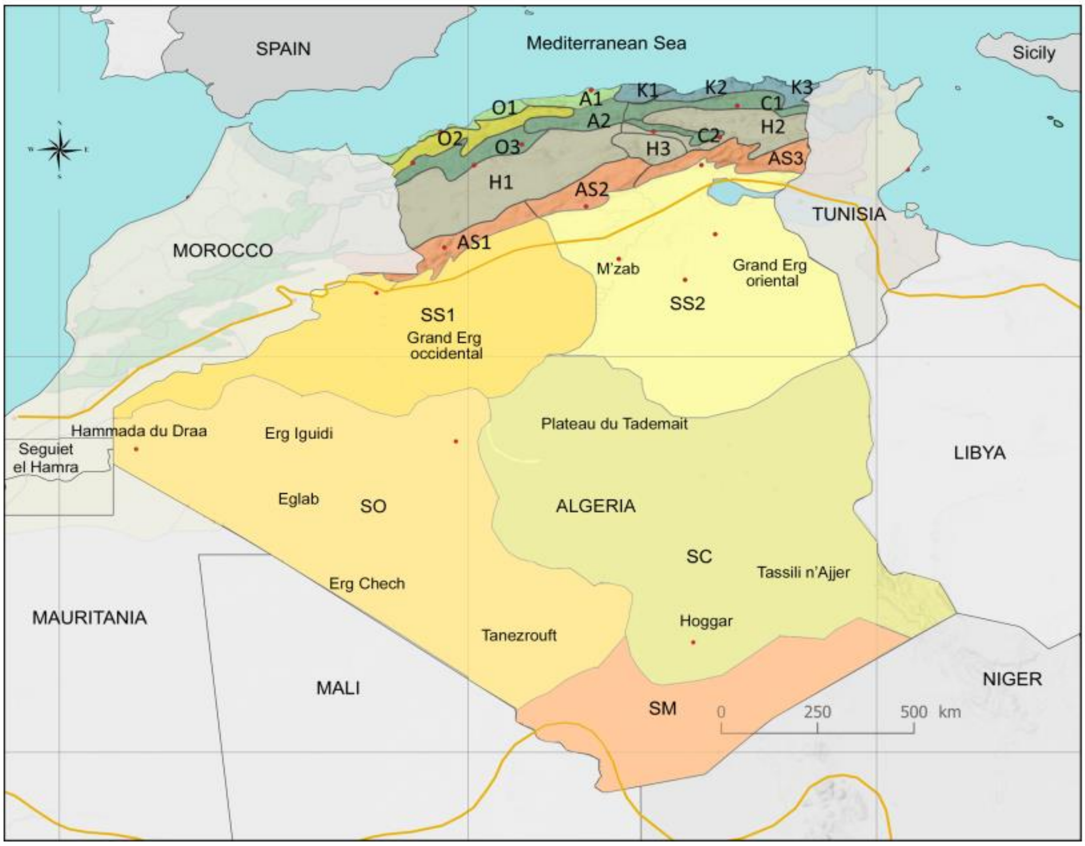


Figure. 17: Floristic regions of Algeria (Quézel & Santa 1962–1963, modified by Chatelain & Meddour in Meddour & al. 2021).

Brown lines delineate the Saharan area. Floristic regions are encoded as follows. – **Littoral and mountains of Tell:** O1: hills of Oran coast; O2: plains of Oran hinterland including La Macta; O3: mountains of Tlemcen and other mountains of Oran Tell; A1: hills and coast near Algiers including Mitidja; A2: mountains of Algiers Tell; K1: Great Kabylia including Djurdjura; K2: Small Kabylia including Babors; K3: Numidia; C1: hills of Constantine Tell; C2: mountains of Bibans/Hodna/Belezma axis. – **High plateaus:** H1: W high plains (from S Oran to S Algiers); H2: E high plains (S Constantine); H3: Hodna plain (N Saharan enclave). – **Saharan Atlas:** AS1: W Saharan Atlas (Ain Sefra region); AS2: C Saharan Atlas (Djelfa region); AS3: Aurès and E Saharan Atlas (Tébessa region).– **Sahara:** SS1: NW Sahara; SS2: NE Sahara; SO: W Sahara; SC: C Sahara including Ahaggar and Tassili n'Ajjer; SM: S Sahara.

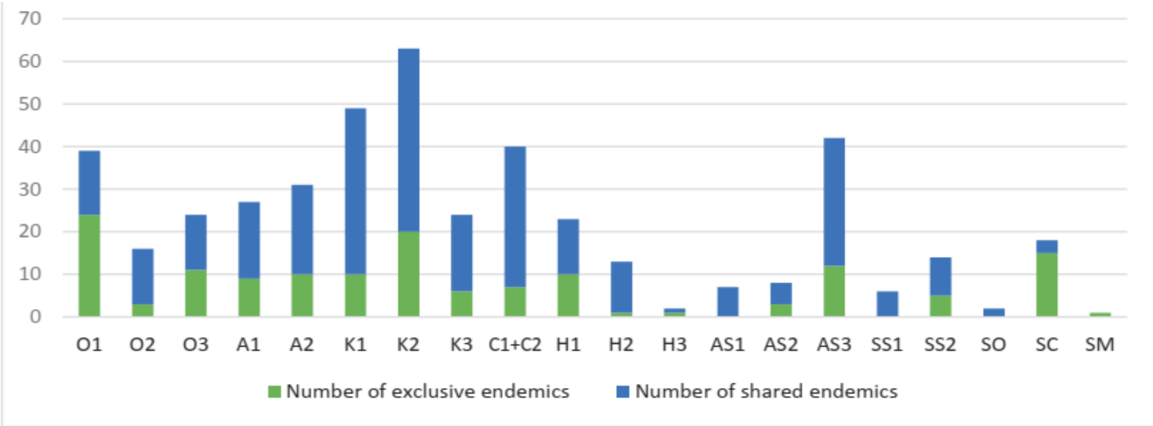


Figure 18: Distribution of Algerian endemic taxa (range-restricted and shared) across floristic regions.

1.2.2.7. Biogeography and ecology of the Algerian island flora

Even though they represent only 3.5% of the land surface, islands contribute disproportionately to global biodiversity, hosting 15–20% of terrestrial species. According to Denslow (2001), islands are of key interest for studies and experimental research in ecology, biogeography, and evolution, particularly as their small size and isolation make them biologically unique.These areas frequently host endemic or genetically distinct taxa as well as taxonomic and trophically unbalanced species assemblages (Williamson 1981).

This makes their communities and biotic interactions simpler, but also very sensitive to any new ecological disturbance, as they have a low resilience capacity due to dispersal/colonisation phenomena. The smaller the island, the higher the species turn-over on a short timescale, a pattern mainly driven by seabirds like gulls and not by physiographic parameters (Panitsa et al. 2008).

The challenge of quickly changing plant communities and the taxonomical vicariance across geography can be bypassed by using ecological/biological traits in addition to the classical taxonomy. This particularity (endemism, genetics, taxonomic and trophic imbalances, etc.), which allows islands to be used as ecological and evolutionary study models, is a major commitment in terms of our responsibility for global biodiversity conservation (Médail 2022). Especially since islands play a key role in the current extinction crisis, such that 60% of documented extinctions of terrestrial species since 1500 AD were island endemics.Among the 36 major hotspots of global biodiversity, the Mediterranean basin hotspot is famous for its numerous islands (ca 11,100 islands according to the recent synthesis of Médail 2022), most of which are small islands or rocky islets, concentrated mainly in the eastern and central sub-basin.

The majority of them have a continental origin and host numerous endemic and narrow-ranged plant taxa. Their high phytodiversity reflects their complex palaeogeographic history, superposing and combining many diversification processes such as long persistence coupled with old vicariance, cumulative clinal speciation by vicariance plus local adaptation (Naciri et al. 2010, 2022, about Silene L. sect. Siphonomorpha/Italicae), active polyploid complexes with hybridogenic speciation (Lidén 1986, about the genus Fumaria Tourn. ex L.; Mifsud and Mifsud 2018, about Allium L. sect. Allium), and active intense radiation by pollinator ethology (Baguette et al. 2020, about Ophrys L.).

According to the Mediterranean Small Islands Initiative (PIM: Petites Iles de Méditerranée, http://initiative-pim.org), the western Mediterranean contains ca 1,500 small islands (i.e. uninhabited and/or smaller than 1,000 hectares); 168 of these are located off the coasts of Algeria, Tunisia, and Morocco (approximately 70 in Algeria). Most of the small islands of the North African coasts of the western Mediterranean belong to two regional biodiversity hotspots, the Baetic-Rifan complex and the Kabylies-Numidie-Kroumirie complex (Véla 2017), showing a bipolar biogeography from western Algeria (Ibero-Maghrebian assemblages in Oranie), to eastern Algeria / northern Tunisia (Tyrrhenian affinities between Kabylies and Sardinia and between Cap Bon and Sicily).(Fig 19.Tab 3).

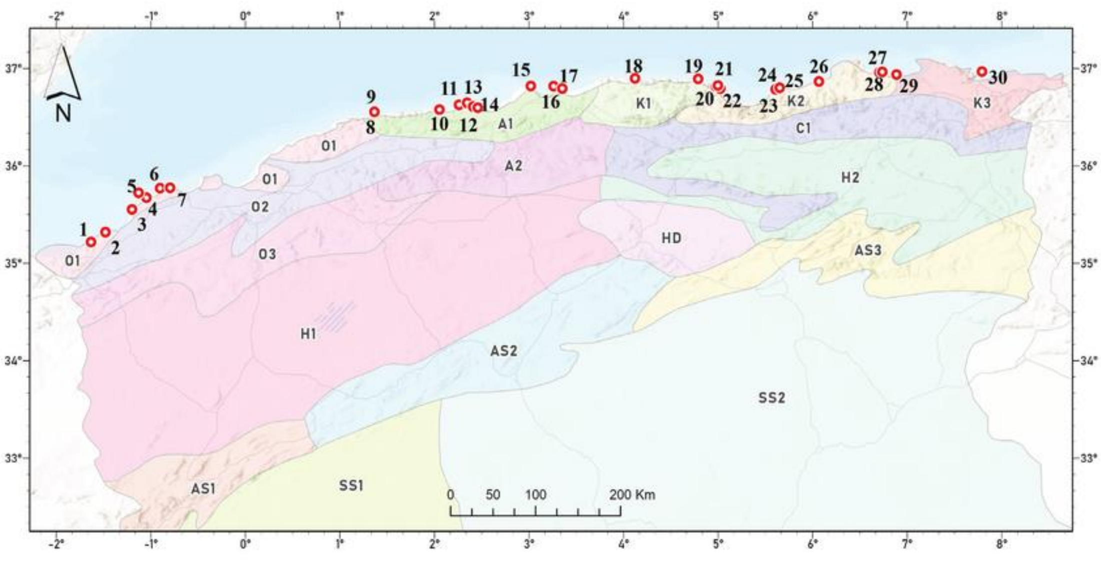


Figure 19. Location of the small islands and islets surveyed along the Algerian coast. Biogeographic divisions: O1: Coastal Sahels subsector; O2: Coastal plains subsector; A1: Coastal subsector; K1: Great Kabylie; K2: Little Kabylie; K3: Numidia. Study sites: 1: Mokreum; 2:

Rachgoun; 3: Sbiaat; 4: île Ronde; 5 (×2): Grande Habibas and Petite Habibas; 6: île Plane; 7: île aux Rats; 8: Sekia; 9: Dziria; 10: Hadjret Ennos; 11: Les 3 îlots; 12: Rocher Barbare; 13: Rocher aux Galets; 14: Tipaza; 15: Pointe Pescade; 16: Sandja; 17: Aguéli; 18: Tigzirt; 19: El-Euch; 20: îlot à l'Ail; 21: Pisans; 22: Sahel; 23: Grand-Cavallo; 24: îlot Grand-Cavallo; 25: Petit-Cavallo; 26: Tazerout; 27: Rahbet Teffah; 28: Ras-Bibi; 29: Serijina; 30: Vivier. Map created with QGIS v.3.36.2 (QGIS Development Team 2024).

Table 3. Small islands and islets studied along the Algerian coast, and source of floristic data used. PIM: Petites Iles de Méditerranée; NPR: National Program of research.

Wilaya	Island or islet	Mission	Surveyors	Date	Reference
Tlemcen	1 Mokreum	PIM Mission	O. Peyre	12 and 13 May 2017	Unpublished
Aïn Témouchent	2 Rachgoun	PIM Mission	E. Véla	30 April 2006	Véla (2017)
Oran	3 Sbiaat (île Ouest)	PIM Mission	T. Mokhtari	29 & 30 April 2015	Unpublished
	4 Île Ronde		S. Bakour & R. Moulaï	December 2018	Unpublished
	5 Grande Habibas	PIM Mission	E. Véla	May 2006/May 2007	Delauge and Véla (2007)
	5 Petite Habibas				
	6 Île Plane (Paloma)		S. Bakour & R. Moulaï	April 2016	Unpublished
	7 Île aux Rats	PIM Mission	T. Mokhtari	April 2015	Unpublished
Chlef	8 Sekia		M. Hamimeche	May 2017	Unpublished
	9 Dziria				
Tipaza	10 Hadjret Ennos		M. Hamimeche	May 2018	Unpublished
	11 Les Trois Îlots				
	12 Rocher Barbare				
	13 Rocher au Galets				

	14 Tipaza		M. Hamimeche & R. Moulaï	May 2016	Unpublished
Alger	15 Pointe Pescade		M. Hamimeche	June 2015	Unpublished
	16 Sandja				
	17 Aguéli	NPR Mission	K. Hamadi & R. Moulaï	2005	Moulaï et al. (2011)
Tizi-Ouzou	18 Tigzirt		R. Djadda, N. Bedjih & R. Moulaï	May 2011	Djadda and Bedjih (2011)
Bejaia	19 El-Euch		S. Benhamiche-Hanifi & R. Moulaï	May 2010	Benhamiche-Hanifi and Moulaï (2012)
	21 Pisans				
	22 Sahel				
	20 Îlot à l'ail		E. Véla et al.	June/July 2011	Véla et al. (2012)
Jijel	23 Grand Cavallo		S. Benhamiche-Hanifi & R. Moulaï	May 2009	Benhamiche-Hanifi and Moulaï (2012)
	25 Petit Cavallo				
	24 Îlot Grand Cavallo				
	26 Tazerout		M. Hamimeche & R. Moulaï	July 2016/May 2017	Unpublished
Skikda	27 Rahbet Teffah		T. Lachouri, L. Mouloudj & R. Moulaï	April 2016	Lachouri and Mouloudj (2016)
	28 Ras Bibi				
	29 Serijina	PIM Mission	E. Véla	May 2008	Véla et al. (2008)
Annaba	30 Vivier		E. Véla & G. de Bélair	2013	Unpublished

On the northern shores of the Mediterranean, many studies concerning island biodiversity, and more particularly plant diversity of the archipelagos of islands and islets, have been carried out. However, on the southern shore, studies concerning island phytodiversity are less numerous: for Tunisia, we can cite the works of Pavon and Véla (2011), Véla and Pavon (2013), Médail et al. (2016), Médail and Véla (2020), Médail et al. (2020), as well as Médail et al. (2015) on the effect of sea level change on plant biodiversity in island environments. In Algeria, despite a coastline of more than 1600 km, the number of islands and islets is quite low. The phytodiversity is generally poorly known, notwithstanding the proximity of the shores and coastal towns. The only studies that have been carried out are very sparse and concern only a few sites such as the Habibas islands (Maire and Wilczek 1936; Delauge and Véla 2007; Véla et al. 2013), Rachgoun island, Serijina island (Véla 2008), and the island systems of Béjaïa and Jijel (Benhamiche-Hanifi and Moulaï 2012).In 2013, Véla and Pavon published a more comprehensive study on the small islands' flora of the Tunisian and Algerian coasts, covering a total of 25 small islands (14 in Algeria and 11 in Tunisia).

This study highlighted the importance of small islands as refuges for biodiversity, local and regional endemic species, as well as their role in global and Mediterranean plant biodiversity conservation programs. The authors highlighted that several Algerian islands or archipelagos can be considered as key biodiversity areas for plants, also named "Important Plant Areas". The main one, the Habibas archipelago, is considered as an autonomous IPA itself thanks to criterion "A" (significant population of threatened species), while the newly assessed one, the El Aouana archipelago, is considered an IPA in accordance with criterion "B" (exceptionally rich flora in a regional context), according to the guidelines by Plantlife International (2004).As far as we know, the present work is the first to provide an overview of the diversity and functional traits of the Algerian island flora. Thirty islands and islets were surveyed along the entire Algerian coastline. Species assemblages and synthetic flora descriptors (species richness, life forms, dispersal and pollination modes, biogeographic range) were related to physiographic characteristics of the islands (e.g. area, isolation, elevation) and to biotic factors that can affect the structure of the island vegetation, such as the number of breeding pairs of yellow-legged gull (Larus michahellis Naumann, 1840). the floristic results are analysed from a biogeographical, ecological, and functional point of view in order to identify their heritage status and draw up priority actions for the management and conservation of the Algerian island flora. Our study can be seen as a baseline survey, in light of possible future diachronic studies of Algerian island vegetation.

- **Physiography of the Algerian islands**

The classification of the 30 Algerian islands and islets through the PCA highlighted the importance of physiographic variables: in western Algeria, islands are represented by the Habibas, Rachgoun, Mokreum, and Sbiaat islands, and are characterised by fairly large surfaces and marked isolation compared to the other islands and islets, a specificity associated with a biogeographical pattern characteristic of the Oranese sector, the Baetic-Rifan arc, and the Iberian-Mauritanian ensemble (Véla et al. 2013). In contrast, the majority of the islets or rocks located on the Central and Eastern coasts of Algeria are very close to the continent and they are characterized by a biogeography influenced by the Kabyle sector, the Algerian-Constantinian Tell, and the Tyrrhenian microplate complex. the same phenomenon occurs in the far east, according to a preliminary analysis of recent data by Hamel et al. (2023).

The morphology and the elevation of the studied islands are not very important factors for the islands' classification; the majority of them are characterised by a more or less that shape and low elevations. As a result, the physiognomy of the Algerian islands is quite peculiar compared to the small islands of Sardinia, for which Fois et al. (2016) demonstrated the importance of the elevation and the SI factor, which strongly contributed to the floristic structuration of these small islands. Indeed, Fois et al. (2016) refer to islands with much larger dimensions and elevations above 500 m a.s.l. The Algerian coast is characterised by a scarcity of islands and islets, compared to the other Mediterranean countries (Médail 2022), and in addition to their rarity, the few existing insular entities are in great majority very small islets of less than one hectare. In fact, when considering the physiographic variables and beside a longitudinal gradient, surface area and isolation (distance from the mainland) resulted to be the two most important determinants of the floristic composition of the Algerian islands.

- **Biogeographical and conservation interest**

As already pointed out by Benhamiche-Hanifi and Moulaï (2012), the flora of Mediterranean origin is dominant on the islands of Jijel and Bejaia, and this pattern was observed on all the studied islands, where the flora is largely dominated by the Mediterranean species (Supplementary material 2). The same characteristics were observed by Hamel et al. (2023) for the islands at the extreme east of the country. However, there is a west-east difference, with the Oranese islands being influenced by the western Mediterranean sub-domain, including the Ibero-Maghrebian complex, whereas the Kabyle and Numidian islands are influenced by the central Mediterranean sub-domain, including the Tyrrhenian complex (Véla and Pavon 2013; Hamel et al. 2023).

In the case of the Algerian and Tunisian islands, Véla and Pavon (2013) showed that a larger surface area does not necessarily mean higher richness, nor does reduced richness mean lower conservation interest, as in the case for Rachgoun Island (large but poor although of high conservation interest), and for the Islets of Garlic and Sahel (small but of high conservation interest). This dissymmetry between surface area, richness, and conservation interest is also confirmed at the extreme east of the country by Hamel et al. (2023). Due to their small surface area, the Algerian islands are not considered as regional hotspots; this is mainly due to the fact that the small surface area is insufficient to allow in situ speciation, and consequently these sites are very poor in exclusive endemics (Triantis et al. 2008).

The Oranese islands belong to the regional hotspot of the Baetic-Rifan Arc and the islands of the coast east of Algiers belong to the regional hotspot Kabylie-Numidie-Kroumirie (Véla and Benhouhou 2007). Nevertheless, for the Habibas archipelago, plant endemics are shared with at least one site on the mainland (Africa and/or Europe) or with other archipelagos in the Alboran Sea or the Algerian-Provençal basin (Véla et al. 2013). Furthermore, a relatively small area sometimes harbours a relatively high level of species richness, such as the archipelago of El Aouana on the Jijel west coast, classified as an Important Plant Area (Véla and Pavon 2013). Finally, the random sharing of a number of endemic and/or threatened species in common with the nearby mainland makes these islands and archipelagos to belong to a mainland IPA: Rachgoun to the Trara Mounts IPA, Sekia and Dziria to the Cap Ténès IPA, Islet à l'Ail and Islet Sahel to the Gouraya National Park IPA, Islet and Islet Grand Cavallo and Petit Cavallo to the El Aouana coastal IPA (Benhouhou et al. 2018), Pain de Sucre, Fontaine Romaine, Gargamiz, Kef Amor, Akacha and Toughnechet in the Edough Peninsula IPA, Boutribicha, Callisar and Hennaya (Lehnaya) in the El Kala-1 IPA (Hamel et al. 2023).

At this stage, the island of Serigina, which also hosts some endemic plants (Véla 2008), is not part of an existing IPA on the continent. However, the process of identifying IPAs is still incomplete, as the coastline between Skikda, Stora, and Oued Bibi hosts several endemic and/or threatened species, including Lotus drepanocarpus Durieu and especially

Anthemis maritima subsp. bolosii Benedí & Molero (Véla 2008; Sakhraoui et al. 2020; present work), which by themselves justify classification as an IPA (Yahi et al. 2012).

Therefore, we propose to denominate this new IPA "Corniche de Stora", which joins the forty or so IPAs already identified in Algeria (Benhouhou et al. 2018; Mostari et al. 2020). This is also the case for Sbiaat Island, where endemic and rare species presumed to be threatened as Anthemis chrysantha J.Gay subsp. chrysantha and Sonchus tenerrimus subsp. amicus (Faure, Maire & Wilczek) Véla (present work) have been recorded, justifying its classification as an IPA according to the criteria of Yahi et al. (2012) (Table 3).

It is worth mentioning that this island belongs to a larger natural complex located on the mainland from Cape Figalo to 215Cape Lindlès. Here, again, it seems important to name a new IPA "from Cap Figalo to Cap Lindlès", which extends westwards the IPA "the Oran hills" with a much more pronounced relief (Yahi et al. 2012; Benhouhou et al. 2018).

- **Diversity and ecological processes**

The floristic factor analysis revealed that the most influential floristic attributes in the separation of the studied Algerian islands are total richness and the proportion of zoochorous species.In accordance with the classic area-species model, the total floristic richness is strongly correlated with the island area ($r = 0.581$, $p < 0.001$).

This relationship was also highlighted, for example, by Médail and Vidal (1998), who stipulated that in the western Mediterranean, the surface area of island groups is the main variable involved in the organisation of the richness and composition of the vegetation on these islands, while its relationship with the distance from the coast (site isolation) is less obvious. Benhamiche-Hanifi and Moulaï (2012) highlighted also this relationship for Jijel and Bejaia islands, which is confirmed for the rest of the Algerian coastal islands through our results, which also reveal a negative correlation between the log-transformed island area and the PAR ($r = 0.800$, $p < 0.001$).Regarding the dispersal syndromes of these island floras, the zoochorous and anemochorous syndromes have significant influence in the classification of the islands. The dominance of zoochorous taxa can be explained by the presence of seabirds, in particular colonies of yellow-legged gulls which spread seeds, either actively by eating seeds or fruits (endozoochory), or passively by plumage (epizoochory) (Calvino-Cancela 2011).

According to Vidal et al. (1998), these birds could induce a functional link between some small island systems of continental origin close to feeding sites located on the mainland. their location close to the shoreline has also favoured the settlement and presence of anemochorous taxa on islands which are exposed to onshore winds. The hydrochorous species are nearly present on all investigated islands, unlike the myrmecochorous and autochorous species. Almost all plant species recorded in our study are characterised by entomogamous or anemogamous pollination; favoured by the sea winds as well as the short distances or the weak isolation of almost all our island sites.

- **Threats and conservation issues**

The RDA showed that the density of yellow-legged gulls, which is positively correlated with the island area, considerably affects the characteristics of the flora in the islands and islets.For island flora conservation planning, some of these small islands can be considered “modern refuges” of terrestrial biodiversity from human pressures (Médail 2017, 2022); particularly in the context of Mediterranean ecosystems characterized by a quasi-permanent presence of humans in the various habitats, and notably along the coasts. But these islands themselves are increasingly attracting more curious tourists, and this in proportion to the phenomenon of recent development of seashore tourism (Véla and Pavon 2013; Boutarcha 2019).The environmental features of these Algerian islands (small area and low slope) make them particularly susceptible to species extinction processes due to sea level rise and genetic drive. Some current estimates, stipulate that a global rise in sea level will need to reach at least 1 m by 2100, and de facto large parts of low-lying island ecosystems are at high risk of being submerged, leading to significant habitat loss (Bellard et al. 2014; Harradine et al. 2015).

The analysis of the Algerian island flora has brought to light a rather important floristic richness, consisting of 295 species and subspecies including several species of high biogeographical and conservation value. By explaining composition, ecological and biogeographical attributes of the flora by physiographic and biotic factors, we can identify the most reliable factors for the conservation planning of the island flora, especially since these small islands can be considered as “modern refuges” with regards to increasing human pressures.This study also constitutes the first botanical synthesis undertaken on the majority of the islands and islets of the Algerian coast. This synthesis will certainly allow to get a global vision on the diversity and the status of the Algerian island plants, and we hope that this will allow to elaborate efficient strategies of conservation of these small fragile islands in order to preserve this unique biotic heritage.

Chapiter II. Climate change

II.1. Definition: What is climate change?

Climate change in IPCC (The Intergovernmental Panel on Climate Change) usage refers to any change in climate over time, whether due to natural variability or as a result of human activity.

The very existence of life on Earth is dependent upon a climate that has varied within relatively narrow bounds over hundreds of millions of years. Climatic variability in the distant past has played a role in shaping contemporary biodiversity, through climate-induced species redistributions, extinctions, and originations (Theodoridis et al., 2020). Global biodiversity has increased over geological time despite climate changes, albeit.

Throughout our existence as a species, humans have manipulated and transformed nature and natural resources to produce materials needed to adapt to, and benefit from, the variable environmental conditions on Earth. Technological advances have allowed us to achieve better living standards on average – but with strong social and economic inequalities – and have contributed to growing human populations worldwide, but at the cost of increasing energy and material consumption (Messerli et al., 2019).

Human use and transformation of terrestrial, freshwater and ocean ecosystems, exploitation of organisms, pollution and the introduction of invasive species have resulted in the rapid and widespread decline of biodiversity and the degradation of ecosystems worldwide (Figure 1.3). Simultaneously, increases in greenhouse gas emissions, now exceeding 55 GtCO2eyr−1, associated with fossil fuel combustion (84%) and land-use changes (16%) have altered atmospheric composition , and in turn the global climate system, influencing global temperatures, precipitation and the intensity and frequency of extreme weather events. Such climatic changes can act to exacerbate biodiversity decline, which can in turn, feedback to further impact climate. (Friedlingstein et al., 2020)

II.2 Relationships between climate change, biodiversity and good quality of life

A well-functioning natural system and a habitable climate are the foundations of people's good quality of life (Fig.19). Protecting biodiversity, avoiding dangerous climate change and promoting an acceptable and equitable quality of life for all is the mandate of several global initiatives, particularly the Strategic Plan for Biodiversity 2011-2020 of the Convention on Biological Diversity (CBD), the Paris Agreement to the United Nations Framework Convention on Climate Change (UNFCCC) and the UN Sustainable Development Goals (SDGs). While each of these initiatives has specific goals, they also clearly state that the challenges of biodiversity decline, climate change and human well-being are closely connected, and a failure to jointly address the dual crises of climate change and biodiversity decline can compromise people's good quality of life (IPBES, 2019).

This co-sponsored IPBES-IPCC workshop report examines the fundamental intertwining of biodiversity and climate and its impacts on people's quality of life (Figure 20) and makes a case for why climate policy and biodiversity policy must be considered jointly to meet the challenge of achieving a good quality of life (GQL) for all.

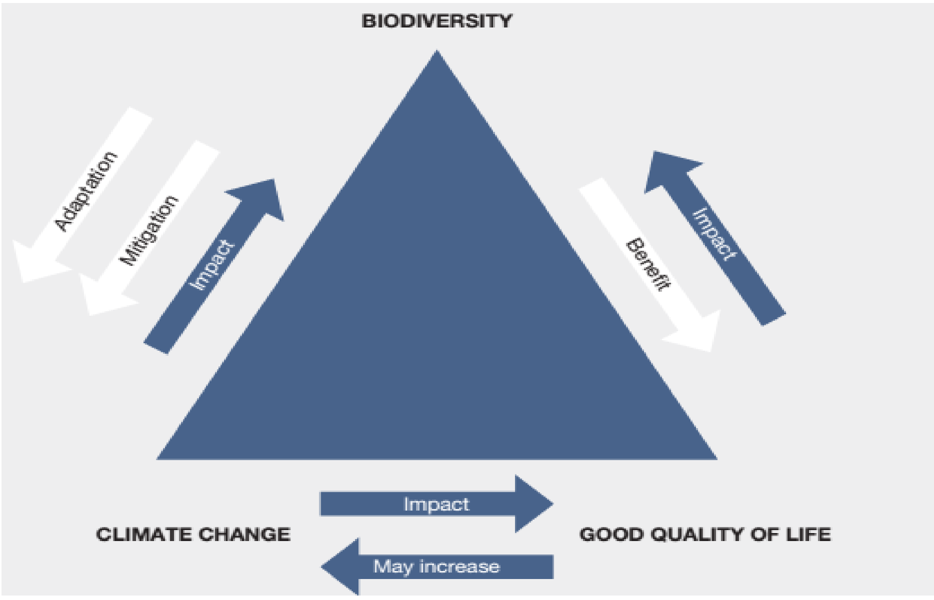


Figure20: Relationships between climate change, biodiversity and good quality of life**.**

Blue arrows represent interactions that are predominantly threats, white arrows predominantly opportunities.Modif ed from Korn *et al.* (2019).

II.3 the main causes of climate change

Climate change is a complex phenomenon influenced by a variety of factors, including both human activities and natural processes:

II.3.1. geological causes

When discussing the geological causes of climate change, we focus on natural processes that occur over long timescales, including those driven by Earth's internal dynamics, orbital variations, and external forces. Below are the main geological causes of climate change:

1. Plate Tectonics and Continental Drift

- Explanation: The movement of Earth's lithospheric plates affects the configuration of continents and oceans, which in turn influences climate patterns.
- Key Mechanisms:
  - ➢ Continental Drift: Over millions of years, the movement of continents alters the distribution of land and sea. This can change ocean currents and wind patterns, leading to shifts in climate. For example, the formation of the Himalayas by the collision of the Indian and Eurasian plates influenced global climate by altering wind patterns and monsoons.
  - ➢ Ocean Basin Formation: The opening and closing of ocean basins due to tectonic activity change the way heat is distributed around the planet, affecting global climate. The formation of the Isthmus of Panama, for instance, re-routed ocean currents, contributing to the onset of the Ice Ages.

2. Volcanic Activity

- Explanation: Volcanic eruptions can have both short-term and long-term impacts on climate by releasing gases and particles into the atmosphere.
- Key Mechanisms:
  - ➢ Volcanic Gases: Eruptions release sulfur dioxide (SO_2), carbon dioxide (CO_2), and water vapor. SO_2 can lead to the formation of sulfate aerosols in the stratosphere, reflecting sunlight and temporarily cooling the Earth. For example, the eruption of Mount Pinatubo in 1991 caused global temperatures to drop by about 0.5°C for a year or two.
  - ➢ Carbon Dioxide: Over longer periods, the release of CO_2 from volcanoes can contribute to the greenhouse effect, warming the planet. Large igneous provinces, such as the Deccan Traps, have been linked to past warming events.
  - ➢ Volcanic Ash: Ash particles from large eruptions can block sunlight, leading to short-term cooling.

3. Orbital Variations (Milankovitch Cycles)

- Explanation: Changes in Earth's orbit and axial tilt alter the distribution of solar energy received by the planet, driving long-term climate cycles.
- Key Mechanisms:

Eccentricity: The shape of Earth's orbit around the Sun changes from more circular to more elliptical on a cycle of about 100,000 years. This affects the distance between Earth and the Sun, influencing the amount of solar energy Earth receives.

- Axial Tilt (Obliquity): The angle of Earth's tilt relative to its orbital plane changes on a cycle of about 41,000 years. This affects the intensity of the seasons; greater tilt leads to more extreme seasons, while less tilt results in milder seasons.
- Precession: Earth's axis wobbles like a spinning top, completing a full cycle approximately every 26,000 years. This changes the timing of the seasons relative to Earth's position in its orbit, affecting climate patterns over long periods.

4. Solar Radiation Variations

- Explanation: Changes in solar output can affect Earth's climate over various timescales.
- Key Mechanisms:
  - Solar Cycles: The Sun undergoes an approximately 11-year cycle of solar activity, including changes in the number of sunspots. During periods of high sunspot activity, the Sun emits slightly more radiation, which can have a small warming effect on Earth.
  - Long-Term Solar Variability: Over longer timescales, changes in solar output (due to processes like changes in the Sun's magnetic activity) can influence Earth's climate. For example, the Maunder Minimum (a period of very low sunspot activity from about 1645 to 1715) is associated with the Little Ice Age in Europe.

5. Impact Events (Asteroids and Comets)

- Explanation: Large asteroid or comet impacts can cause significant climate changes by ejecting dust and aerosols into the atmosphere, blocking sunlight, and disrupting climate systems.
- Key Mechanisms:
  - Impact-Induced Cooling: A major impact can eject large amounts of dust and aerosols into the stratosphere, reducing the amount of sunlight reaching Earth's surface and leading to a temporary cooling period known as an "impact winter." The impact that formed the Chicxulub crater 66 million years ago is thought to have caused a rapid and severe climate shift, contributing to the mass extinction of the dinosaurs.

- Long-Term Climate Effects: The introduction of greenhouse gases from vaporized rocks and forest fires ignited by the impact can lead to longer-term warming after the initial cooling.

6. Ocean Circulation Changes

- Explanation: Changes in ocean currents, often driven by tectonic events or changes in salinity and temperature, can significantly alter climate patterns.
- Key Mechanisms:
  - Thermohaline Circulation: The global conveyor belt, a deep-ocean circulation driven by differences in water temperature and salinity, plays a crucial role in regulating Earth's climate. Disruptions to this circulation, such as those potentially caused by melting polar ice, can lead to significant climate changes, including the triggering of ice ages.
  - Tectonic Events: The repositioning of continents can block or redirect ocean currents, leading to changes in heat distribution across the planet. The closure of the Tethys Sea and the formation of the Mediterranean are examples of such tectonic shifts that altered ocean circulation and, consequently, climate.

7. Methane Clathrates Release

- Explanation: Methane clathrates (methane trapped in ice-like structures under the seafloor) can be destabilized due to changes in temperature or pressure, releasing methane, a potent greenhouse gas.
- Key Mechanisms:
  - Warming of Ocean Waters: An increase in ocean temperatures can destabilize methane clathrates, leading to massive releases of methane into the atmosphere. This process is hypothesized to have contributed to past warming events, such as the Paleocene-Eocene Thermal Maximum (PETM) about 56 million years ago.
  - Submarine Landslides: Tectonic activity or sea-level changes can trigger underwater landslides, disturbing methane clathrates and releasing methane into the atmosphere, potentially leading to rapid climate shifts.

Geological processes have played a significant role in shaping Earth's climate over millions of years. These natural causes, from the movement of continents to volcanic eruptions and orbital variations, have driven major climate shifts throughout Earth's history.

Understanding these processes helps us distinguish between natural and anthropogenic (human-caused) factors in the current context of global climate change.

II.3.2. Astronomical causes of climate change

Astronomical causes of climate change refer to factors related to Earth's position and movement in space, as well as variations in solar activity. These factors influence the amount of solar energy Earth receives, which in turn affects the planet's climate over various timescales. Below are the main astronomical causes of climate change, explained in detail:

1. Milankovitch Cycles

Milankovitch cycles are a set of three periodic changes in Earth's orbit and axial orientation that affect the distribution and intensity of sunlight received by Earth. These cycles are named after the Serbian scientist Milutin Milankovitch, who first theorized their impact on Earth's climate.

a. Eccentricity

- Explanation: Eccentricity refers to the shape of Earth's orbit around the Sun, which changes from more circular to more elliptical (oval-shaped) over a cycle of about 100,000 years.
- Impact on Climate: When the orbit is more elliptical, there is a greater difference in the distance between Earth and the Sun throughout the year, leading to variations in the amount of solar energy Earth receives. These changes influence the severity of seasons and can contribute to the onset and retreat of ice ages.

b. Axial Tilt (Obliquity)

- Explanation: The axial tilt is the angle between Earth's rotational axis and its orbital plane. This tilt varies between about 22.1° and 24.5° over a cycle of approximately 41,000 years.
- Impact on Climate: A greater tilt increases the contrast between seasons, with warmer summers and colder winters, particularly at higher latitudes. Conversely, a smaller tilt leads to milder seasons. Changes in axial tilt are a significant factor in triggering glacial and interglacial periods.

c. Precession

- Explanation: Precession is the wobble in Earth's rotational axis, caused by gravitational forces exerted by the Sun and the Moon. This wobble follows a cycle of about 26,000 years.

- Impact on Climate: Precession changes the timing of the seasons relative to Earth's position in its orbit. For example, it can alter whether the Northern Hemisphere experiences summer when Earth is closest to or farthest from the Sun, affecting the intensity of seasonal changes and contributing to long-term climate variations.

2. Solar Radiation Variations

Changes in the Sun's energy output have a direct impact on Earth's climate. These variations can occur over different timescales, from short-term fluctuations to longer-term trends.

a. Solar Cycles (Sunspot Cycles)

- Explanation: The Sun undergoes an approximately 11-year cycle of solar activity, known as the solar cycle, during which the number of sunspots (dark areas on the Sun's surface) increases and decreases.
- Impact on Climate: During periods of high sunspot activity, the Sun emits slightly more energy, leading to a small but measurable warming effect on Earth. Conversely, during periods of low sunspot activity, such as the Maunder Minimum (1645–1715), solar radiation decreases, which has been associated with cooler temperatures on Earth, contributing to events like the Little Ice Age.

b. Long-Term Solar Variability

- Explanation: Over longer timescales, the Sun's output can vary due to changes in its internal processes, including magnetic activity and solar luminosity.
- Impact on Climate: Significant long-term changes in solar output could have substantial effects on Earth's climate. For instance, a sustained decrease in solar output could lead to global cooling, while an increase could contribute to warming. These changes are less well understood than the shorter-term solar cycles but are considered important in paleoclimate studies.

3. Galactic Cosmic Rays

Galactic cosmic rays are high-energy particles originating from outside the Solar System, primarily from supernovae. Their interaction with Earth's atmosphere is influenced by solar activity.

- Explanation: Galactic cosmic rays are partially shielded by the Sun's magnetic field, which varies with solar activity. During periods of low solar activity, more cosmic rays can reach Earth's atmosphere.
- Impact on Climate: Some theories suggest that an increase in cosmic rays could lead to greater cloud formation by ionizing atmospheric particles, which in turn could increase Earth's albedo (reflectivity) and cause cooling. However, the extent of this effect and its significance in climate change remain subjects of ongoing research and debate.

4. Changes in Earth's Orbital Inclination

- Explanation: Earth's orbital inclination, or the tilt of Earth's orbit relative to the plane of the Solar System (the ecliptic), changes over long periods. This affects how Earth moves relative to the rest of the Solar System and the Galactic Plane.
- Impact on Climate: Although less influential than Milankovitch cycles, changes in orbital inclination can affect the amount of cosmic radiation Earth receives, potentially impacting cloud cover and climate. However, this is considered a minor factor compared to other astronomical causes.

5. Earth's Passage Through Interstellar Dust Clouds

- Explanation: As the Solar System moves through the Milky Way, it occasionally passes through regions of interstellar dust and gas. This process can affect the amount of solar radiation reaching Earth.
- Impact on Climate: If the Solar System passes through a dense cloud of interstellar dust, the dust could reduce the amount of sunlight reaching Earth, potentially leading to global cooling. This is a hypothetical and rare event, but it could have significant climatic consequences if it occurred.

6. Tidal Forces and Orbital Resonances

- Explanation: Tidal forces between Earth, the Moon, and the Sun, as well as gravitational interactions with other planets, can cause slight variations in Earth's orbit and rotation.
- Impact on Climate: While these effects are generally small, over long timescales they can contribute to changes in Earth's orbital parameters, subtly influencing

climate patterns. Orbital resonances with other planets could also play a role in modulating Earth's orbit, contributing to long-term climate cycles.

Astronomical causes of climate change are driven by complex interactions between Earth and the broader cosmos. These factors operate over varying timescales, from the relatively short 11-

year solar cycles to the much longer Milankovitch cycles spanning tens of thousands to hundreds of thousands of years. Understanding these astronomical influences helps to place current climate changes in a broader historical and geological context, providing insight into natural climate variability.

II.3.3 Indirect and direct drivers of biodiversity loss and climate change due to human activities.

Human activities have become the dominant driver of climate change, primarily through the emission of greenhouse gases and alterations in land use. The burning of fossil fuels, deforestation, industrial processes, agriculture, and waste management are key contributors to the enhanced greenhouse effect, leading to global warming and a range of other climatic impacts. Addressing these causes requires concerted efforts at local, national, and global levels to reduce emissions, transition to renewable energy sources, and implement sustainable land management practices.

Technological advances have allowed us to achieve better living standards on average – but with strong social and economic inequalities – and have contributed to growing human populations worldwide, but at the cost of increasing energy and material consumption (Messerli *et al.*, 2019). Human use and transformation of terrestrial, freshwater and ocean ecosystems, exploitation of organisms, pollution and the introduction of invasive species have resulted in the rapid and widespread decline of biodiversity and the degradation of ecosystems worldwide

Simultaneously, increases in greenhouse gas emissions, now exceeding 55 GtCO2eyr-1, associated with fossil fuel combustion (84%) and land-use changes (16%) have altered atmospheric composition (Friedlingstein *et al.*, 2020), and in turn the global climate system, influencing global temperatures, precipitation and the intensity and frequency of extreme weather events (IPCC, 2014). Such climatic changes can act to exacerbate biodiversity decline, which can in turn, feedback to further impact climate **(Fig.21)**.

Currently, less than a quarter (23%) of the Earth's terrestrial area (excluding Antarctica) and 13% of the ocean remains free from substantial human impacts and approximately half the area of coral reefs and over 85% of global wetland area have been lost. Humans and livestock currently account for ~96% of the total mammal biomass on Earth, while the biomass of domestic poultry is nearly threefold higher than that of wild birds. Human activities over millennia have resulted in an estimated 83% reduction in wild mammal biomass (both terrestrial and marine), and ~50% reduction in the biomass of plants, relative to pre-human times (Bar-On *et al.*, 2018). Over the last few centuries, terrestrial vertebrates have gone extinct at rates that are up to 100 times higher than previous (background) levels , and species are now more threatened with extinction than ever before in human history. Although empirical evidence for current climate changedriven extinctions is still meagre , there is evidence to indicate that ongoing climate change is driving geographic range shifts in species, altering phenology and migration patterns and the availability of suitable habitat for species and disrupting key ecological interactions in communities (Lenoir *et al.*, 2020). All of these effects have implications for the way ecological communities and ecosystems function, and thus their capacity to deliver nature's contributions to people .

The rapid decline of biodiversity and changes in climate are tightly intertwined: they share underlying direct and indirect drivers (see Glossary), they interact, and can have cascading and complex effects that impact people's good quality of life and compromise societal goals.
Direct drivers of climate change include greenhouse gas emissions from fossil fuel combustion and land-use change (e.g., deforestation, agricultural practices). Direct drivers of biodiversity decline include land/sea use intensity and change, direct exploitation of organisms, pollution, climate change and invasive species . Some direct anthropogenic drivers such as deforestation, land-use changes associated with agriculture, and pollution can strongly drive both climate change and biodiversity decline, whereas others primarily impact one or the other (e.g., invasive species or direct exploitation of organisms have effects only on biodiversity decline).

Indirect drivers are the more distant causes of biodiversity decline and climate change. They are underpinned by societal values and can be external to the system in question. Climate change and biodiversity decline share the same indirect drivers, which are the ultimate forces that underlie and shape the extent, severity and combination of anthropogenic direct drivers that operate in a given place (Barger *et al.*, 2018). Indirect drivers of climate change and biodiversity decline include key institutional and governance structures in addition to social, economic and cultural contexts that drive human behavioural patterns including consumption and energy use.

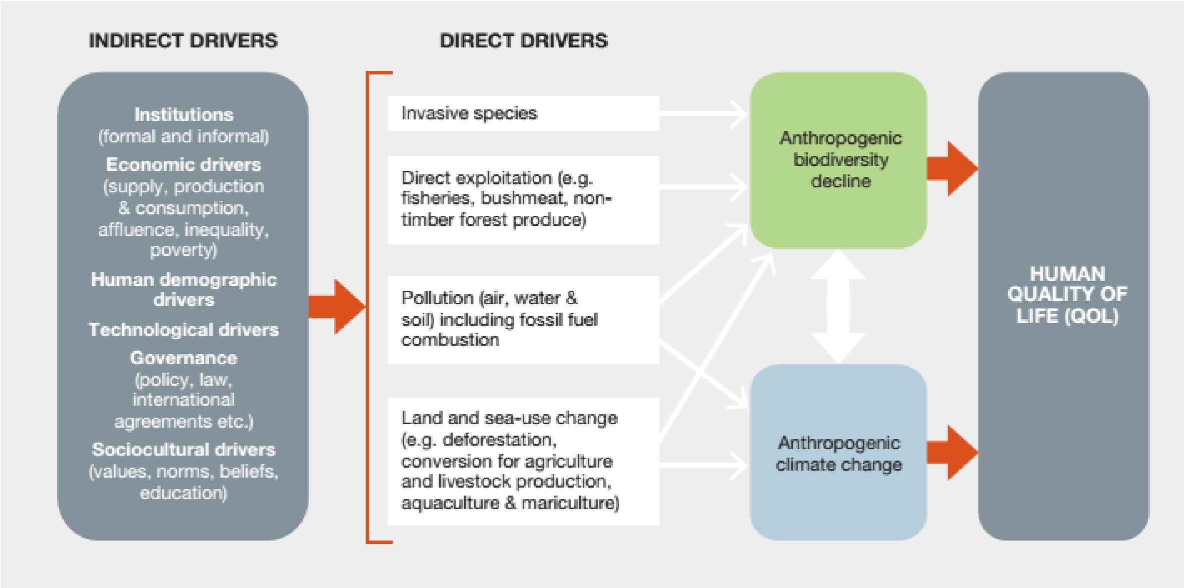


Figure21: Indirect and direct drivers of biodiversity loss and climate change due to human activities. (Friedlingstein *et al.*, 2020)

II.4. The greenhouse effect

The greenhouse effect is a natural process that warms the Earth's surface. It occurs when the Earth's atmosphere traps some of the Sun's energy, preventing it from escaping back into space and thereby keeping the planet warm enough to support life. Here's a detailed explanation:

II.4.1. Basic Mechanism of the Greenhouse Effect

- **Solar Radiation:** The Sun emits energy in the form of solar radiation, which includes visible light, ultraviolet (UV) light, and infrared (IR) radiation. When this solar radiation reaches the Earth, approximately 30% of it is reflected back into space by clouds, atmospheric particles, and the Earth's surface. The remaining 70% is absorbed by the Earth's surface, oceans, and atmosphere.
- **Heating the Earth:** The absorbed energy warms the Earth's surface. In response, the Earth emits this energy back toward space in the form of infrared radiation (heat). However, not all of this heat escapes directly into space.
- **Greenhouse Gases:** Certain gases in the Earth's atmosphere, known as greenhouse gases (GHGs), absorb and re-emit infrared radiation. These gases include:
    - **Carbon Dioxide (CO_2):** Produced by the burning of fossil fuels, deforestation, and other processes.

- **Methane (CH_4):** Emitted from livestock, agriculture (especially rice production), and decay of organic waste in landfills.
- **Nitrous Oxide (N_2O):** Released from agricultural and industrial activities, as well as combustion of fossil fuels and biomass.
- **Water Vapor (H_2O):** The most abundant greenhouse gas, it increases as the Earth's atmosphere warms, but it also amplifies the greenhouse effect.
- **Fluorinated Gases:** Synthetic gases used in industrial applications, such as hydrofluorocarbons (HFCs), which have a very high global warming potential.

- **Trapping Heat:** When the Earth emits infrared radiation, GHGs in the atmosphere absorb and then re-emit this energy in all directions, including back towards the Earth's surface. This process effectively traps heat in the atmosphere, keeping the Earth's surface and lower atmosphere warmer than it would be if the heat were allowed to escape directly into space.

II.4.2. Natural vs. Enhanced Greenhouse Effect

1.Natural Greenhouse Effect: The greenhouse effect is a natural phenomenon that has occurred for millions of years, enabling the Earth to maintain temperatures that support life. Without the greenhouse effect, the Earth's average temperature would be about -18°C (0°F) rather than the current average of around 15°C (59°F).

2.Enhanced Greenhouse Effect: Some human activities also produce greenhouse gases and these gases keep increasing in the atmosphere. The change in the balance of the greenhouse gases has significant effects on the entire planet. Burning fossil fuels - coal, oil and natural gas - releases carbon dioxide into the atmosphere. Cutting down and burning trees also produces a lot of carbon dioxide. A group of greenhouse gases called the chlorofluorocarbons have been used in aerosols, such as hairspray cans, fridges and in making foam plastics.

Since there are more and more greenhouse gases in the atmosphere, more heat is trapped, which makes the Earth warmer. This is known as global warming. A lot of scientists agree that man's activities are making the natural greenhouse effect stronger. If we carry on polluting the atmosphere with greenhouse gases, it will have very dangerous effects on the Earth. Today, the increase in the Earth's temperature is increasing with unprecedented speed. (Fig.22)

To understand just how quickly global warming is accelerating, consider that during the entire 20th century, the average global temperature increased by about 0.6 degrees Celsius (slightly more than 1 degree Fahrenheit). Using computer climate models, scientists estimate that by the year 2100 the average global temperature will increase by 1.4 degrees to 5.8 degrees Celsius (approximately 2.5 degrees to 10.5 degrees Fahrenheit).(Buha.2011)

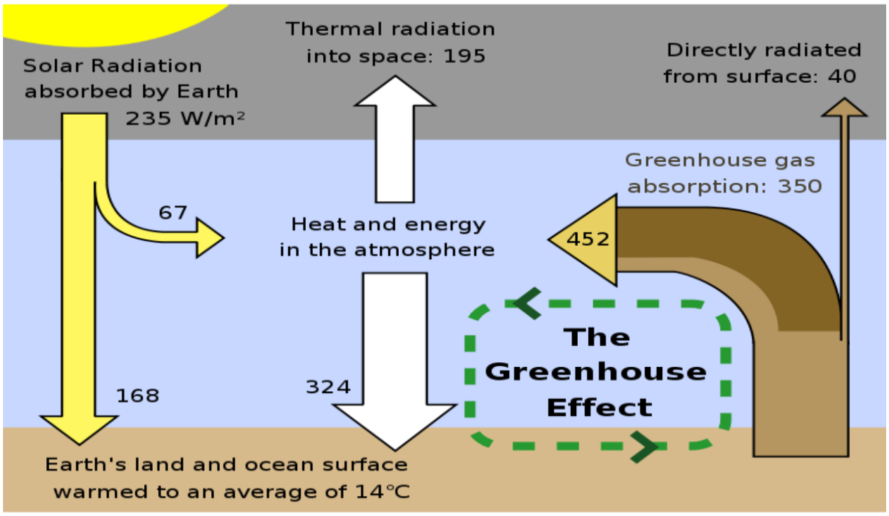


Figure 22: Greenhouse Effect. (Buha,2011)

II.4.3. Sources of Greenhouse Gases

- **Carbon Dioxide (CO_2):** The most significant anthropogenic greenhouse gas, CO_2 concentrations have risen sharply due to fossil fuel combustion (coal, oil, and natural gas), deforestation, and cement production.
- **Methane (CH_4):** Although less abundant than CO_2, methane is over 25 times more effective at trapping heat in the atmosphere over a 100-year period. Major sources include livestock digestion, rice paddies, landfills, and fossil fuel extraction.
- **Nitrous Oxide (N_2O):** With a global warming potential nearly 300 times that of CO_2, nitrous oxide is released from agricultural activities, especially the use of synthetic fertilizers, and from industrial processes.
- **Fluorinated Gases:** These include HFCs, PFCs, and sulfur hexafluoride (SF_6), which are synthetic and have no natural sources. They are used in refrigeration, air

conditioning, and as solvents in industrial applications. Though present in smaller quantities, they are extremely potent greenhouse gases.

II.4.4. Consequences of the Enhanced Greenhouse Effect

- **Global Warming:** The most direct consequence of the enhanced greenhouse effect is global warming, an increase in Earth's average surface temperature. This warming has been observed over the past century, with significant acceleration in recent decades.
- **Climate Change:** Global warming leads to broader changes in climate, including shifts in weather patterns, more frequent and severe heatwaves, changes in precipitation patterns, and more intense storms.
- **Melting Ice Caps and Glaciers:** Rising temperatures contribute to the melting of polar ice caps and glaciers, leading to rising sea levels.
- **Ocean Acidification:** The absorption of excess CO_2 by the oceans not only increases water temperatures but also leads to ocean acidification, which negatively impacts marine life, particularly organisms that build shells and skeletons out of calcium carbonate.
- **Ecosystem Disruption:** Changes in temperature and precipitation patterns disrupt ecosystems, affecting plant and animal species. Some species may not be able to adapt quickly enough, leading to shifts in biodiversity and potential extinctions.

II.4.5. Positive Feedback Loops

- **Water Vapor Feedback:** As the Earth warms, the atmosphere can hold more water vapor, which is itself a greenhouse gas. This increase in water vapor further enhances the greenhouse effect, creating a positive feedback loop that accelerates warming.
- **Ice-Albedo Feedback:** Melting ice reduces the Earth's albedo (reflectivity), as darker ocean or land surfaces absorb more solar radiation than reflective ice or snow. This leads to further warming and more ice melt, creating another positive feedback loop.
- **Permafrost Thawing:** As global temperatures rise, permafrost (frozen soil) in polar regions begins to thaw, releasing stored methane and CO_2. This release of greenhouse gases further enhances warming, contributing to a feedback loop.

II.4.6. Mitigation of the Greenhouse Effect

To mitigate the enhanced greenhouse effect and reduce the impact of climate change, several strategies are being pursued:

- **Reducing Greenhouse Gas Emissions:** Transitioning to renewable energy sources (such as wind, solar, and hydroelectric power), improving energy efficiency, and reducing deforestation are key ways to lower CO_2 emissions.
- **Carbon Capture and Storage (CCS):** Technologies that capture and store CO_2 from power plants and industrial sources before it reaches the atmosphere are being developed and deployed.
- **Reforestation and Afforestation:** Planting trees and restoring forests can help absorb CO_2 from the atmosphere, acting as a carbon sink.
- **Policy Measures:** International agreements, such as the Paris Agreement, aim to limit global warming by setting targets for reducing greenhouse gas emissions. National policies, carbon pricing, and incentives for clean energy are also important tools.
- **Adaptation Strategies:** While mitigation efforts are crucial, adaptation strategies, such as building resilient infrastructure, protecting water resources, and developing climate-smart agriculture, are necessary to cope with the effects of climate change that are already occurring.

The greenhouse effect is a fundamental natural process that keeps Earth warm enough to support life. However, human activities have significantly intensified this effect, leading to global warming and climate change. Understanding the greenhouse effect and its consequences is crucial for developing effective strategies to mitigate climate change and adapt to its impacts. Reducing greenhouse gas emissions, enhancing carbon sinks, and implementing both mitigation and adaptation strategies are vital steps in addressing the challenges posed by an enhanced greenhouse effect. (Fig.23)

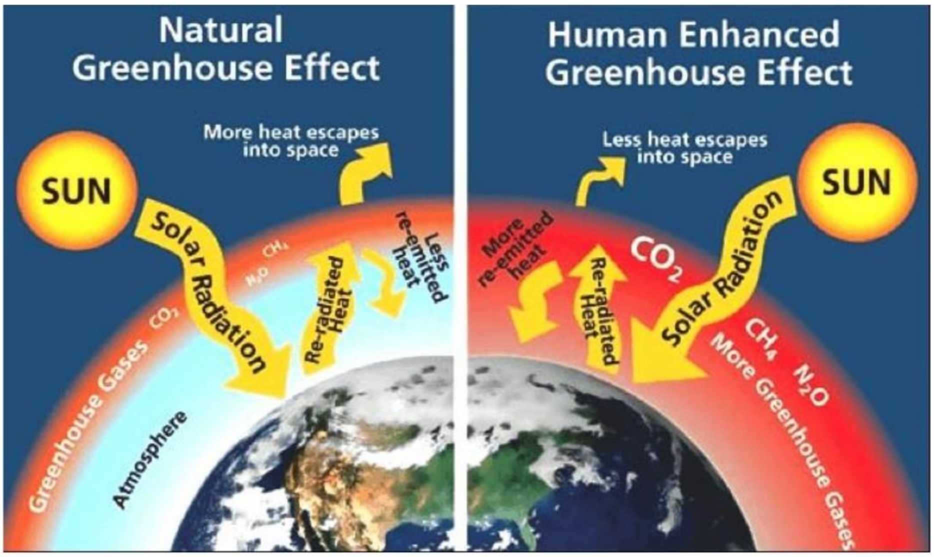


Figure 23: The most important GHGs directly emitted by humans include CO2, CH4, nitrous oxide (N2O), and several others

Chapiter III. Climate change and plant biodiversity

III.1. Climate Change and its Impact

The biodiversity loss has ecological impact (Kumar Ajay et al., 2017) and its main cause is the changes in the environment. Environmental conditions play a key role in defining the function and distribution of organisms, in combination with other factors. Environmental changes have had enormous impacts on biodiversity patterns in the past and will remain one of the major driver s of biodiversity patterns in the future. Environmental changes are studied under the change in climate or changes due to overpopulation, overexploitation of natural resources and deforestation.

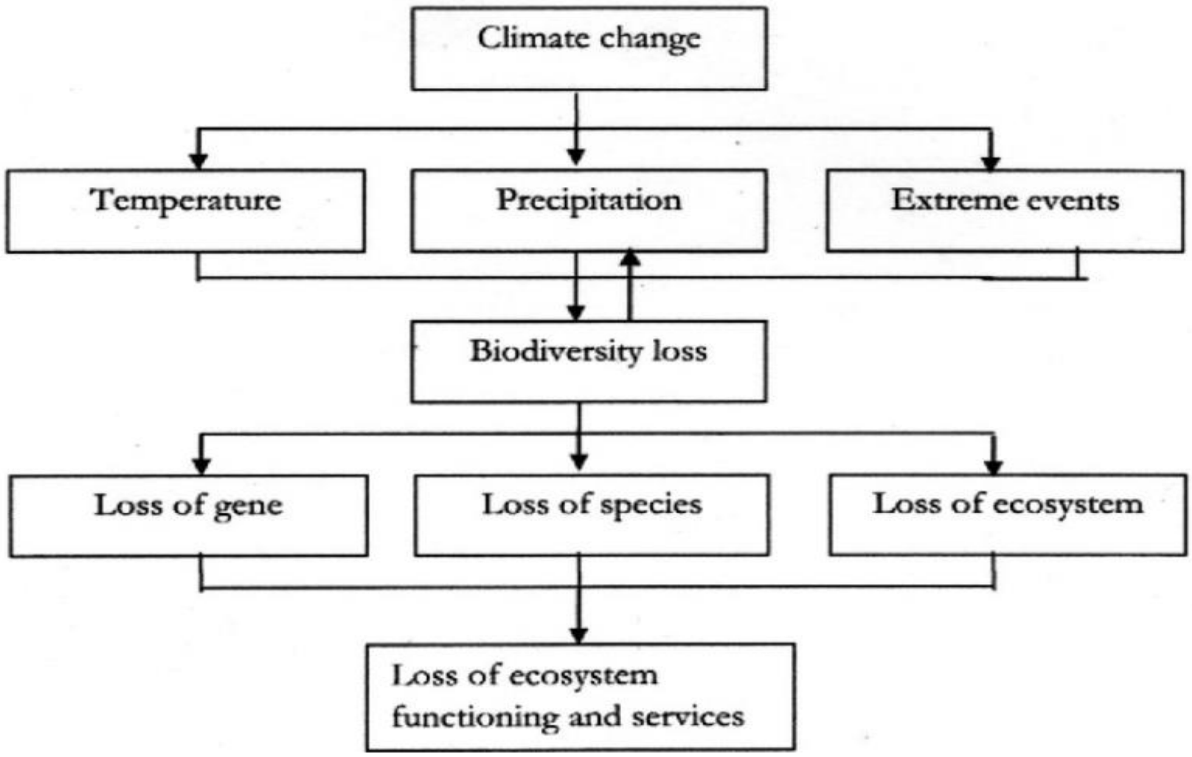


Figure 24: Link between climate change and its impacts on loss of biodiversity and ecosystem.

The word climate refers to the weather variation of any specific area over a period of time. Climate includes the average temperature, amount of precipitation, days of sunlight, and other variables that might be measured at any given site. However, there are also changes within the Earth's environment that can affect the climate. Climate change refers to any change in the environment due to human activities or as a result of natural processes. Climate change refers to significant and long-term changes to a region's climate (Fig 24). These changes can occur over a few decades, or millions of years. Climate change alters entire ecosystems along with all of the plants and animals that live there.

Plants and animals are sensitive to fluctuations in temperature and climate. Evidence of organic evolution clearly indicated that rapid climate changes have been associated with mass extension of plants and animals. Rapid climatic changes could lead to increased diseases, land slide, forest fire which result in destruction of animals and plants. All organisms are adapted to a particular range of climatic conditions. Change in the climatic condition has a danger of extinction of several plants and animals species. Although all species are not directly influenced by changes in environmental conditions but also indirectly influence through their interactions with other species. Indirect impacts are equally important in determining the response of plants to climate change. A species whose distribution changes as a direct result of climate change may 'invade' the range of another species for example, introducing a new competitive relationship.Thus climate change is likely to affect minimum and maximum temperatures and trigger more extreme rainfall events and storms.

Natural drivers involves earth's climate variability caused by changes in the solar radiations, Milankovitch cycle, volcanic eruption, plate tectonics, ocean circulations, earthquakes and so on (Kunzing, 2008). Anthropogenic drivers involves the contribution of human activities to increasing the emission of green house gases like carbon dioxide, methane and nitrous oxide into the atmosphere at an alarming rate in different sectors such as in energy supply (25.9%), industrial sector (19.4%), deforestation (17.4%), agricultural (13.5%), transportation (13.1%), urbanization (7.9%) and waste (2.8%) (Rathore and Jasrai, 2013).

II.1.1. Impact of climate change on environment

- **Global warming**

The impact of the greenhouse gases is the warming near surface global temperature through the green house effect. The average global temperature has increased by 0.6°C since mid 1800s and is predicted to rise by 1.4-5.8°C by the year 2100. The global warming affects plants, animals and microorganisms both by changing their habitats and by directly affecting their physiological processes. The means sea level has risen by 10 to 20 cm and may further rise to 88cm (Rathore and Jasrai, 2013). Climate change has resulted in an increase in the temperature to about 5°C to the normal and has resulted in the melting of the ice, increase in sea level which is threatening the endemic species (polar bears, walruses, seals, emperor penguins, krill and ringed seal).

- **Coral bleaching**

Another important phenomenon associated with temperature rise is coral bleaching. When corals become affected by the rising temperature and other climatic issues they lose their beautiful colours turning white. The rising temperature results into increase in sea temperatures which negatively impacts the corals resulting in vanishing of the reefs which are considered to be one of the most bio-diverse ecosystems.

- **Water resources**

Climate change affects the water resources thought increased evaporation rate. Increased evaporation rates are expected to reduce water supplies in many regions. The greatest deficits are expected to occur in the summer leading to be decreased soil moisture levels and more frequent and severe agriculture drought. More frequency and severe droughts arising from climate change will have serious and management implication for water resource users. Such droughts also impose costs in terms of wildfires both in control costs and lost timber and related resources.

III.1.2. Impact of climate change on biodiversity

Only a small change in pattern of climate has severe impact on the biodiversity, altering the habitats of the species and presenting a threat for their survival, making them vulnerable to extinction. Millennium Ecosystem Assessment (MEA) predicts climate change to be the principal threat to the biological diversity (Anonymous, 2007).

Due to increase in temperature several plant species like *Berberisa siatica*, *Taraxacum officinale*, *Jasminum officinale* etc.have shifted towards higher altitude in Nainital. Teak dominated forests are predicted to replace the Sal trees in central India and also the conifers may be replaced by the deciduous types. According to Gates (1990) 3°Cincrease in temperature may leads to the forest movement of 2.50 km/ year which is ten times the rate of natural forest movement.

Anonymous (2009) reported that changes in climate affects the normal life cycle of plant. He also reported that invasive species (*Lantana, Parthenium* and *Ageratum conyzoides*) are a threat to native species being more tolerant to climatic variations. Variation in temperature and precipitation patterns can result in more frequent droughts and droughts and floods making indigenous plants more vulnerable to pests and diseases (Tibbetts, 2007).

Slight change in climatic condition leads to the extinction of animal species. For example climate change has resulted in extinction of animals like golden toad and Monteverde.

harlequin frog (McCarthy *et al*., 2001). Polar bears are in danger due to reduction in Arctic ice cover; North Atlantic whale may become extinct, as planktons which are its main food have shown declination due to climate change. Though the exact impact of climate change on India's natural resources is yet to be studied in detail, pioneering studies show that endemic mammals like the Nilgiri tahr face an increased risk of extinction (Sukumar *et al*., 1995). Further, there are indicative reports of certain species e.g., Black-and rufous flycatcher (Mikania micrantha) shifting their lower limits of distribution to higher reaches, and sporadic dying of patches of Shola forests with the rise in ambient surface temperatures.

The sex ratio of sea turtle disturb because as a result of high temperature more female turtles are produced. Some threatened species (frogs, toads, amphibians, tigers and elephants) are vulnerable to the impacts of climate change like sea level changes and longer drier spells. Changes in ocean temperature and acidification may lead to loss of 95% of the living corals of Australia's Great Barrier Reef (Anonymous, 2007).

Climate change also alters the disease behavior in animals. The devastating amphibian disease chytrid fungus, likely exacerbated by warmer temperatures, has left many amphibian populations dwindling or extinct.

III.1.3. Impact of climate change on ecosystem

Millennium EcosystemAssessment (MEA) predicts that only a small change in climate has severe impact on the ecosystems (Anonymous, 2007).

- **Marine and Coastal ecosystem**

70% of earth's surface is covered by oceans comprising unique ecosystems like mangroves, coral reefs, sea grass beds. Climate change is leading to sea level rise, increased coastal erosion, flooding, higher storm surges, sea salinity ingress, increased seasurface temperatures, ocean acidification and coral bleaching. Rising sea level presents extreme threat to marine ecosystems which can lead to disturbance in habitat and patterns of survival of marine species. Wetlands and coastal ecosystems are at a huge risk due to increasing sea levels. Many communities have already become climate refugees to evade rising sea level (Anonymous, 2007). Indian coastal areas vulnerable to climate change are Sunderbans, Maharashtra, Goa and Gujarat (Rann of Kutch). Species composition and distribution will surely be affected by such changes (Rathore and Jasrai, 2013).

The Sundarbans is the largest natural low-lying mangrove ecosystem in the world, distributed over 10,000 square kilometers. The sea level rise recorded over the past 40 years is responsible for the loss of 28% of the mangrove ecosystem. Modelling suggests that up to 96% of suitable tiger habitat in the Sundarbans could be lost in the next 50–90 years (Loucks *et al*., 2010).

- **Himalayan ecosystem**

Temperatures in the Himalayan ecosystem are increasing at a rate of 0.9°C annually, which is considerably higher than the global average of 0.7°C per decade. Due to this changes mosquito are seeing first time in Lhasa and Tibet cities, located 3490 meters above sea level. There are similar reports of flies at Mount Everest base camp in Nepal. The presence of these insects suggests the possible spread of vectorborne diseases, such as malaria and dengue fever, to areas where cooler temperatures previously protected people from these threats (FAO, 2012).

- **Island ecosystem**

Islands are rich in biodiversity and has high economic importance. But at present due to climate change more than 23% island species are becoming endangered and hence economic loss in the tourism sector.

- **Inland water ecosystem**

It includes lotic and lentic fresh water ecosystem and comprising 0.8% of the earth's surface, but support 6% of the total species. They are rich source of food, income, employment and biodiversity. Changing climatic conditions like rainfall and temperature lead to changes in the phenology, physiology and migration trends of some organisms like migratory fishes and birds.

- **Forest ecosystem**

One third of earth's surface is covered by forest and it is the home place of two third of all terrestrial species. They are also rich biodiversity hotspots. But half of the original forest has been cleared up till now. Green house effect has led to increase in growth of some forest, migration of tree species towards high altitude, increased attack of pest, invasive species and wild fires, hence modifying the composition of forest. According to FAO (2000), due to these changes many animals, primates and 9% of all known plant species are at verge of extinction.

- **Agriculture**

Climate change leads to variability in rainfall patterns, heat stress, spread of pests and diseases and shortening of the crop cycle and affecting plant growth and production. It affects both sustainable and unsustainable agriculture. The unsustainable agriculture has multiple effects (Verma 2017c) and disturbs the ecological balance (Verma 2018a) and biodiversity structure. Biodiversity loss has impacted the fishing and hunting practices by indigenous people posing an implication on their only source of food. By the middle of the century, crop yields could decreases by 30% in Central and South Asia, while by 20% in East and SoutheastAsia.

- **Dry lands and grassland**

They have localized species (Wild ass, Kutch etc.) and have varied crops and livestock. The risk of wild fire is increasing which could change the species biodiversity.

III.1.4. Impact of climate change on humans

Climate change leads toan increase in temperature, melting of the ice, increased natural events like floods, droughts, and cyclones displace the humans from their home.Hot climate makes insect pests in general and vectors and pathogens in particular to spread over a wider range and enhances their survival rate. An increase of 1°C in surface temperature is estimated to correspond 10% increase in incidence of insects as pests and insurgence of many diseases like cholera, typhoid etc.; spread of tropical and vector borne diseases like malaria, dengue etc. androdent borne diseases like plague. These diseases have shown a persistent increase in the past 50 years.

Thus global climate changes have major implications on human health. It is obvious that effect on ecosystem will change the distribution and burden of vector borne infectious diseases including bacterial diseases. Changes in epidemiology may already be underway, complex biological changes are associated with change in ecosystem. Water and food borne pathogens create havoc in developing countries that too when conditions are conducive for spread of pathogens and compromise with the hygiene conditions. Green house gases play their role by increasing the carbon emission, due to which the disease curve is increasing faster. Carbon emission is increasing to a dangerous level, making animal lives vulnerable to pathogens and diseases. The increasing sea level rise has already submerged many islands and will soon leave millions of refugees for the world to provide shelter. The sea salinity ingress in the fresh water sources has made land barren and will soon be a threat to the food security.

III.1.5. Impact of habitat loss, overpopulation and overexploitation

Besides climatic change, other human activities are also largely responsible for biodiversity loss. It is estimated that about 27000 species become extinct every year. If this will continues, 30% of world's species may be extinct by the year 2050. The current extinction rate is 100 to 1000 times to that of natural rate of extinction. Other human activities are: habitat destruction, invasive species, pollution, population and overexploitation of natural resources (Kannan and James, 2009).

Climate change will provide new ways for invasive species to encroach on new territory. Natural disasters like storm surges and high winds, which increase in number and severity as the earth warms, spread non-native plants and insects to new territories. Virtually all ecosystems worldwide have suffered invasion by the main taxonomic groups . The major invasive alien plant species include *Lantana camara, Eupatorium odoratum, Eupatorium adenophorum, Parthenium hysterophorus, Ageratum conyzoides, Mikania micrantha, Prosopis juliflora* and *Cytisus scoparius*.

Rapidly increasing population has forced down the men to cut down the forests to fulfill the requirements of food and shelter. Deforestation has led to the destruction of the habitats of plants and animals. Loss of habitats is the most important cause of extinction of species. Habitat extinction compels the species to move where they find it difficult to adapt and this may ultimately lead to their extinction. Physically larger species and those living at lower latitude or in the forests or oceans are more sensitive to reduction in habitat area (Drakare *et al*., 2006).

Human activities like deforestation, pollution, overpopulation are ultimately responsible for habitat destruction. Introduction of exotic species is also responsible for the loss of biological diversity. The endemic and other local species may not be able to compete with the exotic species and are unable to survive. Overexploitation, in the form of hunting of animals and plants for their commercial value is one of the major reasons for loss in biodiversity. Illegal wildlife trade is the single largest threat to biodiversity loss. Overpopulation of human and over consumption of natural resources is the root cause of all biodiversity loss (Sharma and Mishra, 2011).

III.2. Biodiversity Hotspot

III.2.1. The biodiversity hotspots concept

The British ecologist Norman Myers first published the biodiversity hotspot thesis in 1988. Myers, although without quantitative criteria but relying solely on the high levels of habitat loss and the presence of an extraordinary number of plant endemism, identified ten tropical forest ‘‘hotspots’’ (Mittermeier et al., 2011). A subsequent analysis added a further eight hotspots, including four in Mediterranean regions. Conservation International (CI—http://www.conservation.org) adopted Myers’ hotspots as its institutional blueprint in 1989, and afterwards worked with him in a first systematic update of the global hotspots. Myers, Conservation International, and collaborators later revised estimates of remaining primary habitat and defined the hotspots formally as biogeographic regions with >1500 endemic vascular plant species and ≤30% of original primary habitat (Myers et al., 2000).

This collaboration, which led to an extensive global review (Mittermeier et al., 1999) and a scientific publication (Myers et al., 2000) saw the hotspots expand in area as well as in number, on the basis of both the better-defined criteria and new data. A second major revision and update in 2004 did not change the criteria but by redefining several hotspots boundaries, and by adding new ones that were suspected hotspots for which sufficient data either did not exist or were not easily accessible, brought the total to 34 biodiversity hotspots (Mittermeier et al., 2011).
Recently, a 35th hotspot was added (Williams et al., 2011), the Forests of East Australia. The 35 biodiversity hotspots (Table 4, Fig. 25) that cover only 17.3% of the Earth's land surface are characterized by both exceptional biodiversity and considerable habitat loss (Myers et al., 2000). More precisely, hotspots maintain 77% of all endemic plant species, 43% of vertebrates (including 60% of threatened mammals and birds), and 80% of all threatened amphibians (Mittermeier et al., 2011; Williams et al., 2011).

Biodiversity is important in the oceans as on land. Myers and colleagues, however, excluded the oceans from their analysis. In particular, coral reefs are one of the most biologically diverse ecosystems in the ocean and provide important structures and habitat in tropical and sub-tropical coastal waters (Bellwood et al., 2004).

In these areas, where the explanation for the high number of species is still debated, ocean acidification and changes in sea surface temperature are likely to cause major coral reef losses and changes in the distribution and relative abundances of marine organisms. Moreover, apart from the intrinsic biodiversity value, there are economic arguments for the protection of marine biodiversity (Balmford et al., 2002).
This makes the maintenance of marine biodiversity a valuable environmental management goal. Roberts et al. (2002), through the publication of one of the most comprehensive studies of hotspots on global coral reefs, have brought much-needed attention to marine hotspots, extending the hotspot concept to coral reefs and arguing that biodiversity hotspots are major centers of endemism in the sea as well as on land. Overall, the analysis revealed the 18 richest multi-taxon centers of endemism, of which 10 were considered to be marine biodiversity hotspots. Furthermore, 8 of 10 marine biodiversity hotspots and 14 of 18 centers of endemism were found to be adjacent to terrestrial biodiversity hotspots, suggesting a possible integration among terrestrial and marine conservation (Roberts et al., 2002).

III.2.2. Criticism of biodiversity hotspots

Since its introduction, the concept of hotspots was used as a key strategy for global conservation action. For this reason, it has become the principal global conservation-prioritization approach, attracting over $1 billion in conservation investment (Sloan et al., 2014).

The approach is thus partly economic and it is based on the fact that it is not possible to protect the full range of biodiversity since it would certainly not be a realistic target. Basically, biodiversity conservation requires prioritization to be effective, if only because funds are limited and must be allocated carefully (Myers, 2003).

Therefore, among many others, entities like Conservation International, have explicitly adopted the hotspot concept as a central conservation-investment strategy (Sloan et al., 2014).
In a 2003 essay entitled ‘‘Conserving Biodiversity Coldspots’’, conservation biologists Peter Kareiva and Michelle Marvier argued that non-governmental organizations, foundations and international agencies have been seduced by the simplicity of the hotspot idea, and significant financial resources have been directed toward them. In particular, the two conservation biologists argued that coldspots, despite begin poorer for number of species, play an important ecological role. By investing exclusively in hotspots and ignoring coldspots the risk is to lose large, natural and ecologically important areas that contribute to many ecosystem services (Kareiva and Marvier, 2003).

On the same wavelength, Jepson and Canney (2001) have warned that the biodiversity hotspots approach provides only a partial response for the conservation. The authors agree that promoting biodiversity hotspots, as a ‘‘silver bullet’’ strategy for conserving the most species for the least cost is a risk in complex areas of international policy, such as biodiversity conservation, because decision makers may view it as a cure-all. As a result, they conclude that spatial priorities and public policy cannot be determined on the basis of simple species counts, which is the foundation of the biodiversity hotspot approach. Furthermore, as pointed out by Smith et al. (2001) biodiversity hotspots entirely ignore regions of ecological transition. Hence, the authors promote a more comprehensive approach to include regions important to the generation and maintenance of biodiversity, regardless of whether they are ‘‘species-rich’’.

Recently, Stork et al. (2014) have emphasized the lack of consideration for the role of invertebrates (e.g. herbivorous insects, herbivorous fungi and nematodes) in decision-making about global biodiversity hotspots, suggesting a more detailed analysis of the role of plants as umbrella species for these herbivorous organisms.

Furthermore, since data on species distributions are usually scarce the conservation of an entire global hotspot may be difficult and unsustainable. In this regard, Cañadas et al. (2014) pointed out the need to focus strategies on small areas that represent maximum diversity and/or endemism.

Finally, for some of the same reasons that fueled disputes for terrestrial ecosystems, hotspots on coral reefs (Roberts et al., 2002) have also been the subject of controversy. In this respect, Parravicini et al. (2014) have recently identified tropical reef areas that are critical for preventing the loss of fish taxonomic and functional biodiversity. These areas, such as the Western Indian Ocean, differ in important ways from the fish richness hotspots previously identified close to the Indo-Australian Archipelago.

These criticisms highlight the problems associated with the idea of biodiversity hotspots, even though Myers (2003) (whose criteria include endemism and species richness) points out that other criteria are not ruled out by the theory itself. Essentially, the author affirms that the hotspot approach does not exclude other areas that need conservation, but nevertheless claims that a conservation strategy will always need a measure to determine priorities. In conclusion, although not completely free from criticism, the hotspot approach has become a key tool to guide conservation efforts and presently plays a leading role in decision-making regarding conservation cost-effective strategies (O'Donnell et al., 2012).

III.2.3 Hotspots identification Biodiversity hotspots

are particular areas where extraordinary concentrations of biodiversity exist. Although hotspots have also been identified through different ways , these areas are usually defined by one or more species-based metrics (number of species – species richness; number of species restricted to a particular area – endemicspecies richness; and number of rare or threatened species) or focusing on phylogenetic and functional diversity in order to protect species that support unique and irreplaceable roles within the ecosystem.

- **Species-based metrics**

A central issue in conservation today is to identify biodiversity-rich areas. Species richness (SR) has been the main focus of conservation studies and is still widely used, mainly because it is easy to quantify and interpret data (Davies and Cadotte, 2011). In particular, conservation planning has traditionally used richness information combined with different irreplaceability measures (e.g. endemism or rarity) to prioritize some regions over others (e.g. biodiversity hotspots). In the methodology proposed by Myers et al. (2000), the key factors considered for the analysis were: (1) numbers of endemics and endemic species/area ratios for both plants and vertebrates, and (2) habitat loss. More precisely, vascular plants were chosen as the metric for endemism because fairly well known and essential to all forms of animal life, while vertebrates (four groups: mammals, birds, reptiles and amphibians) were mainly used to determine congruence and to facilitate other comparisons among the hotspots. However, the analysis omitted invertebrates because they are not yet well documented and fish, because of lack of good data. Finally, the boundaries of the hotspots were determined by examining biological commonalities with each of the areas featuring a separate biota or community of species that fits together as a biogeographic unit. Therefore, selecting biodiversity hotspots requires data on species distributions together with the definition of a threshold useful to define the boundaries between hotspots and non-hotspots (Cañadas et al., 2014).

Increasing evidence, both in marine and terrestrial environments, shows that hotspots of total species richness are not always concordant with hotspots of endemism or threat. Concentrations of threatened species or local endemics may also occur in areas of lower richness.

Orme et al. (2005), using a global database to map the geographical distribution of birds, found an alarming lack of congruence between hotspots defined with the criterion of species endemism and areas of high species richness and concentrated threat. Furthermore, species richness for one taxon may not match perfectly with hotspots in the richness of another. For example, while Lamoreux et al. (2006) have found high congruence between conservation priorities for terrestrial vertebrate species, Grenyer et al. (2006) reported low congruence between conservation priorities for mammals, birds, and amphibians. Recently, a new assessment of global conservation priorities mapped global priority areas using the latest data on mammals, amphibians, and birds at a scale 100 times finer than previous assessments.

This analysis has identified areas in the world that are currently ignored by biodiversity hotspots but critical for preventing vertebrate extinctions. Finally, focusing on small areas Cañadas et al. (2014) showed that even in areas that are noted to be hotspots, the endemic-plant richness is not uniformly distributed, but rather depends largely on environmental conditions. Specifically, according to the authors, it is possible to identify hotspots within hotspots that can be organized in a hierarchy helping to focus conservation efforts at different scales within a given hotspot.

- **hylogenetic diversity**

The use of species-based metrics remains the primary method for characterizing and mapping the distribution of biological diversity and thus to identify areas as biodiversity hotspots. However, because diversity, or evolutionary history, is distributed unequally between taxa as well as between areas, taking into consideration only traditional species diversity may not be sufficient to fully capture differences among species. Therefore, to quantify biodiversity the focus shifted from pure species counting to a more integrative approach that quantifies the evolutionary information represented within groups of taxa (i.e. phylogenetic diversity, PD) along with the diversity of ecological traits (i.e. functional diversity, FD). The loss of FD or PD per unit of habitat loss may be a better indicator of ecosystem vulnerability, providing a more comprehensive measure than those based exclusively on the loss of single species. Recently, D'Agata et al. (2014) showed that despite a minimal loss of fish richness that can occur along a human pressure gradient, many functions and phylogenetic lineages might be lost. PD might thus be more useful than species richness in maintaining ecosystem services. Its use redefines the identification of species of conservation interest by taking into consideration the evolutionary information represented within groups of taxa, providing additional information to guide conservation decision-making. Phylogenetic information is increasingly being used in ecological studies (Cadotte et al., 2010) in parallel with an increasing number of new and sophisticated metrics that incorporate different community attributes such as abundance information and geographical rarity.

Probably, the increasing availability of molecular data and the recent advances in software and phylogenetic methods (Roquet et al., 2013) will enhance even more the use of phylogenetic information to better characterize and describe biodiversity patterns and ecosystem functioning.

Table 4 :Biodiversity hotspots from 1988 to 2011. Source: Modified from: Mittermeier et al. (2011).

Myers (1988)	**Myers (1990)**	**Myers et al. (2000)**	**Mittermeier et al. (2004)**	**2011 Revision**
Uplands of Western	Uplands of Western			
Amazonia	Amazonia	Tropical Andes[a]	Tropical Andes	Tropical Andes
Western Ecuador	Western Ecuador			

Myers (1988)	**Myers (1990)**	**Myers et al. (2000)**	**Mittermeier et al. (2004)**	**2011 Revision**
Colombian Choco	Colombian Choco	Choco/Darien/western Ecuador[b]	Tumbes-Choco-Magdalena	Tumbes-Choco-Magdalena
Atlantic Coast Brazil	Atlantic Coast Brazil	Atlantic Coast Brazil	Atlantic Forest	Atlantic Forest
		Brazilian Cerrado	Cerrado	Cerrado
	Central Chile	Central Chile[a]	Chilean Winter Rainfall and Valdivian Forest	Chilean Winter Rainfall and Valdivian Forest
		Mesoamerica	Mesoamerica	Mesoamerica
			Madrean Pine-Oak Woodlands	Madrean Pine-Oak Woodlands
		Caribbean	Caribbean Islands	Caribbean Islands
	California Floristic Province	California Floristic Province	California Floristic Province	California Floristic Province
	Ivory Coast	Guinean Forest of West Africa[a]	Guinean Forest of West Africa	Guinean Forest of West Africa
	Cape Floristic Region	Cape Floristic Province	Cape Floristic Region	Cape Floristic Region
		Succulent Karoo	Succulent Karoo	Succulent Karoo
			Maputaland–Pondoland–Albany	Maputaland–Pondoland–Albany
	Tanzania	Eastern Arc and Coastal Forest of Tanzania/Kenya[c]	Eastern Afromontane[d]	Eastern Afromontane
			Coastal Forests of Eastern Africa[d]	Coastal Forests of Eastern Africa
			Horn of Africa	Horn of Africa
Eastern Madagascar	Eastern Madagascar	Madagascar and Indian Ocean Islands	Madagascar and Indian Ocean Islands	Madagascar and Indian Ocean Islands
		Mediterranean Basin	Mediterranean Basin	Mediterranean Basin
		Caucasus	Caucasus	Caucasus
			Irano-Anatolian	Irano-Anatolian
			Mountains of Central Asia	Mountains of Central Asia
	Western Ghats in India			

Myers (1988)	Myers (1990)	Myers et al. (2000)	Mittermeier et al. (2004)	2011 Revision
	Southwestern Sri Lanka	Western Ghats and Sri Lanka[b]	Western Ghats and Sri Lanka	Western Ghats and Sri Lanka
		Mountains of South-Central China	Mountains of South-Central China	Mountains of South-Central China
			Indo-Burma	Indo-Burma
Eastern Himalayas	Eastern Himalayas	Indo-Burma[e]	Himalaya[f]	Himalaya
Peninsular Malaysia	Peninsular Malaysia			
Northern Borneo	Northern Borneo	Sundaland[b]	Sundaland	Sundaland
		Wallacea	Wallacea	Wallacea
Philippines	Philippines	Philippines	Philippines	Philippines
			Japan	Japan
	Southwest Australia	Southwest Australia[a]	Southwest Australia	Southwest Australia
				Forests of East Australia[g]
			East Melanesian Islands	East Melanesian Islands
		New Zeeland	New Zeeland	New Zeeland
New Caledonia	New Caledonia	New Caledonia	New Caledonia	New Caledonia
		Polynesia–Micronesia	Polynesia–Micronesia	Polynesia–Micronesia

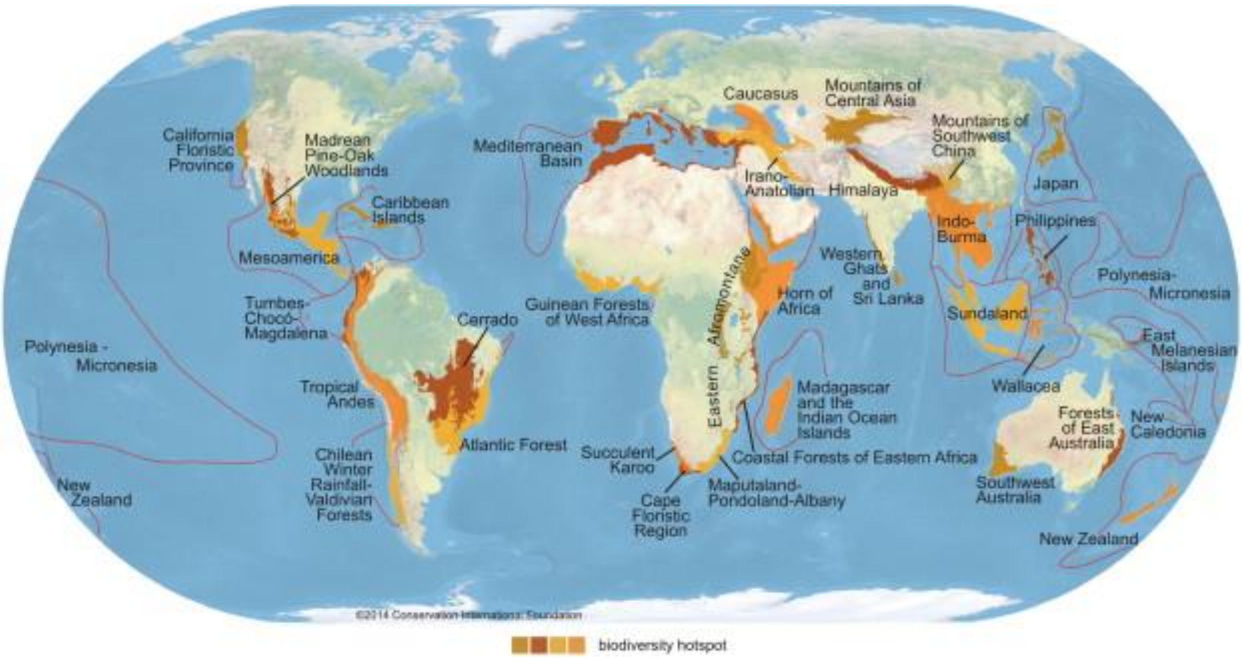


Figure 25. The world's biodiversity hotspots .International license (Author: Conservation International).

III.3. The impact of climate change on plant biodiversity

The major concern of the climate change impacts is decreasing genetic diversity of a population due to directional selection and reparation. It could also affect ecosystem functioning and resilience (Botkin et al., 2007).

"Climate change is now affecting every country on every continent. It is disrupting national economies and affecting lives, costing people, communities and countries dearly today and even more tomorrow. People are experiencing the significant impacts of climate change, which include changing weather patterns, rising sea level, and more extreme weather events. The poorest and most vulnerable people are being affected the most."

Climate change is also expected to have a negative impact on traditional coping mechanisms and food security thereby increasing the vulnerability of the world's poor to famine and perturbations such as drought, flood and disease. Finally, the impacts of climate change on natural resources and lab our productivity are likely to reduce economic growth, exacerbating poverty through reduced income opportunities. Anthropogenic climate change is also threatening biodiversity and the continued provision of ecosystem services (Fig.26). Hence the global community has issued an urgent call for additional research and action towards reducing the impacts of climate change on biodiversity and increasing synergy of biodiversity conservation and sustainable use with climate change mitigation and adaptation activities.

-The vegetation is exhibiting's may be replaced by the deciduous types. According to climatologists and palynologists, temperature change of 3°C may lead to forest movement of250 km at a rate of 2.5 km/year which is ten times the rate of natural forest movement.

The impact of climate change on plant biodiversity is a critical and complex issue, affecting ecosystems worldwide. Here are five key impacts:

- **Altered Distribution of Plant Species**

As temperatures rise and precipitation patterns shift, many plant species are forced to move to new areas to find suitable conditions for growth. This can lead to shifts in plant community compositions, with some species thriving while others decline. The migration of plants to higher altitudes or latitudes disrupts existing ecosystems and can lead to the loss of species that cannot adapt quickly enough.

- **Increased Risk of Extinction**

Climate change exacerbates the risk of extinction for many plant species, particularly those with narrow ecological niches or limited geographic ranges. As their habitats change or disappear, these plants may not be able to adapt or migrate fast enough, leading to a loss of biodiversity. Endemic species, those found in specific locations and nowhere else, are especially vulnerable.

- **Changes in Phenology**

Phenology refers to the timing of biological events such as flowering, fruiting, and leaf-out in plants. Climate change has led to shifts in these events, with many plants blooming earlier in the year due to warmer temperatures. This can create mismatches between plants and the animals that rely on them, such as pollinators, potentially disrupting entire ecosystems. (Dileepkumar et al. 2018)

- **Increased Invasions by Non-Native Species**

Climate change can facilitate the spread of invasive plant species, which often thrive in disturbed or changing environments. These invasive species can outcompete native plants, leading to a reduction in biodiversity. The spread of invasive species is often accelerated by the altered climates that make it easier for them to establish in new areas. (Parmesan,2006).

- **Disruption of Ecosystem Services**

Plants provide essential services such as carbon sequestration, soil stabilization, and water regulation. Climate change-induced losses in plant biodiversity can compromise these services, leading to broader environmental degradation. For example, the loss of certain tree species can reduce a forest's ability to capture carbon, exacerbating climate change.

Overall, the impact of climate change on plant biodiversity is profound, leading to both direct and indirect consequences that threaten the health and stability of ecosystems globally.

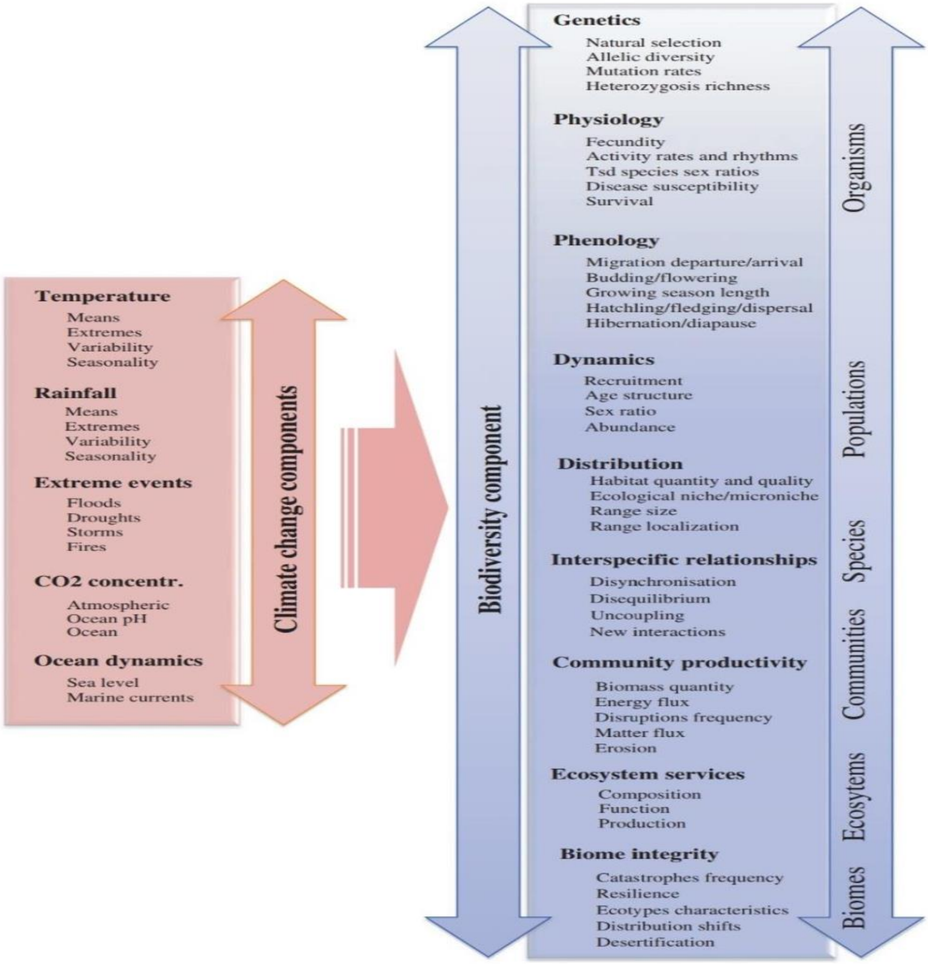


Figure 26: Summary of some of the predicted aspects of climate change and some examples of their likely effects on different levels of biodiversity.

III.3.Widespread Effects of Climate Change on Local Plant Diversity

Human activity has sent many measures of biodiversity into long-term decline, and there are suggestions that the sheer scale of this impact is sufficient to consider the modern era as a geological epoch of its own, known as ‘‘The Anthropocene (Lewis and Maslin,2015). However, recent meta-analyses show that local alpha diversity is often stable or slightly increasing. Here, we show that the local alpha diversity (species richness) of plants found in quadrats and transects has increased the most in cooler regions of the world that have experienced the highest absolute changes (i.e., changes in either direction) in climate. The greatest statistical support is for the effects of precipitation change. On average, alpha diversity declined slightly (4.2% per decade) in the third of sites that experienced the lowest precipitation change but increased (+10.8% per decade) in the third of sites with the highest precipitation change. These results suggest that the ‘‘perturbation’’ of local communities during climatic transitions increases the average number of species, at least temporarily, an effect likely to remain important as climate change continues.

Local plant diversity is of fundamental scientific interest to those wishing to understand why diversity varies in space and time, and it is of practical importance as we contemplate the impacts of humanity on biodiversity across the Earth's surface. For example, the local alpha diversity of plants underpins diversity in animals and contributes to the functional performance of ecosystems, their resilience when the environment changes, and the provision of ecosystem services (Cardinale and all, 2012).

Here, we find that the alpha diversity of plants has, on average, been increasing in regions of the world where the climate has been changing the most. Insofar as the sites and climates we analyze here are globally representative, this implies that the Earth's (changed and changing) Anthropocene climate can support higher levels of alpha diversity in plants than previously and/or terrestrial ecosystems that are in a state of transition associated with climate change tend to contain excesses rather than deficits of species. It is widely appreciated that many metrics of global biodiversity are declining , but quite how and why local alpha diversity is changing is still unclear. Major land use transitions may have been responsible for reducing local animal and plant diversity by a global average of approximately 13% over the last 500 years (Newbold et al,2015). However, human-associated disturbances and species introductions can, on occasion, increase local diversity .

Thus, some anthropogenic habitats support more species than the original vegetation , and longitudinal studies on timescales of a few decades typically find that local losses of species in some locations are balanced by species gains in others . There is agreement that local biological communities have been changing, but no consensus has yet emerged whether the processes that are contributing to local increases in some locations are sufficient to offset losses elsewhere (cardinale et al ,2018).

We investigated the role of climate as a driver of local diversity change by using Vellend et al.'s database of locations (Figure 27A) where plant species richness (a) had been remeasured after an interval of at least 10 years (median duration 26 years), in plot sizes of 102 to 104 m2 (median size 25 m2). We used the estimates of local richness change for each site provided in the database, which were calculated by dividing the final measured species richness of each study by the initial measured species richness, before taking the natural logarithm of this number and subsequently dividing by the study duration (ln [SR final year/SR initial year] per decade).

We found that richness has increased the most (Figure 27E) in the ''cold'' and ''polar'' Ko¨ ppen (Köppen et al,1936) global climate regions (oneway ANOVA: $F(4,413) = 4.58$; $p = 0.001$), where rates of climate change were greatest (Figure 27D).

Considering climate and climate change as a number of continuous variables (as opposed to Ko¨ ppen regions), local plant species richness increased the most in the coldest parts of the world, and also where the climate had changed the most, such that local richness declined by a mean rate of 4.2% per decade (raw, exponentiated rate) in the third of sites (bottom tercile) that experienced the least precipitation change but increased by a mean of 10.8% per decade in sites with ''high'' (top tercile) rates of precipitation change. Local richness also declined by a mean rate of 2.8% per decade in sites that experienced the least temperature change (mean of bottom tercile), but increased by 9.1% per decade in sites with ''high'' (mean of top tercile) rates of temperature change.

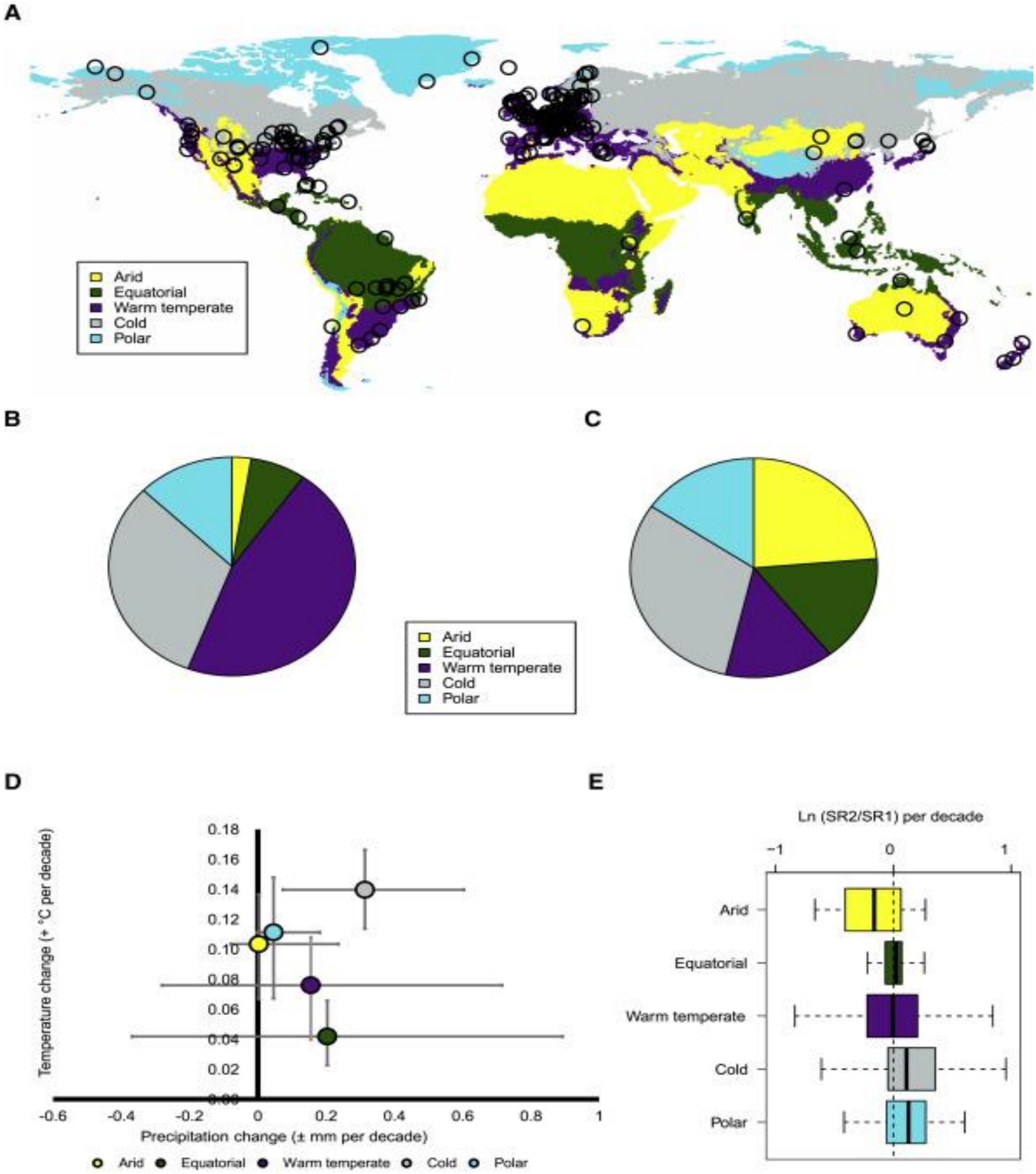


Figure 27. Climate and Climate Change at Study Sites Investigating Species Richness (α) Change

(A) The global distribution of the five major Köppen climate classifications overlain by Vellend et al. study sites.(B and C) The representation of these climate classifications in the Vellend et al. dataset (B) does not reflect the total proportion of the Earth's land surface they occupy (C; excludes Antarctica), with a particular bias toward the sampling of "warm temperate" sites.

(D and E) Median rates of climate warming have been higher in "cold" or "polar" zones (D), calculated for 1901–2013, with error bars extending to the 25^{th} and 75^{th} percentiles across 0.5° × 0.5° cells), where median richness has also increased (E; with hinges extending to the 25^{th} and 75^{th} percentiles). Because richness at warm temperate sites has shown the lowest rate of change (E), change in local diversity could be underestimated overall.

III.4.Biodiversity responses to climate change

Because of climate changes, species may no longer be adapted to the set of environmental conditions in a given region and could therefore fall outside its climatic niche. As other components of the ecological niche of species are not supposed to change directly, we will hereafter refer only to climatic niches of species (*i.e.*, the climatic components of the n-dimensional hypervolume *sensu* Hutchinson). In order to persist, individuals, populations or species must produce adaptive responses, which can be of several types, and are provided by two categories of mechanisms.

III.4.1.Response mechanisms: plastic versus genetic

One of the crucial questions in the debate on ecological effects of climate change is whether species will be able to adapt fast enough to keep up with the rapid pace of changing climate (Salamin *et al.* 2010).

Whatever the type of adaptive responses, underlying mechanisms are either due to micro-evolution (i.e., species can genetically adapt to new conditions through mutations or selection of existing genoty:Salamin *et al.* 2010; Olofsson *et al.* 2011) or plasticity, which provides a means of very short-term response (within individual's lifetimes, Charmantier *et al.* 2008).

It may involve intraspecific variation in morphological, physiological or behavioural traits, which can occur on different time scales within the populations' spatial range. Empirical evidence suggests that plastic contribution is often more important than genetic contribution, as observed in birds and marmots. On the other hand, there is increasing empirical evidence that evolution can be very rapid (Lavergne *et al.* 2010).

This is the case for many introduced species, for which selection-driven phenotypic changes have enhanced the invasive potential . Recent experiments on evolutionary rescue also confirm that rapid evolution through mutation and selection could allow species with rapid life cycles to adapt very severe and rapid environmental changes (Bell & Gonzalez 2009).

III.4.2.Responses: along three axes

Whatever the mechanisms involved in response to climate change, species can in theory change, and changes have already been observed, along three distinct but non-exclusive axes (Figure 28): spatial, temporal or self. The first two axes correspond to easily observable and well-documented responses to global warming . "Self" corresponds to less visible physiological and behavioural changes that allow species to adapt to the new climatic conditions in the same spatial and temporal frame.

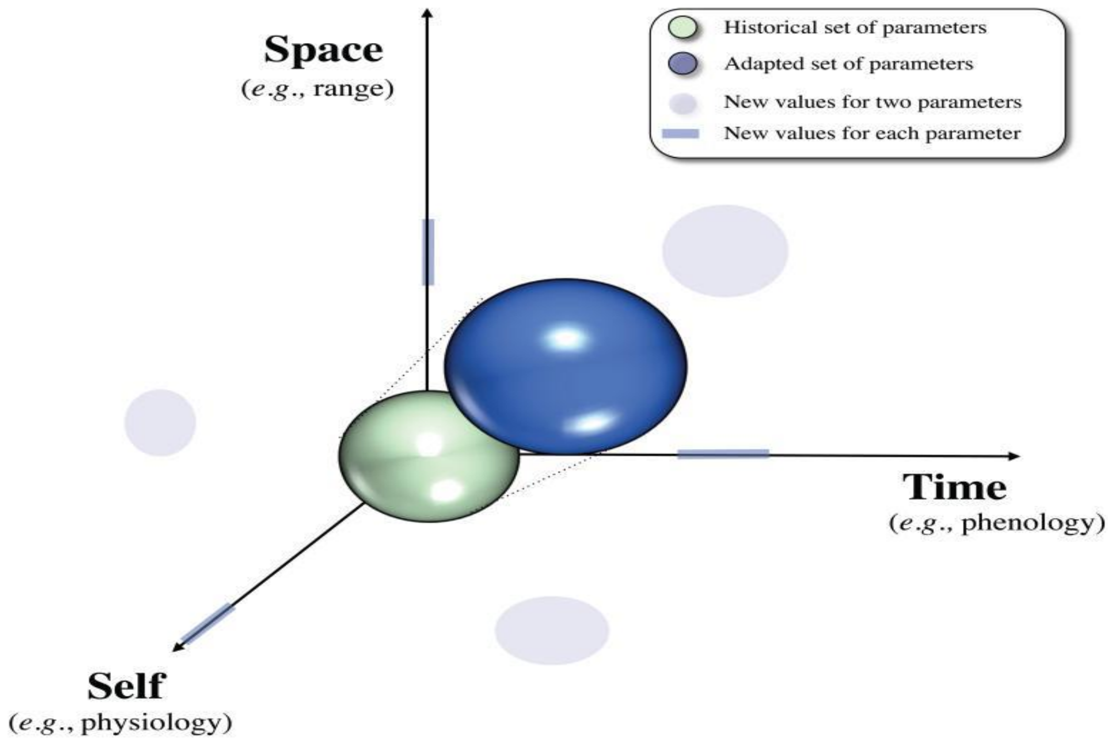


Figure 28. The three directions of responses to climate change through phenotypic plasticity or evolutionary responses : moving in space (dispersing to areas with suitable habitat or changing location on a microhabitat scale), shifting life history traits in time (adjusting life cycle events to match the new climatic conditions, including phenology and diurnal rhythms), or changing life history traits in its physiology to cope with new climatic conditions. Species can cope with climate change by shifting along one or several of these three axes.

- **Spatial**

First, species can track appropriate conditions in space and follow them. This is typically done through dispersion, but spatial changes are not limited to this: shifts to a different habitat at the local or micro-habitat levels are also relevant. One of the best-documented responses – from both paleontological records and recent observations - is a spatial shift of species tracking suitable climatic conditions at the regional scale. Latitudinal and altitudinal range shifts have already been observed in more than 1,000 species – especially those with high dispersal capacities like birds, insects and marine invertebrates , leading to a reduction in range size particularly in polar and mountaintop species (Forero-Medina 2010).

However, individuals shift their distribution in order to stay in quasi-equilibrium with the climatic conditions they are adapted to, but they may not be adapted to other abiotic variables such as photoperiod or novel biotic interactions (Visser 2008). In these cases, micro-evolution may be needed for them to persist (Visser 2008).

- **Temporal**

In order to keep up with changing abiotic factors that show cyclic variation over time, such as temperature on a daily or yearly period, individuals can also respond to climate change through a shift in time (on a daily to seasonal basis). Phenology, *i.e.*, the timing of life cycle events such as flowering, fruiting and seasonal migrations, is one of the most ubiquitous responses to 20th century climate warming. It has already been documented in many species (Charmantier *et al.* 2008).

In a meta-analysis of a wide range of species including animals and plants, the mean response across all species responding to climate change was a shift in key phenological events of 5.1 days earlier per decade over the last 50 years. Flowering has advanced by more than 10 days per decade in some species (Parmesan 2006). These phenological changes can help species keep synchrony with cyclical abiotic factors. Yet, they can also be disruptive, by increasing asynchrony in predator-prey and insect-plant systems (Parmesan 2006), which may lead to species extinction. Temporal shifts may also occur at a small temporal scale, *e.g.* with activity patterns adjusted in daily activity rhythms, or behaviours adjusted in length to match changes to costs due to a different climatic condition.

- **Self**

Last, species can cope with changing climatic conditions by adapting themselves to the new conditions in their local range, rather than by tracking their current optimal conditions in space or time. For lack of a better term, we refer to these *in situ* changes that are not related to spatial or temporal changes, as changes in “self”. Species can move along this third, “self” axis by physiological alterations that allow tolerance to warmer or drier conditions or by behavioural modifications of their diet, activity and energy budget, for example. Although they are often less obvious than changes in time or space, some physiological responses have already been reported during the 20th century climate change, especially from many ectotherms, as their locomotion, growth, reproduction and sex determination are temperature sensitive (Tewksbury *et al.* 2008).

However, for many traits, plastic phenotypic responses should reach a physiological limit and 'saturate' in extreme environments. For example, body size or metabolic rate cannot increase or decrease indefinitely under sustained environmental change (Chevin *et al.* 2010). In this case, strong selection is needed to cope with climate change. As they remain in the same spatial and temporal frame, thereby limiting alterations of interspecific relationships, changes in self also have different consequences for ecosystem responses than do changes in time and space.

III.5. Assessing the future of global biodiversity

Our understanding of the effects of global climate change on biodiversity and its different levels of response is still insufficiently well developed. Yet, it is enough to raise serious concern for the future of biodiversity. The most pressing issue is to quantitatively assess the prospects for biological diversity in the face of global climate change. Although several methods exist to draw inferences, starting with existing paleontological or recent data, experiments, observations, and meta-analyses (e.g., Lepetz *et al.* 2009), ecological modelling is the most commonly used tool for predictive studies.

Progress in this field is characterised by both an extremely high pace and a plurality of approaches. In particular, there are three main approaches to projecting species loss, concentrating either on future changes in species range or species extinction or changes in species abundance. However, all three modelling approaches have so far largely focused on one axis of response (change in space), largely overlooking the importance of the other aspects. In addition, they seldom account for the mechanisms of these responses (plasticity and evolution). We briefly discuss here the basic principles and the weakness of the models that are the most widely used at global or at large regional scales in this context, focusing on representative examples of recent work. Table 5 summarizes the specific advantages and limitation of each model type

Table 5. Advantages and disadvantages of the two components of major modelling approaches used to estimate loss of biodiversity due to climate change.

	Advantages	Disadvantages	Key references
Biodiversity range model component			
• Bioclimatic Envelope Models (BEM)	-can be applied to a large number of species and a variety of taxonomic groups - implicitly capture many ecological processes in the relationship between occurrence data and spatial information - require few data	- do not explicitly account for mechanisms that mediate species range - may handle novel climates poorly - lack temporal dynamics - assume that the current distribution of a species is a good indicator of favourable climate	(3, 5, 6, 11, 12, 15, 16, 17)
• Dynamic Vegetation Models (DVMs)	- include the dynamics of plant growth, competition and, in a few cases, migration - allow the identification of future trends in ecosystem function and structure - can be used to explore feedbacks between biosphere and atmospheric processes	- require detailed physiological data - do not include plant interactions with other taxonomic groups - limit biodiversity to a very small number of plant functional types. - do not take into account fine scale spatial heterogeneity - are not adapted for predicting species extinctions at local scales	(1, 4, 7, 17, 18, 19)
Species loss model component			
• Species Area Relationships (SAR)	- are easy to couple with distribution models because they are based on range or habitat loss - can be applied to a variety of taxonomic groups - require few data	- use values of key parameters that are not well constrained - lack empirical evidence concerning applicability of SAR for climate change or at species range level - lack temporal dynamics - don't account for processes influencing extinction rates (e.g., population dynamics, adaptive responses)	(3, 18, 20, 21)
• IUCN status methods	- use a widely accepted measure of threat - are simple to couple with distribution models because partly based on criteria of range or habitat loss	- depend on thresholds that are somewhat arbitrary - rely on sole criteria of declining range size in most studies - often don't respect time frame for declines (i.e., 10 years or 3 generations in most cases)	(3, 5, 22)
• Dose response relationships	- are anchored in measured responses of biodiversity to global change drivers - can assess the impact of a wide range of global change factors alone or their cumulative effects - can include time lags	- "undisturbed" ecosystems used as baseline are difficult to define - inadequately account for interactions between global change drivers. - lack validation at large regional or global scales - use metrics that are difficult to relate to common biodiversity indices	(7, 8)

III.6. Presentation of cases around the world (abridged)

Here's an abridged overview of five cases from around the world illustrating the impact of climate change on plant biodiversity:

1. Amazon Rainforest (South America)

- Impact: The Amazon is facing more frequent and severe droughts due to climate change, which has led to increased tree mortality. The loss of large, slow-growing trees reduces biodiversity and alters the forest structure. Invasive species and forest fires, exacerbated by changing climate conditions, further threaten the diversity of plant life in the region.

2. Alpine Regions (Europe)

- Impact: Alpine plants, adapted to cold environments, are highly sensitive to temperature changes. Warming temperatures in the European Alps are causing species to migrate to higher altitudes. However, as they reach the peaks, there is no higher ground to escape to, leading to a risk of extinction for these specialized species. The shift also disrupts the balance of alpine ecosystems, with lower-altitude species encroaching on traditional alpine habitats.

3. Great Barrier Reef (Australia)

- Impact: While primarily known for its marine biodiversity, the Great Barrier Reef's surrounding coastal ecosystems are also under threat. Rising sea levels and increased temperatures are affecting mangroves and seagrass beds, critical for maintaining plant biodiversity. Coral bleaching indirectly affects plant life by disrupting the entire marine ecosystem, altering nutrient flows that coastal plants depend on.

4. California Chaparral (North America)

- Impact: The chaparral biome in California is increasingly vulnerable to wildfires, which are becoming more frequent and intense due to climate change. Many native plant species in this region are fire-adapted, but the changing fire regimes are pushing some species to their limits. The loss of native shrubs and trees is being compounded by the invasion of non-native grasses, which thrive in the altered conditions and further suppress native plant recovery.

5. African Savannah (Africa)

- Impact: Climate change in the African savannah is leading to shifts in rainfall patterns, with some areas experiencing more prolonged dry seasons. This change impacts the growth and distribution of plant species that are crucial for both wildlife and human livelihoods. The loss of plant diversity affects the entire ecosystem, leading to a decline in species that depend on specific plants for food and habitat.

These cases highlight the global reach of climate change and its varied impacts on plant biodiversity, illustrating the urgency for mitigation and adaptation strategies to protect these ecosystems.

Chapiter IV. Climate Change in Algeria

IV.1. Climate Change in Algeria and its Impacts

Current rates of climate change have shown that the effects of global warming on temperatures in the Maghreb, specifically Algeria, are higher than the world average. Whereas the global temperature rise in the twentieth century was 0.74°C, it was somewhere between 1.5 and 2°C in the Maghreb, depending on the region; more than twice the global average rise.

Algeria is increasingly facing extreme climate events that have gradually increased its vulnerability. In addition, the recurring periods of drought, which have become longer, have exacerbated the desertification (NDC,2015) phenomenon. In fact, more than 50 million hectares are currently suffering from a very high level of desertification , where the rural population - consisting mainly of farmers and cattle breeders - are forced to migrate to large cities to ensure their survival. This situation is a direct cause of soil degradation and scarcity of water resources in those areas.

Recent analyzes of climate change have shown that its impacts are now being felt in the Mediterranean region and that it is increasingly leading to the recurrence of unusual and extreme weather events. The scientific community has considered these changes inevitable. In other words, global efforts to mitigate climate change can only partially reduce it. The average annual temperature rise in the Mediterranean region is about 1.5°C above pre-industrial levels (1880-1899) .

Current rates of climate change have shown that the effects of global warming on temperatures in the Maghreb, specifically Algeria, are higher than the world average. Whereas the world temperature rise in the twentieth century was 0.74°C, it was between 1.5 and 2°C in the Maghreb, depending on the region - more than twice the global average rise .(NCP,2020).

Moreover, the precipitation decrease ranges between 10 and 20% . Thus, Algeria ranked 11th in the world in terms of temperature rise, with an average temperature of about 33°C (Sakhri,2016).

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IV.2. The impact of climate change on the different bioclimatic levels in Algeria

Algeria, a country with diverse bioclimatic regions ranging from coastal Mediterranean areas to arid Saharan zones, is significantly affected by climate change. Each bioclimatic level experiences distinct impacts due to varying climatic conditions. Here's a detailed look at how climate change affects different bioclimatic zones in Algeria:

1. Coastal and Sub-Humid Zones (Northern Algeria)

- **Climate Characteristics**: These areas experience a Mediterranean climate with wet, mild winters and hot, dry summers.
- **Impact**:
  - ➢ **Rising Temperatures**: Increasing temperatures lead to extended dry periods and more intense heatwaves, stressing plant species that are adapted to cooler, wetter conditions.
  - ➢ **Reduced Precipitation**: A decline in rainfall results in lower water availability, affecting agricultural productivity and reducing the diversity of native plant species.
  - ➢ **Sea Level Rise**: Coastal erosion and salinization of soils due to rising sea levels threaten coastal plant communities and agricultural lands.

2. Semi-Arid Zones (Central Algeria)

- **Climate Characteristics**: This region experiences moderate rainfall, which supports a mix of grasslands and shrublands.
- **Impact**:
  - ➢ **Desertification**: Climate change accelerates desertification, with the Sahara encroaching into semi-arid zones. This results in the loss of grasslands

and the replacement of diverse plant species with more drought-resistant but less diverse flora.

- **Water Scarcity**: Reduced rainfall and higher evaporation rates lead to water shortages, stressing both natural vegetation and agricultural crops. Theses further decreases plant biodiversity, as water-dependent species struggle to survive.

3. Arid Zones (Southern Algeria)

- **Climate Characteristics**: Characterized by extremely low rainfall and high temperatures, this region is part of the vast Sahara Desert.
- **Impact**:
  - **Intensified Drought**: Climate change exacerbates already harsh conditions, with longer and more intense droughts becoming the norm. This limits the growth of even the most drought-tolerant plants, reducing overall biodiversity.
  - **Shifting Sand Dunes**: Increased wind activity, combined with a lack of vegetation, leads to more mobile sand dunes, which can bury and destroy plant life. This further reduces plant diversity and alters the landscape.
  - **Oasis Degradation**: Oases, crucial for supporting plant and animal life in the desert, are under threat due to reduced water availability and increased salinity, leading to the decline of unique plant species that thrive in these microhabitats.

4. Saharan Zones (Far Southern Algeria)

- **Climate Characteristics**: Extremely arid, with minimal precipitation and extreme temperature fluctuations between day and night.
- **Impact**:
  - **Increased Aridity**: Even small changes in temperature or precipitation can have drastic effects on this fragile ecosystem. The already scarce vegetation, such as date palms and acacia trees, faces further stress, leading to potential local extinctions.
  - **Loss of Traditional Agriculture**: The few areas suitable for agriculture, primarily around oases, are becoming less viable as water resources dwindle. This not only impacts food security but also reduces the plant diversity that has traditionally been cultivated in these areas.

- **Biodiversity Hotspots**: Unique microhabitats in the Sahara, such as rocky outcrops and wadis (dry riverbeds), may lose their specialized plant species due to climate change, leading to a significant loss of biodiversity.

5. High Plateau Regions

- **Climate Characteristics**: Located between the coastal mountains and the Sahara, these regions have a steppe-like climate, with cold winters and hot summers.
- **Impact**:
  - **Changing Vegetation Patterns**: The steppe regions are seeing shifts in vegetation, with grasslands being replaced by more drought-resistant shrubs and hardy species. This shift reduces the diversity of plant life and affects the animals that depend on specific plants for food.
  - **Soil Degradation**: Increased aridity leads to soil erosion and degradation, making it harder for plants to establish and grow. This, in turn, leads to a decline in plant biodiversity and alters the ecosystem balance.

Climate change in Algeria is having profound effects across all bioclimatic levels, with significant implications for plant biodiversity. From coastal zones to the heart of the Sahara, each region faces unique challenges that threaten the delicate balance of these ecosystems. Understanding and addressing these impacts are crucial for preserving Algeria's rich biodiversity in the face of ongoing climate change.

IV.3. The impact of climate change on spontaneous vegetation (arid and Saharan) in Algeria

Sahara Desert is an extremely arid zone characterized by very harsh climatic conditions that render plant species spontaneous survival very restrictive . In comparison to the limited number of species that inhabit this desert and the immensity of its surface, Saharan flora life tends to be very low. Despite this floristic poverty, Saharan plants species are still of great importance among medicinal plants. Many researchers have confirmed the effectiveness of extracts from Algerian Saharan plant species in several fields such as pharmacy and agriculture (biopesticide) about a number of plant species from the northern Sahara of Algeria. (Dehliz et al., 2018, 2020).

The impact of climate change on spontaneous vegetation in the arid and Saharan regions of Algeria is significant, with several examples highlighting these effects:

- **Reduction in Vegetation Cover**

  The arid regions of Algeria, including the vast Sahara, have experienced a notable decline in vegetation cover. This reduction is largely due to prolonged droughts and increasing temperatures. For example, the spontaneous vegetation in regions like the Hoggar Mountains and the Tassili n'Ajjer has diminished, as species that once thrived in these areas struggle to survive under harsher climatic conditions. The Sahara Desert itself has been expanding, encroaching on areas that once supported more diverse vegetation.

- **Shift in Species Composition**

  Climate change has caused a shift in the types of vegetation that can survive in these regions. In Algeria’s arid zones, drought-resistant species such as *Aristida pungens* (a type of grass) are becoming more dominant, replacing less resilient plants. The hardy *Acacia raddiana*, once more widespread, is now retreating to even more isolated pockets due to reduced water availability. This shift is altering the ecosystem balance and impacting species that rely on the displaced vegetation for habitat and food.

- **Degradation of Habitats**

  The degradation of plant habitats is another critical issue. In the Saharan oases, where spontaneous vegetation like palm groves used to flourish, the combination of decreasing groundwater levels and higher temperatures has led to a reduction in both the number and vitality of these plants. The Beni Abbes oasis, for instance, has seen its palm groves dwindle due to water scarcity exacerbated by climate change.

These examples underscore the fragile nature of spontaneous vegetation in Algeria’s arid and Saharan regions, as well as the urgent need for sustainable management practices to mitigate the ongoing impacts of climate change.

IV.3.1. Some detailed examples of how specific plants are being impactedw

1. Acacia raddiana (Saharan Acacia)

- **Impact**: Acacia raddiana (Fig.29), a key species in the Saharan and pre-Saharan ecosystems, is highly adapted to arid conditions. However, increasing temperatures and decreasing precipitation have led to a decline in its population. The tree's ability to survive is being compromised by prolonged droughts, which reduce water availability, making it difficult for young seedlings to establish.

- **Example**: In regions like the Hoggar Mountains, these trees are becoming less common, with older trees dying off and fewer new trees growing to replace them. This decline impacts not only the vegetation itself but also the wildlife that depends on these trees for shade and food.

Figure 29: *Acacia raddiana*

https://greeningisrael.com/portfolio/acacia-raddiana/

2. *Aristida pungens* (Drinn Grass)

- **Impact**: Aristida pungens (Fig.30), a hardy grass species common in Algeria's arid regions, is showing resilience to changing climatic conditions. This species is known for its ability to thrive in extremely dry environments, and as such, it is becoming more dominant as other, less resilient species decline.
- **Example**: In the M'zab region, the dominance of Aristida pungens is increasing as other grasses and shrubs fail to compete in the increasingly arid conditions. While this may suggest a level of adaptation, it also indicates a loss of biodiversity as more diverse plant communities are replaced by a few drought-resistant species.

Figure 30: *Aristida pungens.*

https://atlas-sahara.org/Poaceae/Stipagrostis%20pungens/Stipagrostis%20pungens.html?cat=Poaceae

3. *Tamarix aphylla* (Athel Tamarisk)

- **Impact**: The Athel Tamarisk (Fig.31), is another plant that has traditionally been a part of Algeria’s arid landscapes, particularly around oases. Climate change, however, has caused shifts in water availability that are threatening these plants. Reduced groundwater levels, combined with higher temperatures, are leading to stress and decline in Tamarisk populations.
- **Example**: In the oases of the northern Sahara, where Tamarix aphylla has historically thrived, the plants are showing signs of water stress, such as reduced growth and dieback of branches. This is particularly evident in the Beni Abbes oasis, where changes in water dynamics are leading to a reduction in these critical species.

Figure 31 : *Tamarix aphylla*

https://atlas-sahara.org/Tamaricaceae/Tamarix%20aphylla/Tamarix%20aphylla.html?cat=Tamaricaceae

4. *Ziziphus lotus* (Jujube)

- **Impact**: Ziziphus lotus (Fig.32), a thorny shrub common in arid and semi-arid areas, is also being affected by climate change. This plant is crucial for stabilizing soil and providing habitat in desert environments. However, increased temperatures and decreased rainfall are affecting its growth and reproductive success.
- **Example**: In the semi-arid regions of Algeria, such as the area surrounding the Saharan Atlas, Ziziphus lotus is becoming less common, with lower seedling survival rates due to harsher climatic conditions. This decline is reducing the plant's role in preventing desertification and supporting local wildlife.

Figure 32: ***Ziziphus lotus***

These examples illustrate how climate change is not only altering the overall vegetation cover in Algeria's arid and Saharan regions but also shifting the composition of species, with potential long-term consequences for the entire ecosystem.

IV.4. Climate change and phoeniciculture

Algeria, one of the potential date producers in the world, is exposed to the different impacts of global warming. This climatic phenomenon probably has repercussions on date palm cultivation.

According to the FAOSTAT website (2020), in 2019, the total global area occupied by productive date palms was 1,381,434 hectares, with a production of 9,075,446 tons (Fig. 33), resulting in a yield of 6,569.6 kg/ha. During the same year, Algeria produced 1,136,025 tons of dates, with a yield exceeding the global average (6,679.3 kg/ha). The area of agricultural land occupied by date palms in Algeria has shown an upward trend since the early 2000s, reaching

170,082 hectares in 2019 , placing it second globally (behind Iraq). It holds the third position in terms of production, following Egypt and Saudi Arabia.
Date palm production in Algeria is expected to increase in the coming years, with the entry into production of young palms cultivated or to be planted in newly developed lands..(Faci,2021)

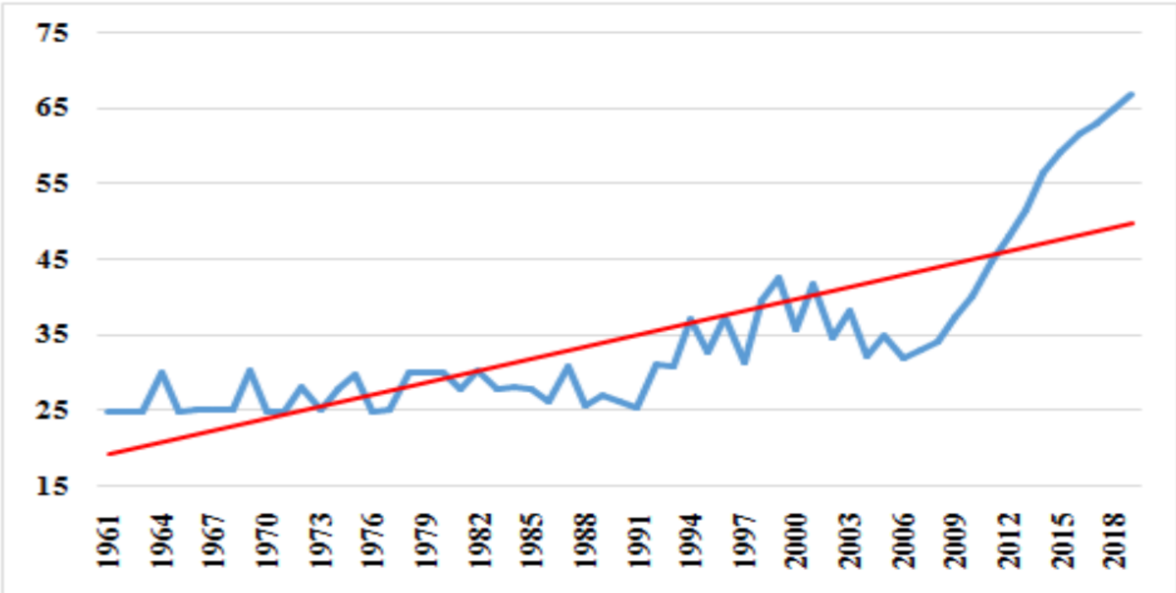

Figure 33: Evolution of date yields in Algeria (in tons/ha) between 1961-2019 (trend line in red). (Source: FAOSTAT, 2020)

However, palm oil farming encounters difficulties in its operation, especially in the production, marketing and environmental segments. According to Faci (2021), the average yield per palm tree remains low due to several constraints, particularly those related to climate change. Indeed, the hypothesis of a major climate disruption is now established with certainty (90%).
Climate change has significant effects on date palm cultivation in Algeria. Several key impacts include:

IV.4.1. effects on varietal diversity

The effects of climate change on the varietal diversity of phoeniciculture (date palm cultivation) in Algeria have been increasingly observed, with significant impacts on both the growth conditions and the genetic diversity of this essential crop.

- **Key Effects**

1. **Temperature Increase**:

- ➢ **Heat Stress**: Rising temperatures are causing heat stress on date palms, which can reduce their overall productivity and affect the quality of the fruits. Some varieties that are not well adapted to high temperatures may suffer more, leading to a decrease in their prevalence.
- ➢ **Flowering and Fruiting Cycles**: Higher temperatures can alter the timing of flowering and fruiting, which can affect the synchronization between male and female trees, leading to lower pollination success and reduced fruit set.

2. **Water Scarcity**:
   - ➢ **Drought Conditions**: Algeria is experiencing more frequent and severe droughts due to climate change, which limits water availability for irrigation. Date palms require substantial water, and reduced access can lead to lower yields and can stress the trees, making them more susceptible to diseases.
   - ➢ **Salinization**: In areas where groundwater is the primary source of irrigation, overuse can lead to salinization, which negatively impacts soil quality and can reduce the suitability of certain date palm varieties that are less tolerant of saline conditions.
3. **Pests and Diseases**:
   - ➢ **Increased Pest Pressure**: Warmer temperatures and changing humidity levels can increase the prevalence of pests such as the Red Palm Weevil and diseases like Fusarium wilt, which can disproportionately affect certain varieties of date palms.
   - ➢ **Spread of Diseases**: Climate change can facilitate the spread of diseases to new areas, threatening the diversity of date palm varieties that are not resistant to these pathogens.
4. **Impact on Genetic Diversity**:
   - ➢ **Loss of Traditional Varieties**: As farmers increasingly favor high-yielding or climate-resilient varieties, traditional and locally adapted varieties may be abandoned, leading to a reduction in genetic diversity. This loss of diversity can make the entire phoeniciculture sector more vulnerable to future environmental changes.

- **Shift in Cultivation Zones**: Climate change may force the relocation of date palm cultivation to more favorable areas, which could lead to a reduction in the range of varieties that are traditionally grown in certain regions.

5. **Socioeconomic Impacts**:
   - **Livelihoods**: Many communities in Algeria rely on date palm cultivation for their livelihoods. The decline in certain varieties due to climate change could have serious socioeconomic consequences, particularly in regions where specific varieties have cultural and economic significance.

- **Adaptation Strategies**

To mitigate these impacts, strategies such as the development of climate-resilient date palm varieties, improved water management practices, and the conservation of traditional varieties through seed banks and in situ conservation are crucial. Additionally, raising awareness among farmers and supporting research into the effects of climate change on phoeniciculture are essential steps in preserving this vital agricultural sector.
Algeria, being one of the world's leading producers of dates, must address these challenges to maintain both the productivity and diversity of its date palms in the face of climate change.

IV.4.2. Effects on the biological cycle

The effects of climate change on the biological cycle of phoeniciculture (date palm cultivation) in Algeria are becoming increasingly evident, impacting various stages of the growth and development of date palms. These effects can disrupt the normal biological cycle, affecting productivity, fruit quality, and overall plant health.

- **Key Effects on the Biological Cycle**

1. **Alteration of Growth Phases**:
   - **Vegetative Growth**: Rising temperatures can extend the vegetative growth phase of date palms, potentially delaying the onset of flowering. This can lead to asynchronous flowering between male and female plants, reducing the chances of successful pollination.
   - **Flowering Period**: Higher temperatures can shorten the flowering period, reducing the window for effective pollination. Additionally, extreme heat during the flowering phase can cause flower drop, leading to a decrease in fruit set.
2. **Impact on Pollination**:

- **Temperature Sensitivity**: Date palm pollination is highly sensitive to temperature changes. Ideal temperatures for pollination range between 25°C to 35°C. However, with increasing temperatures, pollination efficiency can decrease, particularly if temperatures exceed this range during the pollination period.
- **Pollinator Activity**: Insects and wind are primary pollinators for date palms. Climate change can alter the behavior and activity of pollinators, potentially reducing pollination success. Additionally, hotter and drier conditions can reduce the viability of pollen, further affecting pollination outcomes.

3. **Fruit Development**:
   - **Heat Stress**: Prolonged exposure to high temperatures can lead to heat stress in developing fruits, causing them to mature prematurely or unevenly. This can result in a reduction in fruit size, quality, and yield.
   - **Fruit Ripening**: Changes in temperature and humidity can accelerate the ripening process, which might lead to an uneven ripening of fruits on the same tree. This not only affects the uniformity of the harvest but can also reduce the commercial value of the dates.
4. **Water Requirements and Irrigation**:
   - **Increased Water Demand**: With rising temperatures, the water requirements of date palms increase. However, climate change has also led to reduced water availability in many parts of Algeria, creating a mismatch between water supply and demand. Insufficient water during key stages of the biological cycle, such as flowering and fruit development, can severely affect crop outcomes.
   - **Irrigation Timing**: Climate change can disrupt traditional irrigation schedules. Farmers may need to adjust irrigation timing and frequency to cope with changing weather patterns, but this can be challenging due to water scarcity and changing evaporation rates.
5. **Pest and Disease Dynamics**:
   - **Enhanced Pest Breeding**: Warmer temperatures can accelerate the breeding cycles of pests like the Red Palm Weevil, leading to more frequent infestations. This can disrupt the biological cycle of the date palms by damaging the trunk and affecting the overall health of the tree.

- **Disease Proliferation**: Climate change can also create more favorable conditions for the spread of diseases, particularly fungal pathogens that thrive in warmer and more humid environments. For example, Bayoud disease, caused by the fungus *Fusarium oxysporum*, can be exacerbated by changing climate conditions, affecting the life cycle of date palms.

6. **Impact on Harvest and Post-Harvest**:

   - **Harvest Timing**: The shift in the biological cycle due to climate change can alter the timing of the harvest. Farmers may need to adapt to earlier or later harvests, depending on how the growth cycle is affected. This can also impact post-harvest handling, as the storage conditions required to maintain fruit quality might change.
   - **Storage and Preservation**: With changes in the biological cycle and the timing of the harvest, traditional storage methods may no longer be as effective. Higher temperatures and altered humidity levels can lead to faster spoilage of harvested dates if not managed properly.

- **Adaptation Strategies**

To mitigate the impacts of climate change on the biological cycle of date palms, several adaptation strategies can be employed:

- **Breeding and Selection**: Developing and selecting heat-tolerant and drought-resistant varieties of date palms.
- **Improved Irrigation Techniques**: Implementing efficient irrigation systems, such as drip irrigation, to optimize water use and reduce wastage.
- **Integrated Pest Management**: Adopting integrated pest management (IPM) strategies to control pests and diseases more effectively in a changing climate.
- **Research and Monitoring**: Continuous research and monitoring of the impacts of climate change on the biological cycle of date palms are essential for developing targeted interventions and supporting farmers in adapting to new conditions.

Overall, climate change is posing significant challenges to the biological cycle of phoeniciculture in Algeria, necessitating adaptive measures to ensure the sustainability and productivity of this crucial crop.

Cold waves during the winter, and more precisely during the periods of appearance and opening of spathes and the period of pollination, can reduce the number of fertilized female spathes; things that will produce parthenocarpic fruits and that will subsequently fall or give small, dried fruits, called “Siche”. Whereas the heat waves of the month of September, which coincide with the stage of maturity, cause the drying of the fruits, in a partial way (the head of the fruit) or total.

In addition, heavy precipitation, in intensity and/or duration, at the time of flowering causes the rot of the spathes, while during the stage of development of the fruits and the stage of maturity, they cause either the fall or the rot (Khamaj) of the fruits.(Faci,2021)

IV.4.3. effects on pathologies

Climate change is having profound effects on agriculture worldwide, and phoeniciculture (the cultivation of date palms) in Algeria is no exception. The primary pathologies affecting date palms, such as Fusarium wilt (Bayoud disease), red palm weevil infestations, and other pests and diseases, are being influenced by changing climatic conditions. (Sedra,2020). Here’s a detailed overview (Fig.34)

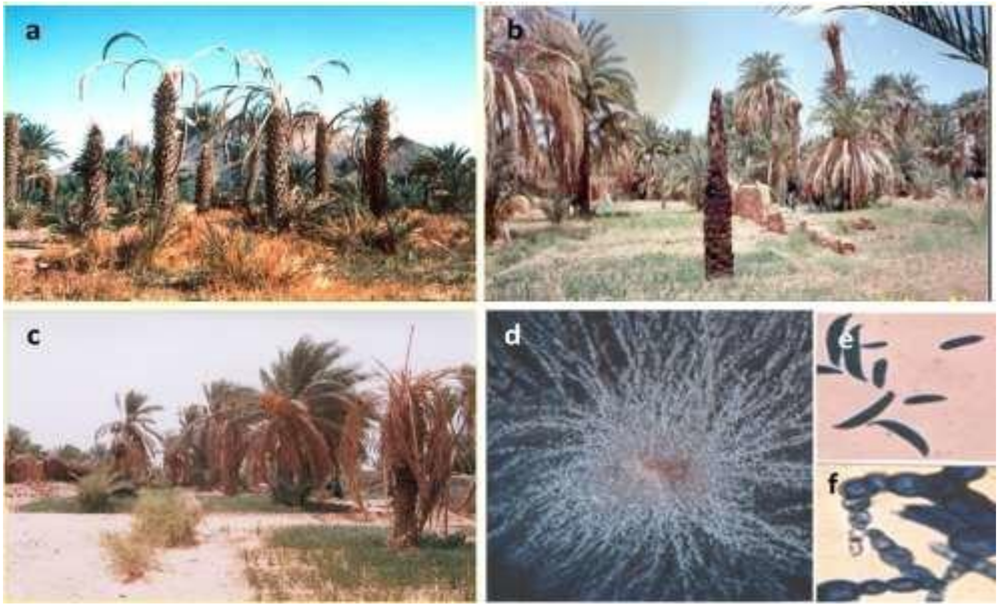

Figure 34: Bayoud disease focus indicating destroyed palm orchard in Morocco (a), Algeria (b) and Mauritania (c), cultural aspect of the fungus colony (d), microconidia and macroconidia (e), and chlamydospores (f) of causal agent Fusarium oxysporum f. sp. albedinis Kill. & Maire.Sources of all photos: Sedra My.H. 2020

1. Temperature Increases

- **Heat Stress**: Rising temperatures, particularly during summer, can cause heat stress in date palms, leading to reduced photosynthesis, impaired growth, and lower fruit quality. High temperatures can also affect the pollination process, reducing the overall yield.

- **Prolonged Drought**: Algeria, like much of North Africa, is experiencing increased drought frequency and severity. Date palms are naturally drought-resistant, but prolonged periods without sufficient water can weaken trees, making them more susceptible to diseases like Fusarium wilt and increasing mortality rates.

2. Increased Disease Incidence

- **Fusarium Wilt (Bayoud Disease)**: Fusarium oxysporum f.sp. albedinis, the causative agent of Bayoud disease, thrives in warmer and drier conditions. Climate change could expand the range of this pathogen, leading to more widespread outbreaks. The disease, which causes wilting and death of palms, remains one of the most significant threats to phoeniciculture in Algeria.
- **Red Palm Weevil**: The red palm weevil (Rhynchophorus ferrugineus) is a pest that has been spreading due to warmer temperatures. The weevil lays eggs inside the date palm, and the larvae feed on the palm tissue, leading to the tree's collapse. Warmer winters allow the weevil to survive in regions where it was previously unable to, increasing the risk of infestations.

3. Altered Rainfall Patterns

- **Erratic Rainfall**: Changes in rainfall patterns, including more frequent heavy rain events and prolonged dry spells, can lead to water stress or waterlogging. Both conditions are detrimental to date palm health, leading to increased susceptibility to diseases like root rot and other fungal infections.
- **Flooding**: In some regions, heavy rains can cause flooding, which can lead to soil erosion and root rot, weakening the date palms and making them more vulnerable to diseases.

4. Shifts in Pests and Pathogen Distribution

- **Increased Pest Pressure**: With milder winters and warmer temperatures, pests that affect date palms, such as the lesser date moth (Batrachedra amydraula) and scale insects, are likely to expand their range and become more prevalent. This can lead to increased damage to date palms and potentially lower yields.

- **New Pathogens**: Climate change may also lead to the introduction of new pathogens that were previously not a threat in Algeria. These could include fungal, bacterial, or viral pathogens that date palms have little resistance against.

5. Impact on Date Palm Varieties

- **Varietal Susceptibility**: Different varieties of date palms may respond differently to climate change. Some may be more resistant to heat and drought, while others may be more susceptible to diseases exacerbated by climate change. This could lead to a shift in the types of date palms cultivated, with a preference for more resilient varieties.

6. Socio-Economic Impacts

- **Reduced Yields and Quality**: The combined effects of climate change on date palm health are likely to result in reduced yields and fruit quality. This can have significant socio-economic impacts in Algeria, where phoeniciculture is an important agricultural sector.
- **Increased Costs**: Farmers may need to invest more in pest and disease management, irrigation, and other adaptive measures to cope with the effects of climate change, leading to increased production costs.

7. Adaptation Strategies

To mitigate these effects, Algeria may need to adopt several adaptation strategies:

- **Breeding and Selection**: Developing and promoting climate-resilient date palm varieties.
- **Improved Irrigation Techniques**: Efficient water management practices to cope with drought and erratic rainfall.
- **Integrated Pest Management (IPM)**: Combining biological, cultural, and chemical control methods to manage pests and diseases in a sustainable manner.
- **Research and Monitoring**: Continuous research and monitoring to track the effects of climate change on phoeniciculture and to develop new strategies to combat emerging threats.

In conclusion, climate change poses significant challenges to phoeniciculture in Algeria, affecting the health and productivity of date palms. Addressing these challenges will require a combination of traditional knowledge and modern agricultural practices to ensure the sustainability of this vital sector.

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