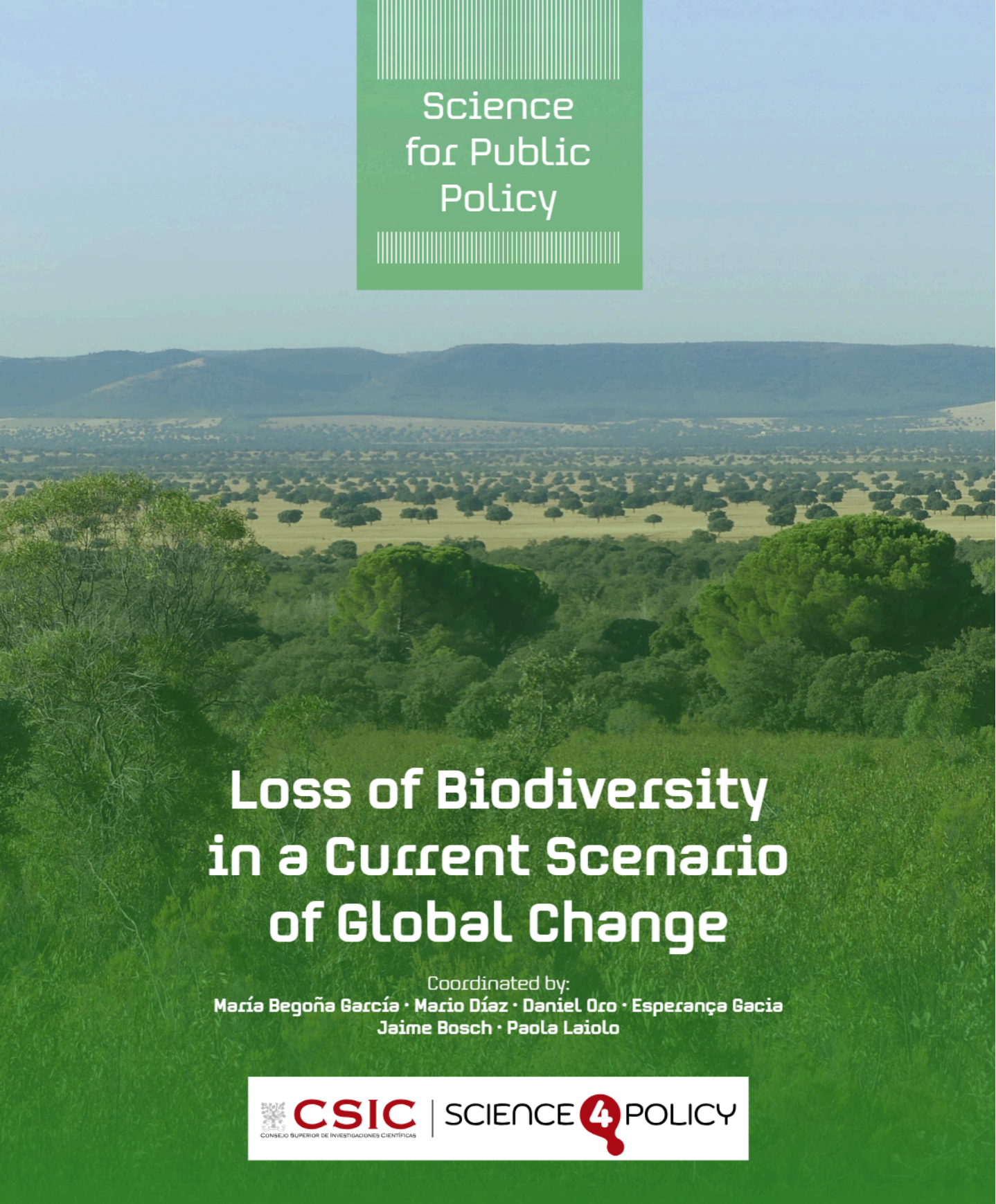




Science
for Public
Policy

Loss of Biodiversity in a Current Scenario of Global Change

Coordinated by:

**María Begoña García • Mario Díaz • Daniel Oro • Esperança Gacia
Jaime Bosch • Paola Laiolo**



CSIC
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

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Science for Public Policy



Knowledge Transfer
Report



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Publications Catalogue of the General State Administration:
<https://cpage.mpr.gob.es>

EDITORIAL CSIC: <http://editorial.csic.es> (email: publ@csic.es)



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NIPO: 155-25-214-X

e-NIPO: 155-25-215-5

Depósito Legal: M-25565-2025

Non-commercial edition

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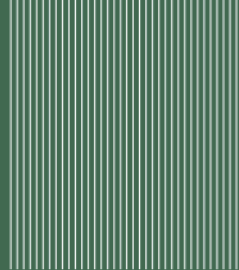
How to cite this report: García, M. B., Díaz, M., Oro, D., Gacia, E., Martín, D., Bosch, J., & Laiolo, P. (Coord.). (2025). *Loss of Biodiversity in a Current Scenario of Global Change*. CSIC.

Printed in Spain

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ONE of the CSIC's functions is to inform, assist and advise public and private entities on science and technology, as stated in article 5 of its Articles of Association. As part of this function, the report *Loss of Biodiversity in the Current Scenario of Global Change* is presented as a document aimed at administrations and society in general. It analyses the complexity and social importance of biodiversity for life on earth, as well as the main causes and consequences of its loss over the years. This work also outlines some of the main lines of action being carried out by the CSIC to address this issue at the national level in relation to long-term conservation, legislation and land use planning, and scientific assessment activities to reverse certain trends. It also includes the institution's main contributions to major international policy lines, especially at the European level.

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M. DÍAZ

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Definitions, Societal Importance, and Key Dimensions of the Issue

11.

Key concepts

THE word *biodiversity* often conjures up pristine landscapes, with flowers, butterflies, the sounds of birds, lush forests, sparkling streams... images that are becoming increasingly rare and more distant from cities, where most of the world's population is concentrated. Biodiversity, however, is something much more varied and complex, found everywhere, from the atmosphere to several kilometres deep in the oceans or in the rocks, as well as in the centre of large cities. Biological diversity is thus the variety of life on Earth: genetic variety, which makes all individuals in a population and all populations different; the variety of species, ranging from micro-organisms to large mammals or trees; and the variety of habitats and ecosystems that cover the entire planet.

Figure 1 The three levels of biodiversity



Source: Compiled from Primack, R. B. (1993).
Essentials of conservation biology. Sinauer.

Beyond being the sole source of food and other material goods, biodiversity provides, for free, other **vital ecosystem services**, such as air and water purification, climate regulation, protection against the transmission of diseases from wild animals to humans (zoonoses), and plays a fundamental role in mental health and spiritual development. Early estimates of its value suggested figures of three times the value of the world's entire commercial production, although there is as yet no unanimously accepted system for rigorous comparison. What is clear is that its loss is of enormous human significance. Understanding and conserving it, and halting its deterioration and loss in an increasingly human-altered world, is therefore an absolutely vital objective because of the significant implications for both the overall health of the planet and for human survival and physical and mental well-being.

The complexity of biodiversity is the result of the evolution of life and the way in which the resources of a changing environment have been efficiently exploited over millions of years. This long process has generated a spectrum of multiple life forms. But, as these have emerged, they have also been lost through genetic erosion, the disappearance of populations, the extinction of species or the transformation of habitats. In general, the changes experienced have been slow over the course of Earth's history, with more rapid episodes of mass extinction associated with geological catastrophes, such as volcanic eruptions or the impact of large meteorites, or accelerated processes of species formation resulting from the emergence of new ecological opportunities. Due to the numerous environmental modifications that our planet has undergone, about 98% of the species that have inhabited it (not only the dinosaurs) have disappeared and have been replaced by others. Sadly, we are far from such replacements in the current moment of biodiversity crisis, considered as **the sixth extinction**, because the big difference with the previous five is the enormous speed at which it is happening. The other big difference is the cause of the crisis: human activity.

Figure 2 Evolution of ideas regarding the need to conserve nature

Source: Compiled from Mace, G. M. (2014). Whose conservation? *Science*, 345, 1558-1560.

Biodiversity is highly varied and complex. It includes not only the species we can see, but also the microscopic organisms that live in the air, soil, water and inside other organisms like ours (hidden biodiversity) and whose activity is crucial for maintaining species and ecosystems. Genetic diversity is inside all of them, responsible for making each being slightly different from the rest of the same species. This genetic diversity means that, during a bad year or in the face of a pest, some have advantages over others, for example in terms of reproduction or survival. This is why populations in which individuals vary have a much better long-term future than those whose members are very similar to each other, as in monocultures optimised by the agri-food industry for a single type of environment. Moreover, the genetic diversity of a population is greater if it is made up of many individuals, so that small populations are less able to cope with change than large ones.

On the other hand, living things are not static as in a museum, but constantly interact to survive and reproduce, and species often hybridise, a phenomenon that in some cases allows the development of adaptations to new environmental conditions. Plants, animals, and bacteria naturally interact in intricate **biological networks** involving processes ranging from fierce competition, parasitism or predation to mutual collaboration (e.g. pollination of plants by animals or the action of many of the bacteria that inhabit our bodies). Such networks tend to be stable after slow adjustments at each site, but destabilise in response to external disturbances, such as the entry of invasive species, persistent drought, or overexploitation of forests or fisheries. Similarly, the loss of a single species in an ecosystem may be of little ecological significance if another species takes over its function; hence ecosystems with higher biodiversity tend to be more stable and resilient. However, there are also some irreplaceable species whose extinction can have a cascading effect on the extinction of the species that depend on them.



Lake Plan in Aiguestortes National Park and Lake San Maurici, a place where the LIFE ResqueAlpyr project is carrying out ecological restoration actions.
/ E. BALLESTEROS



Some ecosystem services of biological diversity

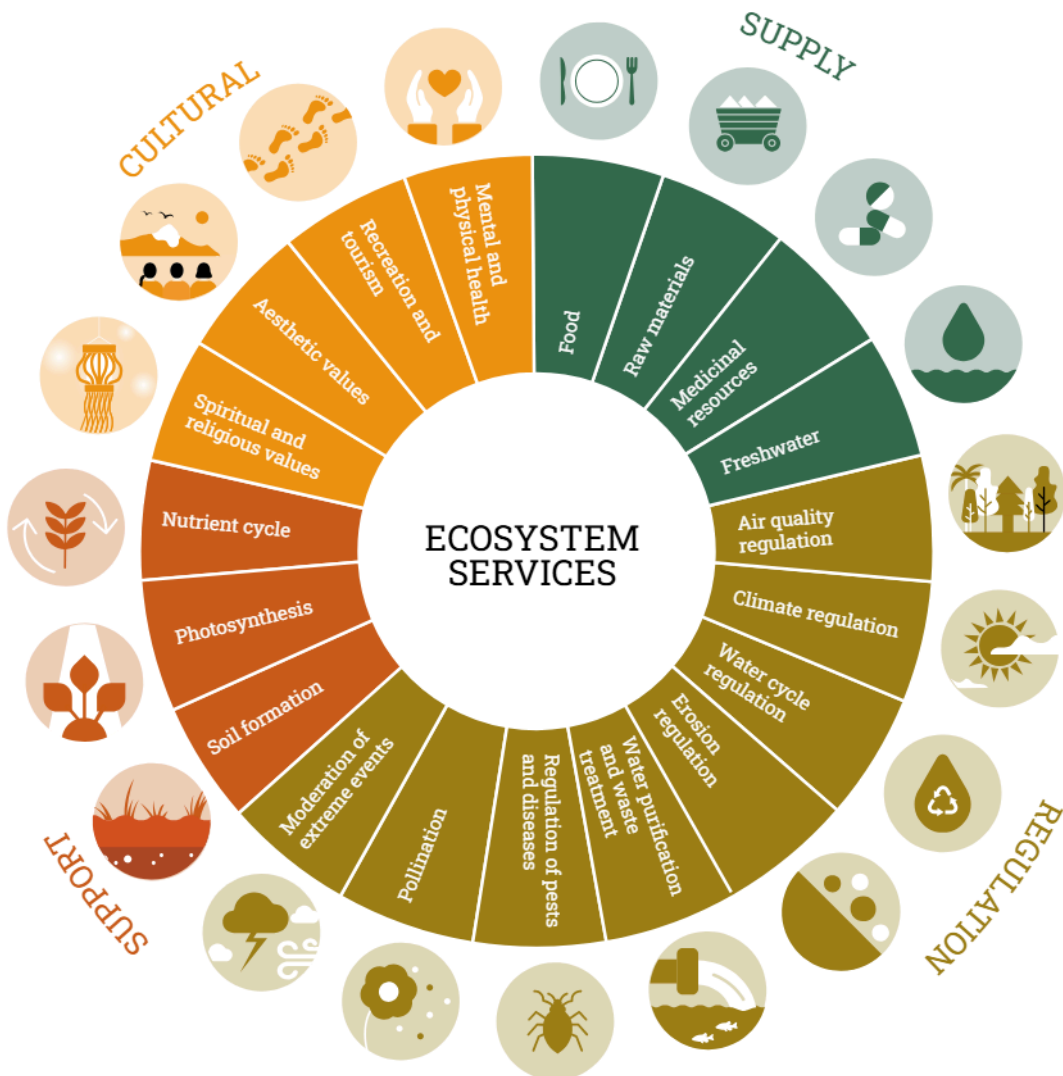
Food production. All the food we use has its origin in nature and its biodiversity. We have learned to domesticate species without which we would not survive, but we also depend on a multitude of non-domesticated organisms, such as many fish or the insects responsible for pollination. Without them we cannot guarantee food security. Maintaining the diversity of local ancestral varieties is essential for the genetic improvement of current foods, for their adaptation to future environmental conditions and for reducing the likelihood of diseases and pests. The survival of local human communities and their cultural heritage depend directly on biodiversity.

Human health. The active ingredients of many medicines come from naturally occurring plants, animals and micro-organisms. The loss of biodiversity can affect the ability to find new cures and medical treatments. In addition, we have learned from the recent COVID-19 pandemic that disruption of natural ecosystems may be behind emerging diseases and that those with high biodiversity act as firewalls in the potential transmission of pathogens between animals and humans [zoonoses].

Climate regulation. Vegetation cools environmental temperatures and regulates evapotranspiration (moisture loss). Mature tree forests, wetlands, angiosperm seagrass meadows (especially *Posidonia oceanica*, endemic to the Mediterranean) and macroalgae forests act as carbon sinks. They fix CO₂ that accumulates in undecomposed soils and sediments, and help mitigate climate change. In cities, the presence of trees and vegetation helps moderate extreme temperatures in heat waves.

Ecosystem stability and resilience. Scientific evidence has corroborated the stabilising role of biodiversity in the face of disturbances. It has been shown that simpler systems are more vulnerable than more complex ones. An example of this is represented by Mediterranean ecosystems, where fire has historically been a recurrent problem. In these ecosystems, some species such as holm oak and cork oak have developed adaptations that allow them to resist fire and coexist with fast-growing colonising plants that help post-fire regeneration. This diversity of ecological strategies promotes rapid recovery and maintains their long-term stability.

Figure 3 Ecosystem services



Source: WWF Living Planet Report, 2016



Some ecosystem services of biological diversity *(continuation)*

Leisure. Tourism is a huge driver of local and national development. The strong return to the enjoyment of nature after the recent pandemic boosts the economy. Tourists seek out well-preserved places with a rich biodiversity, such as national parks. The deterioration of these resources has a negative impact on the local and global economy.

Cultural and recreational value. Many communities depend on biodiversity for their traditions, spiritual practices and recreational activities. The loss of well-conserved species or environments can have a profound impact on their cultural identity. Programmes have also demonstrated the role of landscape in improving physical and mental health.

Ethics and intergenerational responsibility. Preserving biodiversity is a matter of ethics and responsibility towards future generations. As users, but also guardians of the planet, we are obliged to maintain biological diversity so that future generations can also enjoy the benefits it provides.

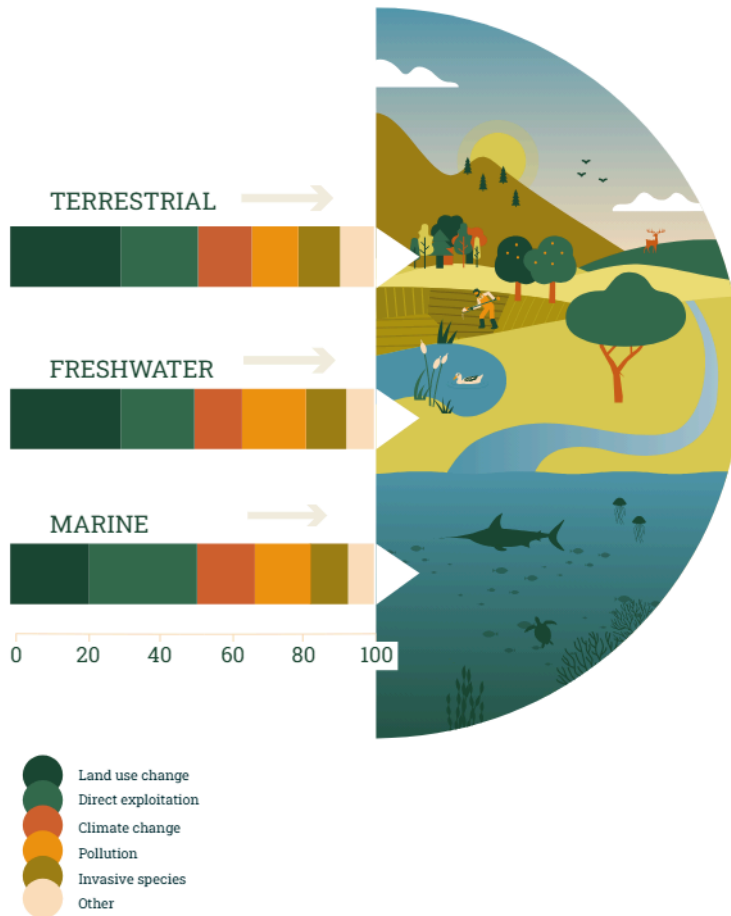
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Causes of biodiversity loss

SOME reports, such as those resulting from the Millennium Ecosystem Assessment (MA) or those of the Intergovernmental Platform for Biodiversity and Ecosystem Services (IPBES), list the drivers of **biodiversity loss and leave no doubt that the human footprint is the main cause of biodiversity loss**, especially since the Industrial Revolution. The global drivers of biodiversity loss are mostly well known and are usually grouped into five broad types: habitat loss or deterioration, introduction of alien species, overexploitation, pollution and climate change. Some directly destroy habitats, others reduce populations and push them to a critical size below which they become unviable due to genetic problems (inbreeding, loss of adaptive capacity) and others, more random, can lead to population collapse even if the causes have ceased. Only in a few cases is the disappearance of species due to destructive natural processes, such as volcanic eruptions, cyclones, tsunamis or major fires.

Many human activities are involved in the **loss of natural habitats**. This is currently the most aggressive factor in terrestrial and freshwater environments. Examples are land use change for intensive food or goods production (crops, wind farms, irrigation infrastructure, etc.) or the construction of urban areas and transport routes. The exponential growth of the human population, a higher standard of living and the relatively recent development of mass tourism, especially on the coasts and in mountain areas, all contribute to this. The progressive abandonment of the rural environment in Spain, accentuated since the revolution of the tourist industry in this country, has determined the gradual loss of habitats such as pastureland and cereal steppes, subalpine pastures and high-altitude crops, and has halted the spread of forest growth. On the coast and around large cities, urbanisation and large infrastructures, such as motorways, ports, solar farms and wind farms, have been developed. This has led to a decline in the population of most open space species, both plant and animal. At the same time, the remaining open areas are often impacted by intensive agricultural and livestock farming practices (including the generation of slurry, the use of biocides and high water consumption), with high environmental costs.

Figure 4 Drivers of global change and relative importance by ecosystem type



Source: IPBES. (2019). *Summary for policymakers of the global assessment report on biodiversity and ecosystem services* (Summary for policymakers version). Zenodo. <https://doi.org/10.5281/ZENODO.3553579>

Another relevant cause to be taken into account is the arrival of **invasive species**. With globalisation, the movement of species between countries has become common. In this regard, species that enter new systems (allochthonous) are an important factor in biodiversity loss, particularly if they are pathogens or become invasive. They not only take up space, but often also prey on, compete with or transmit diseases to native plants. In Europe, several thousand alien species are considered to be already established, and more than 300 have been detected in inland waters, where invertebrates predominate, followed by vertebrates (mainly fish) and plants. In Spain, more than 200 have been officially recognised as invasive and, in addition to having become established, they cause economic, health or ecological damage.

Similarly, the **overexploitation** or harvesting of wild species beyond their reproductive capacity particularly affects marine fisheries. In terrestrial environments, this phenomenon is particularly severe in relation to those associated with luxury markets (elephants, rhinoceroses, mahogany) or traditional oriental medicine (tigers, pangolins). In Europe, it affects game (hunting is authorised) and sport fishing, which is managed intensively with techniques imported from livestock farming (captive breeding and release of partridges and quails, management of deer and wild boar in fenced farms), with excessive capture quotas that do not take into account other causes of decline, such as habitat loss or pollution (European turtledoves, partridges), or which are protected but die accidentally from gunshots or lead poisoning from hunting ammunition.

Pollution is particularly damaging to aquatic ecosystems. The use of **biocides** represents a very serious threat to them, as their presence spreads through soils and aquifers to reach marine systems through run-off and connection with watersheds. Intensive agriculture and livestock farming use large quantities of these products, manufactured to combat pests and diseases. However, as these compounds are not very selective, they tend to decimate insect and plant populations that play an important role in the functioning of ecosystems. Plastics and microplastics, which are already present in even the most remote places on Earth, are also among the most prevalent pollutants today.



Protected areas and the Natura 2000 Network in general are the best tools currently available for preserving the diversity of species and habitats in the face of the drivers of global change. National parks such as Ordesa y Monte Perdido are home to a great biodiversity despite their small size (15,000 ha) / M.B. GARCÍA

Climate change, resulting from the increase in greenhouse gases due to various human activities, not only aligns with overall warming, but also with an increase in the frequency of extreme events and droughts. No one can doubt its existence, which has been assessed and discussed ad nauseam by scientific and technical communities around the world. Its effects are extremely varied, ranging from bringing forward the flowering period (with its resulting impact on the economy) and the annual cycles of many organisms or the need for displacement of species unable to withstand it, to losses in productivity or the extinction of small populations. The greatest danger of this phenomenon is that slowing or reversing it will be very complex and costly, because, being global in nature, it can continue to affect the entire planet even if some countries reduce the agents that feed it.

Determining the specific cause of biodiversity loss in each country or environment or for each individual species is crucial to effectively combat the problem. While in the richer countries there is an exaggerated consumption of chemicals to increase productivity and combat pests and diseases, in developing countries habitat loss, overexploitation of resources and pollution (much of it uncontrolled and promoted by developed countries) are the most pressing causes of loss. At this point, if the problem is habitat loss, overhunting or overfishing, it will be of little use to have an excellent seed bank or to breed wild species in captivity for their reintroduction. Some breeding and reintroduction projects have failed after taking the step of keeping individuals in captivity and releasing them, as it is not possible to maintain viable populations in the long term in the absence of further releases. Similarly, habitat management or prohibition of capture is of little use if the wild population size is already genetically impoverished or below the critical size.

Methodological complexity and technical limitations

The first problem in analysing biodiversity loss is that we **have a poor understanding of it**, which reduces our ability to meet the challenge of halting it. Such is its complexity and diversification that no one can currently answer the question “how many species are there on planet Earth?” The current estimate is around eight to nine million, not counting groups as numerous and diverse as bacteria. In the case of insects, it is estimated that only one fifth of their species have been identified. We often know little about where they live: one may have a single population worldwide, many in a small mountainous region, or tens of thousands scattered across the globe. Their vulnerability is largely linked to their rarity. Without precise information on their distribution, it is not possible to assess their ecology and role in the ecosystem.

Knowledge of biodiversity is also not uniform across the globe. It varies between territories and is often associated with their level of development and geographical accessibility. We know more about European countries such as Sweden than about megadiverse but poorly explored environments such as the Amazon rainforest. In other words, not all countries know their biodiversity equally well. Although each country must organise its own information on this subject, there are some supranational structures such as the Global Biodiversity Information System (**GBIF**) that make available to the whole world the knowledge collected and contributed over decades by academic institutions, herbaria, and other collections, as well as naturalists from all over the world, on the places where each species has been found. This organisation currently has more than three billion records.

In the specific case of Spain, there are currently almost 66,000 taxa, of which invertebrates are the largest group, followed by plants and birds. Spain is considered to have a high level of biodiversity thanks to both present and historical factors: it is located in the Mediterranean region, it includes different types of climate, it has a complex orography ranging from deep valleys and semi-deserts to alpine peaks, and it is influenced by different types of water bodies. Its role as a refuge during the ice ages, the ancient connection with the African continent and human occupation for at least 800,000 years have also contributed to the current biodiversity.

However, knowing where species are found is not enough to determine their conservation status. It certainly helps to know whether they live within protected areas or in places with a high probability of human disturbance. For those that are threatened, more information is needed to assess their likelihood of persistence or decline, such as population sizes and trends, as well as a list of actual and potential threats. The methods for surveying **population sizes** are very different for different biological groups and may vary between teams (researchers, technicians, naturalist associations, etc.); in terms of the **threats, these may vary from one territory to another**. Therefore, bringing all this information together in order to process it, harmonise the data and indicators and reach solid conclusions is a great challenge, which highlights the need to design coordinated and consensual plans in all the administrations and areas where the species and habitats of interest are found.

Unlike what happens in other scientific disciplines, **in the study of biodiversity there are no standardised measuring devices** that can alert us to, for example, the dramatic situation or decline of a certain amphibian population or certify when a certain butterfly population has disappeared. It requires a highly diversified human capital specialised in identifying species, quantifying their genetic variability, analysing interactions or monitoring their evolution over time. All that implies a great deal of field work, as well as experts to assess their vulnerability. However, the classical professions of botanists and zoologists, understood

as those skilled in the identification of plant and animal species, are also in danger of disappearing. The methods of field observation and of gathering and storing specimens in collections are becoming scarce, and naturalists are beginning to play a greater role in carrying out this work, through a system known as **citizen science**, while technology and new molecular tools are spreading in research centres.

New technologies, such as artificial intelligence, are gaining ground exponentially in the last decade, although they still (and will continue to) require expert supervision. Image recognition incorporated into apps such as iNaturalist or Pl@ntNet helps many naturalists learn to identify organisms while helping to inventory plants and animals and improve knowledge of their areas of distribution. The use of artificial intelligence to analyse large amounts of data obtained from environmental DNA (DNA that living things leave behind in their environment) or from recordings of nature sounds (soundscapes) has become a very useful tool for cataloguing the diversity of life in a given place. Analysis of remotely sensed images provides an overview of land cover change as an indicator of biodiversity. For example, if a forest has been cleared, it can be assumed that all species associated with that habitat have disappeared. In this respect, satellite images obtained since the 1980s combined with more recent and sophisticated methods, such as LiDAR technology (which uses laser light to measure distances and create highly accurate three-dimensional maps) and multispectral images collected with drones, can give us a very accurate picture of the loss of structures and functionality in some ecosystems.

All these technologies promise to make the process of recording biodiversity easier in the future, but they also have their limitations. Although there are success stories, it is difficult for AI-based analysis of images from a camera trap (which is triggered by motion in the presence of an animal) to identify which of the more than 1100 species of bees on the Iberian Peninsula have pollinated a plant. In order for many of these systems to work correctly, it is necessary to have numerous training images, libraries where everything that we later intend to identify in the

field is previously documented, as well as supervision by experts in order to detect errors. Nor can a satellite image tell us whether a population of a threatened herbaceous plant has disappeared, nor can a high-resolution image taken by a drone tell us which species of bacteria, ants or birds have ceased to inhabit a place. These means can only alert us to important changes in the structure of that biodiversity. Although new technologies will take us to unimaginable places and promise a simpler future, science cannot be reduced to approximate and partial characterisations; it needs to improve both observational and computational effort to create a solid base on which to work with certainty.

If the intrinsic complexity of life on Earth is compounded by the fact that hazards are becoming more diverse and frequent as a consequence of the global change process we are undergoing, it is easy to understand the difficulty of measuring biodiversity loss, detecting its causes, combating it effectively and assessing its consequences. It is impossible to cover it all, and therefore **the approach of estimating habitat loss or threats to the most vulnerable species is** often used, these being the issues requiring the most urgent action.

Official data

Supranational bodies such as the International Union for Conservation of Nature (IUCN) ensure the assessment of the status of species at greatest risk and maintain an inventory of vulnerability through red lists of threatened species for fungi, plants and animals. Using criteria of geographic rarity and observed past or estimated future trends under climate and land-use change scenarios, the IUCN classifies species into categories such as "critically endangered" or "vulnerable", depending on their risk of becoming extinct in the short to medium term. According to the IUCN, more than 45,300 species are currently threatened with extinction, and 41% of amphibians, 36% of corals, 26% of mammals and 12% of birds would be affected. However, it should be made clear that **the IUCN does not have the capacity to assess everything, and therefore starts with what it considers most urgent**, so the above data corresponds to the status of the 163,000 species assessed. This model of classifying their conservation status, as well as taking action to prevent their loss, falls to the

national natural heritage managers in each country, but it is the scientists who really have the most expert knowledge about them. Hence the need for both groups to be well connected.

Spain has the List of Wildlife Species under Special Protection Regime (**LESRPE**), which includes species, subspecies and populations deserving particular attention and protection on the basis of their scientific, ecological or cultural value, their uniqueness or rarity or their degree of threat, as well as those listed as protected in the annexes of the directives and international conventions ratified by Spain. There is also a *Spanish Catalogue of Endangered Species* (**CEEAA**) listing, which includes the categories "in danger of extinction" and "vulnerable" and requires the adoption of a recovery or conservation plan, respectively. These lists are approved by the Administrations and have non-binding scientific advice. The red lists of endangered species are drawn up by the scientific community and societies, normally on behalf of the corresponding ministry. In addition, in Spain, each autonomous community may have its own catalogue and, sometimes, its own red lists, as they have broad competences in conservation matters. This territorial fragmentation, added to the fact that threat categories are not always consistent in terms of terminology and criteria, makes coordination for knowledge management and actions at national level difficult.

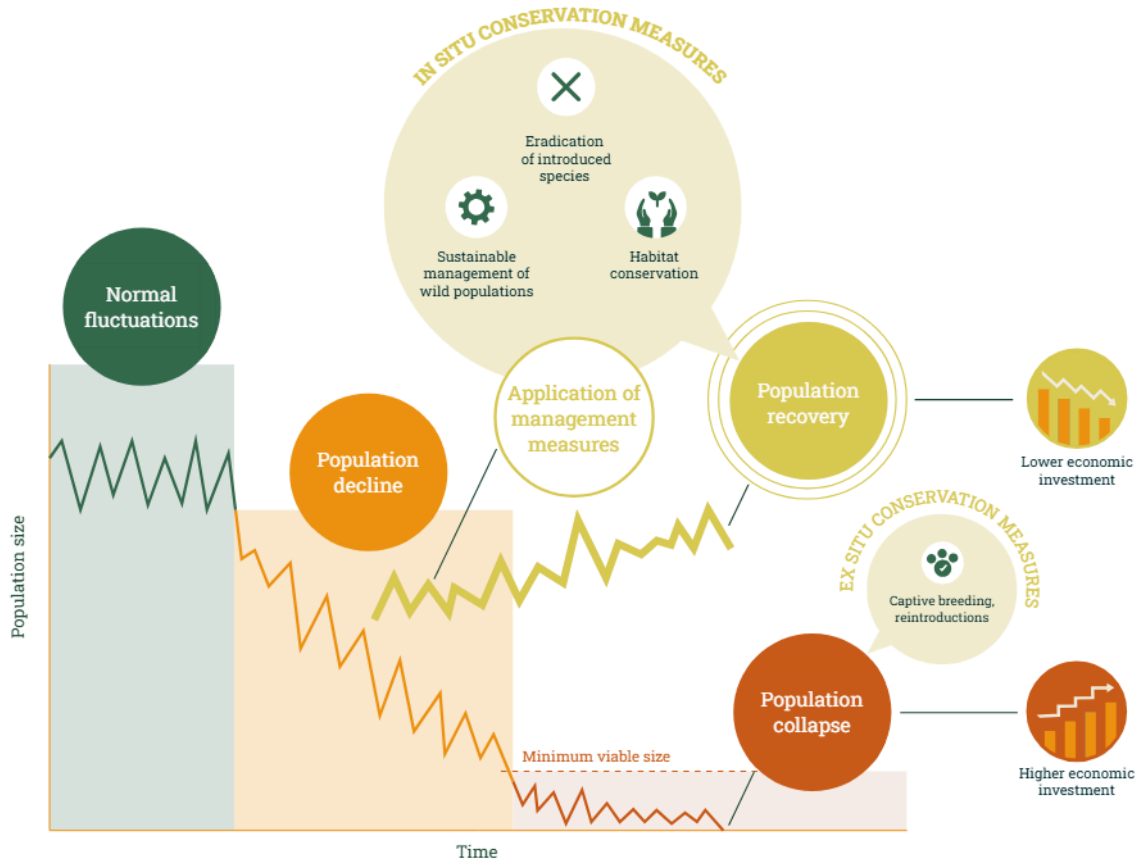
The extinction of a species is the end point of a long process preceded by the loss of its populations (extirpations). If this loss does not occur through direct habitat removal (e.g. through clearing or construction of infrastructure) or of all individuals (e.g., through hunting or the effect of an introduced species), a number of negative trends occur beforehand in addition to natural population fluctuations (figure 5). Systematic monitoring of species and habitats is therefore the best warning system and allows us to act before it is too late. The Living Planet Index (LPI), adopted by the Convention on Biological Diversity, measures trends in almost 35,000 populations of 5500 vertebrate species worldwide since 1970. The latest *Living Planet Report 2024* warns of a 73 % decline in natural populations of these organisms. The Living Planet Index reveals that mammals and birds have experienced huge population declines largely due to habitat fragmentation, hunting and the introduction of invasive species, especially in

the Amazon region. However, it says nothing about other groups as abundant and important in the functioning of ecosystems as insects or plants.

There are striking geographical differences in the rates of species loss. Latin America has experienced the largest average decline in wildlife populations, while Europe has undergone the smallest thanks to conservation and ecosystem restoration policies. In South America, large areas of tropical forests have been replaced by soybean crops and pastures for cattle ranching, resulting in considerable loss of native plant diversity. In remote Arctic and sub-Arctic ecosystems, climate change is altering the composition of soil micro-organisms, which could have unpredictable consequences for the rest of the ecosystem. In closer areas, such as the Mediterranean, many endemic plant species are at risk due to habitat loss or global warming, especially in coastal environments where the expansion of tourist infrastructure has wiped out many populations or reduced their habitat. The disappearance of plant species, as a structural part of habitats, in turn compromises networks of ecological interactions and all the organisms that depend on them, such as pollinators and seed dispersal organisms. Nor can we forget the effect that the loss of biodiversity has on other biological groups, such as fungi and micro-organisms, which play an essential role in biogeochemical cycles and soil fertility.

In both inland and marine aquatic ecosystems, amphibians and fish are particularly vulnerable. Although inland waters cover only 2.3% of the Earth's surface, these ecosystems are home to at least 9.5% of the planet's described animal species. Freshwater species have been severely affected, with extinction rates far higher than those observed in terrestrial and marine environments. The biodiversity crisis in the world's lakes, reservoirs, rivers, streams and wetlands has intensified. Amphibians have suffered severe declines globally, partly due to diseases such as chytridiomycosis and pollution of their habitats. In tropical regions of Africa and Asia, many freshwater fish species are disappearing as a result of overfishing and alteration of waterways by dams and irrigation projects. In addition, according to the Living

Figure 5 History of extinctions, phases and effective management measures in each phase



Source: Díaz, M., Barba, E., Barbosa, A., de Juana, E., Jordano, P., Lope, F. de, Moreno, J., Obeso, J. R., Ruiz, X., Sánchez, A., Sanz, J. J., Soler, M., Tella J. L., & Velando, A. (2008). ¿Cuándo son necesarios los proyectos de reintroducción de especies? Reflexiones sobre la conservación ex situ y sus fundamentos científicos. *Quercus*, 264, 28-33.

Planet Index , the decline in populations of vertebrates native to these waters (85% between 1970 and 2024) continues to outstrip contemporary declines in marine or terrestrial systems, with particularly high rates of loss of reptile, amphibian and fish species, especially in Latin America and the Caribbean.



Also, an important process that often goes unnoticed is **delayed extinction**. This is nature's overdue bill for damage caused. This process indicates that some species that are still present are doomed to disappear in a few years or decades due to the drastic changes we have made in recent times, as they no longer have the necessary requirements to survive and reproduce. Understanding delayed extinction is crucial for biodiversity conservation because it warns us that some damage has irreversible future consequences. This means that even if we protect a natural area after it has been degraded, some species may disappear anyway in the future because it is already too late for them. Therefore, the best strategy is to prevent such damage before it happens, rather than trying to repair it afterwards.



Spain regulates the management of its biodiversity through Law 42/2007, of 13 December, on Natural Heritage and Biodiversity. In addition, as a member state of the European Union, Spain has been required to report every six years on the conservation status of the species and habitats listed in the annexes of the Habitats Directive since it was approved in 1992. This is done by centralising the information collected by the corresponding ministry at national level and that contained in the reports of the autonomous communities, which requires significant coordination, given that each territory has different needs and resources.

Coastal marshes such as the Delta de l'Ebre are relict habitats in our country. / D. ORO



Examples of endangered species in aquatic environments in Spain

Many inland water species are threatened, especially fish that inhabit wetlands, marshes or coastal lagoons. Among them, the Valencia toothcarp (*Valencia hispanica*), a fish endemic to the Spanish Levante, is critically endangered according to the IUCN; or the Spanish toothcarp (*Aphanius iberus* and *Aphanius baeticus*), also endemic to the Iberian Peninsula and distributed in small isolated populations from the marshes of the Ampurdán (Gerona) to the Adra lagoon (Almería) and the lower Guadalquivir, respectively. The sturgeon (*Acipenser sturio*), whose habitat is large rivers such as the Guadalquivir or the Ebro, is also in the same situation, due to overfishing, the construction of dams that interrupt migratory routes and, in general, the degradation of the river environment. All of this has led to the disappearance of the commercial fisheries that existed in the 20th century and, in fact, today, for several decades now, not a single specimen has been detected. But one biological group that is seriously threatened in these environments comprise the amphibians, with almost all their species currently in decline. The widespread loss and deterioration of their habitats is compounded by the introduction of crabs, fish, and, more recently, a parasitic oomycete (fungus-like organism) from Asia, which has led to reductions of more than 20 % in their numbers in less than 20 years.

As for reptiles, the European pond turtle (*Emys orbicularis*) and the Iberian pond turtle (*Mauremys leprosa*), distributed in rivers and wetlands throughout the territory, are in a vulnerable state of conservation, largely due to competition from an invader: the pond slider (*Trachemys scripta*), which is very common as a pet. Some species of aquatic invertebrates, such as the naiads or river mussels or the native crayfish (*Austropotamobius pallipes*), are strongly threatened by pollution, works in the riverbeds, the decline of mutualistic fish in which the larvae spend part of their life cycle or introduced crabs carrying parasitic oomycetes. In the clean rivers of the southwest, the Iberian dragonfly (*Macromia splendens*), also endemic to the Peninsula, is categorised as vulnerable.

With regard to aquatic vegetation, frequent and abundant in shallow lakes and slow-moving rivers, the most endangered species are usually found in temporary pools or shallow wetlands. This is the case, for example, of the four-leaved water clover (*Marsilea strigosa*) or the quillwort (*Isoetes setaceum*), due to habitat loss and eutrophication. Some floating-leaved species are also endangered such as the floating water-plantain



The CSIC monitors the effects of fisheries on marine biodiversity. / J. M. ARCOS

(*Luronium natans*) or the fringed water lily (*Nymphoides peltata*); the sources of threat are, in addition to those mentioned above, waterworks.

Finally, with regard to the sea, the Balearic shearwater (*Puffinus mauretanicus*), endemic to the Balearic Islands, stands out among the seabirds at risk. It is one of the most endangered birds in the European Union and, although it has been considered critically endangered for 20 years, its breeding distribution is not well known and there is no reliable estimate of its population size or trends.

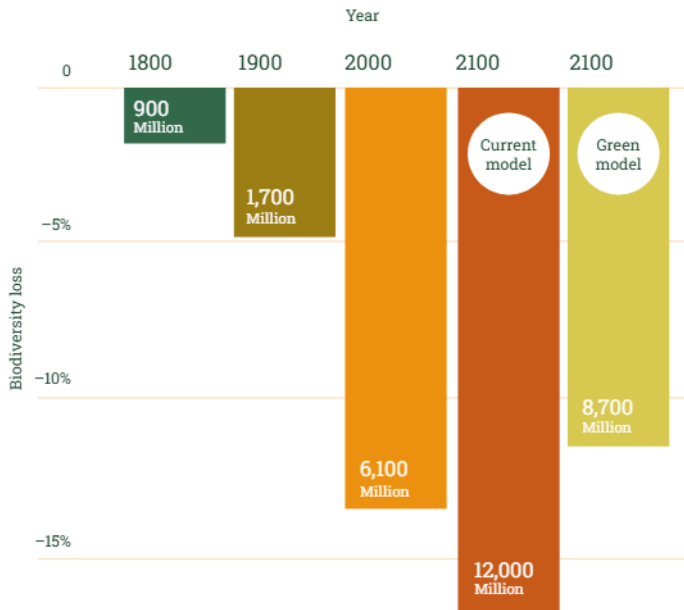
13.

Consequences of biodiversity loss

THE consequences of biodiversity loss are wide-ranging and sometimes unpredictable. The first is the **irreplaceable loss of the genetic heritage** of species that nature has taken millions of years to gestate and that play a role in maintaining the system in which they live, although generally unknown to us. No matter how much technology we develop, to date humans have not been able to generate new species, only to domesticate them or produce varieties or hybrids from those already existing in nature. The extinction of this legacy is irresponsible towards human societies, both present and future, because it may be the key to solving as yet unimaginable problems.

The second major consequence is the **loss of ecosystem services** provided by biodiversity, such as the natural goods on which we depend: water and air of the highest quality, food, materials... And, beyond the effect on the present, the annihilation of future research and development opportunities, such as the disappearance of potential sources of medicines, must also be taken into account.

When the population of individuals of a species is reduced or becomes extinct, **the balance between the different levels of the biological network of which it is part is altered**, which can lead to the disappearance of those that depend on it (cascading extinctions) and the proliferation of others. Some of these may become pests, which in turn often results in damage to food crops and sometimes in the transmission of disease to humans. The interconnectedness of all living things in a system is precisely what generates unpredictability in response to loss and cascading extinctions. For example, the disruption of elements at the top of food chains, such as the disappearance of large predators or herbivores, has a major impact on the abundance of the organisms they regulate. Therefore, whenever a species is removed from its natural habitat, it is necessary to foresee the consequences it will have on the rest of the beings with which it cohabits.

Figure 6 Biodiversity loss. Extinctions over time

Source: UN Environment Programme projection on habitat loss due to transformation

In general, the loss of species leads to **a reduction in functionality and simplification of systems**, resulting in the **globalised homogenisation of communities**. In the same way that all shopping centres in large cities look alike and it can be difficult to distinguish which city or country we are in because they feature the same brands and shops, the most opportunistic or fast-growing species tend to end up dominating degraded environments and taking space away from those that have managed to gain a place for thousands or millions of years. A paradigmatic case is New Zealand, sparsely populated and used for farming since its colonisation by Europeans: in some altered places, a Spanish botanist may recognise a multitude of plants and think he is in his own continent, while the range of native species in an unaltered place is radically different from that of its antipodes.

The loss or transformation of native biodiversity may be merely local and have little impact when involving organisms whose function is replaced by that of similar organisms, but in other cases, such as the introduction or local extinction of a major predator or ecosystem engineer, it may be of great significance. Thus, for example, the disappearance of elephants in the tropical savannah affects countless processes that have **consequences for the dynamics of numerous species** of plants, mammals, birds, reptiles, and soil micro-organisms. The introduction of the Nile perch into Lake Victoria or the extinction of wolves (and subsequent recolonisation) in Yellowstone National Park have significantly **altered the food web and landscape** of these sites. But, as mentioned above, there may also be global impacts, such as the **loss of ecosystems and their influence on climate**. The reduced functionality of the oceans reduces their capacity to absorb CO₂ and regulate the global climate. The degradation and disappearance of environments such as forests leads not only to the extinction of species that depend on that ecosystem, but also to the loss of filtered water sources from aquifers, changes in temperature and rainfall patterns, reduced CO₂ uptake and soil fertility, and increased erosion.

The resilience of systems (recovery and reversion to the initial state) is key to understanding the effects of biodiversity loss. **While some environments can recover over time, others will never recover, having gone beyond a threshold that prevents them from returning to their initial state.** The current transformation of some habitats is not only the result of disturbances that reduce their biodiversity, but also of a decrease in the intensity of human activity with varying consequences. In industrialised countries, there is a clear decline in open terrestrial ecosystems due to the abandonment of traditional uses and the spread of forest cover, resulting in the regression of certain types of organisms and the recovery of others. However, recovery due to the overexploitation of water resources (irrigation, runoff pollution, excessive consumption in tourist areas, etc.) is particularly serious and complex in countries such as Spain.

A very obvious case of the effects of biodiversity loss is the introduction of **species that become invasive**, a common process both in degraded systems and in others that are extremely fragile, such as islands. The presence of invasive species leads to the direct disappearance of native species, with which they compete or prey on, and to the simplification of environments. To take the case of New Zealand, millions of invasive rabbits roam freely eating any tender shoots that sprout from the ground, disrupting the age-old balance of its landscapes. The same phenomenon, albeit on a smaller scale, also occurs in the Canary Islands. **The economic cost generated by invasive species is one of the few that have been quantified**, although the cost of management and eradication actions is better known than the cost of species loss. In Spain, the main groups of alien species are found among plants (e.g., common reed or *Arundo donax*, sour fig or *Carpobrotus* sp. or common water hyacinth or *Eichhornia crassipes*), followed by arthropods (such as the Asian hornet or *Vespa velutina*) and molluscs (such as the zebra mussel or *Dreissena polymorpha*). The estimated cost for these groups is 261 million euros between 1997 and 2017. It is very significant that only 10 % of these amounts associated with invasive species seem to affect protected areas, which clearly shows the important role of active protection of territories to avoid biodiversity loss and reduce the costs involved.

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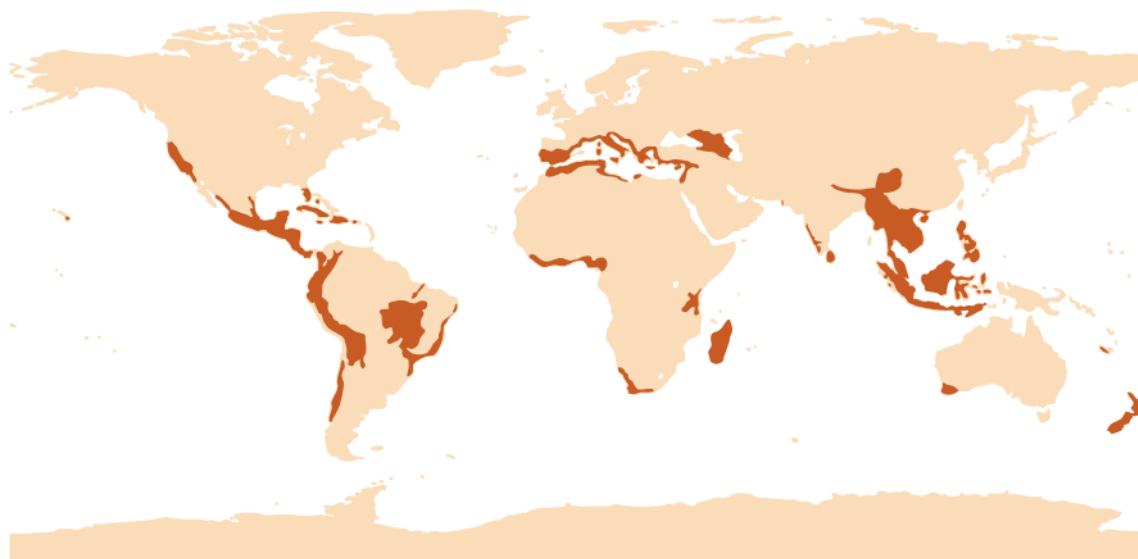


CSIC's Role in Addressing the Understanding of Biodiversity and Related Problems

DUE to its spatial location, Spain is a major contributor to the biodiversity of the European Union and the second largest hotspot of globally threatened biodiversity: the Mediterranean basin. The description, analysis, and monitoring of the enormous national biodiversity requires the commitment and leadership of organisations with national coverage such as the CSIC, with researcher teams distributed throughout the country, from the Canary Islands to the peaks of the Pyrenees, including the arid steppe, the Mediterranean forest and the large coastal and inland wetlands.

The CSIC has more than 30 institutes throughout Spain where biodiversity research is carried out; some of these centres have more than 80 years of experience. Currently, more than 400 researchers focused on the understanding and conservation of biological diversity participate in and lead short, medium and long-term research projects in marine and terrestrial ecosystems. A number of centres focused on the study of wild varieties have recently joined the CSIC, such as the Instituto Nacional de Investigación y Tecnología Agraria y Agroalimentaria (INIA, CSIC) [National Institute of Agricultural and Food Research and Technology], responsible for the conservation of crop and livestock varieties, as well as for the periodic carrying out of the National Forest Inventory; also the Instituto Español de Oceanografía (IEO, CSIC) [Spanish Institute of Oceanography], responsible for the monitoring of marine fisheries. In addition, the CSIC has experimental farms where domestic and wild biodiversity is monitored and conserved at local and regional scales. It also has official recognition of two environment-related unique scientific and technical infrastructures (ICTS): the oceanographic research vessel Hespérides, for polar prospection, and the Doñana Unique Scientific and Technical Infrastructures (ICTS-RBD), which aims to provide access and support for research and to develop and implement infrastructures that allow automated monitoring of wildlife and ecosystems in the Doñana Biological Reserve. The combination of centralised and regional, thematic and multidisciplinary infrastructures helps to cover the entire national territory, to coordinate available information, to maintain effective and efficient protocols and to incorporate and validate new technologies.

Figure 7 Earth's biodiversity hotspots



Source: Myers, N., Mittermeier, R. A., Mittermeier, C. G., Da Fonseca, G. A., & Kent, J. (2000). Biodiversity hotspots for conservation priorities. *Nature*, 403(6772), 853-858.

In turn, collections such as those of the Real Jardín Botánico (RJB, CSIC) [Royal Botanical Garden] or the Museo Nacional de Ciencias Naturales (MNCN, CSIC) [National Museum of Natural Sciences] are benchmarks for research into the world's flora and fauna, as their collections, developed over the last few centuries, include material collected during the Spanish colonial period, especially in Latin America and part of Asia. These collections are also the basis for ambitious projects such as **Flora Ibérica** and **Fauna Ibérica**, aimed at inventorying and describing the plant and animal diversity of the Iberian Peninsula and the Balearic Islands. Other scientific collections of a more local or regional nature complement these collections, for example, those located at the Instituto Pirenaico de Ecología (IPE, CSIC) [Pyrenean Institute of Ecology], the Institut Botànic de Barcelona (IBB, CSIC-Museu de Ciències Naturals de Barcelona) [Botanical Institute of Barcelona], the Centro de Estudios Avanzados de Blanes (CEAB, CSIC)

[Blanes Centre for Advanced Studies], the Instituto de Ciencias Marinas de Andalucía (ICMAN, CSIC) [Andalusian Institute of Marine Sciences], the Instituto Mediterráneo de Estudios Avanzados (IMEDEA, CSIC-UIB) [Mediterranean Institute of Advanced Studies], the Estación Biológica de Doñana (EBD, CSIC) [Doñana Biological Station], the Estación Experimental de Zonas Áridas (EEZA, CSIC) [Experimental Station of Arid Zones], the Institut de Ciències del Mar (ICM, CSIC) [Institute of Marine Sciences], and the Instituto de Acuicultura Torre de la Sal (IATS, CSIC) [Torre de la Sal Aquaculture Institute]. Thanks to these infrastructures, the CSIC participates in international consortia such as the Distributed System of Scientific Collections (DiSSCo), which focuses on the cataloguing of biological collections in Spain, and the Global Biodiversity Information System (GBIF), all through a ministerial management assignment, in order to coordinate and maintain information on biodiversity from the national network.

More recently, the CSIC is developing multidisciplinary groups focused on the monitoring and conservation of wild and cultivated biodiversity in the face of the challenges of global change, supported by the structuring of interdisciplinary thematic platforms (ITPs). These address complex problems, such as the monitoring of standardised and essential variables, the study of environmental factors or the design and conservation of viable socio-ecological systems, while advising on the actions of companies and administrations through the application of the best available scientific knowledge. The genesis of these platforms was facilitated by the previous development of white papers published by the CSIC, aimed at addressing the current state of the problems and imminent major challenges and defining CSIC's potential involvement in their resolution. These papers identified the potential of research groups on issues related to the biodiversity conservation crisis, and have stimulated coordination between groups and explicitly addressed issues such as the monitoring of wild and cultivated biodiversity, corresponding responses to global change, the analysis of the effectiveness of public policies with environmental objectives (e.g., the common agricultural policy, CAP), the study of polar ecosystems or the adaptation of agriculture and forestry to climate change.

2.1.

Long-term biodiversity conservation

NEW technologies (environmental DNA, remote sensing, camera traps, sound recorders, etc.) are helping to develop extensive systems for obtaining ecological information, increasing our capacity to inventory how biodiversity is distributed and what environmental variables are associated with this distribution. However, **establishing their status and vulnerability requires monitoring over time**, including strict analysis of the processes and variables that determine change at any given time. Only by estimating **trends and recording actual evidence of extinction and decline rates**, based on systematic and repeated work, can we know the true status of organisms, communities and habitats.

The great biodiversity of the national territory means that Spain has much responsibility for its conservation on a continental and global scale. Like other EU member states, it is obliged to report to the European Commission on compliance with nature conservation directives and, as of January 2023, also on the degree of compliance with the environmental objectives of the Strategic Plan of the common agricultural policy (CAP). **In terms of the conservation of threatened biodiversity**, the Birds Directive and the Habitats Directive are relevant, as they include lists of species and habitats that require protection and establish management plans and periodic assessment (every six years or less) of their conservation status. These lists generally integrate international obligations stemming from earlier conventions, such as those protecting migratory species or those subject to international trade. **From the point of view of the common agricultural policy**, it must be assessed whether the measures being developed, which allocate some 8 billion euros per year to maintain viable and sustainable agricultural activity, are capable of maintaining viable populations of farmland birds, pollinators, and, in general, species of the directives dependent on agricultural activity. In addition to the aforementioned international obligations, **national and regional strategies for the conservation of endangered species** must be developed, implemented and evaluated, as well as **national strategies for the management of**

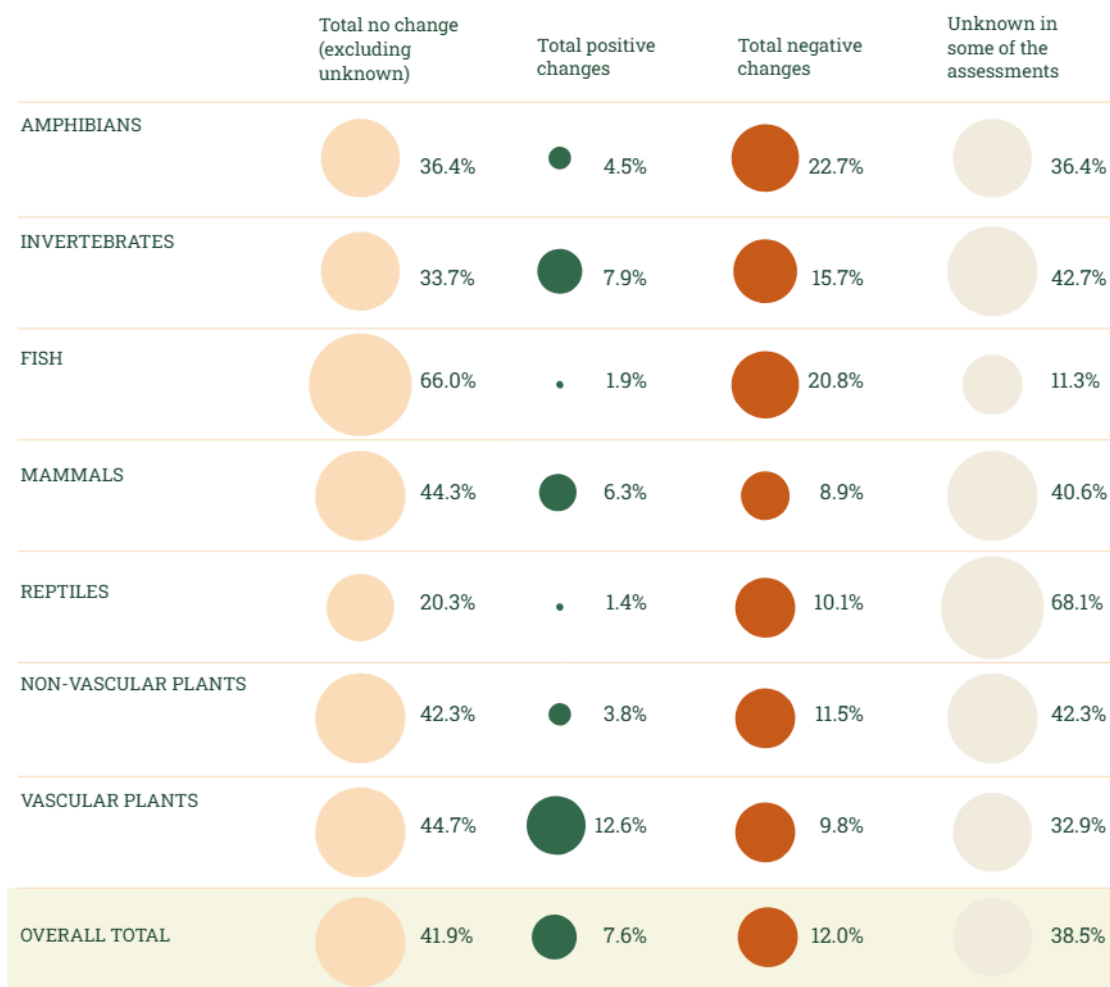
invasive alien species, pollinators, and ecological connectivity.

Spain should therefore be developing numerous protocols for the periodic monitoring of species and habitats, and we still have a long way to go to catch up with other European countries.

In this respect, **only a small proportion of the species and habitats that are officially catalogued**, whether at regional, national or international level, **have stable protocols for monitoring** their populations and conservation status. These are generally a small group of iconic, rare and localised species and therefore easier to monitor on a regular basis. For the most widespread and relatively common species, the strength of the monitoring results is highly irregular. One of the causes of this situation, which generates doubts about the credibility of the conclusions obtained, is based on the fact that the legal powers for the development, implementation and evaluation of monitoring protocols lie with the autonomous communities, which results in substantial differences in the quality of these protocols, as well as in their continuity over time on a national scale. They are not usually advised or implemented by scientists, with a few national exceptions such as the monitoring of fisheries or the forest inventory carried out by the CSIC. In the case of the common agricultural policy, a protocol for evaluating the actions of its strategic plan is being slowly developed, in principle with the agreement of the Autonomous Communities, with the advice from the CSIC from the outset.

Traditional sources of information on **biodiversity trends** are to be found in **scientific teams**, as well as in **some of the protected areas, such as national parks**. For example, the IEO monitors stocks of marine species exploited for sustainable management, while various CSIC teams monitor threatened plants in the Ordesa and Doñana national parks. In addition, different NGOs and scientific institutions (e.g., SEOBirdLife or the Spanish Herpetological Association) rely on research staff for the implementation of monitoring protocols or analysis of data on the abundance of selected animal species. They have managed to maintain annu-

Figure 8 Degree of unawareness of trends in species of community interest, according to the report on the state of natural heritage and biodiversity in Spain in 2020



Source: https://www.miteco.gob.es/content/dam/miteco/es/biodiversidad/temas/inventarios-nacionales/iepn20_sexenal_tcm30-527047.pdf

al monitoring of common birds on a national scale since 1998, as well as amphibians and reptiles in the national parks of Doñana, Sierra de Guadarrama and Picos de Europa over the last 20 years. Some protected areas have also set up their own processes or allowed the development of those carried out by researchers, with the advice or intervention of CSIC research staff, such as the Doñana Biological Reserve, the Ordesa National Park, or the Cabañeros National Park and its surroundings. The Autonomous National Parks Organisation (OAPN) itself has a consolidated line of funding dedicated to promoting quality research in these areas, for which CSIC groups regularly apply.

In Spain there are many initiatives focused on the inventory and monitoring of species, many of them supported by volunteers capable of recognising or photographing them with sufficient quality. The problem lies in the fact that the designs are not always adequate to obtain robust results, as well as in the dispersion of information. It would be necessary to incorporate protocols validated in international networks or endorsed by research teams. A recent project led by the CSIC (BIOTREND) coordinates more than 25 teams that conduct time-based series and long-term monitoring within Spain, with the aim of making visible the enormous work being done, validating those procedures with a correct sampling design (standardised methodologies, repetitions over time...) and comparatively analysing trends in lake and terrestrial plants, bumblebees, butterflies, rodents, birds, amphibians, reptiles, and large mammals. To date, it has validated monitoring of about 1000 different species in as many locations throughout the country. The aim is to qualify the generalised sense of biodiversity loss and to highlight the points and species accumulating decline or extinction, as well as to assess the extent to which changes in land use or droughts are affecting each group and in each environment.

22.

Supporting scientific assessment and monitoring, environmental and legislative actions

As a research organisation, the CSIC has no authority in biodiversity management. However, it is obvious that the knowledge it generates, its collections and its capacity to design protocols and analyse monitoring data and environmental initiatives is essential to improve the legislation and measures implemented by those who do: the public administrations. This is why researchers are frequently asked to participate in scientific committees such as that of the National Parks Autonomous Body (OAPN), the authority responsible for drawing up official lists of protected or invasive species, nature protection councils or the boards of protected areas. Many of them are also active members of the scientific institutions and NGOs that carry out partial or state monitoring.

As part of its scientific vocation, the CSIC is currently involved in **research projects focusing on various issues related to the loss of biodiversity and ecosystem services**. Examples include the effect of the replacement of traditional extensive livestock farming by intensive macro-farms, of the loss of pollinators, biological invasions on islands, light pollution for coastal birds, renewable energy and transport infrastructures, of anthropic pressure on the abundance of birds and mammals, water pollution and nano-plastics, among other issues. Similarly, its researchers are working on **solutions** such as enhancing the beneficial role of hidden (microbial) biodiversity in soils, the restoration of wetlands, the role of biodiversity as a modulator of pathogen transmission by insect vectors, the benefit of sustainable agricultural practices in semi-arid agrosystems, the detection of refuges for biodiversity, the effect of the restoration of abandoned rural areas on ecosystem services and the incorporation of new technologies and artificial intelligence to improve the diagnosis of the state of biodiversity in marine and terrestrial systems. In the last decade, CSIC has also been promoting the **implementation of citizen science-based platforms or networks** for early warning of losses in this field, exemplified by SOSanfibios, SeaBirdstagram, Observadores del Mar or Adopta una Planta, as well as the award-winning Mosquito Alert for monitoring the dynamics of mosquito populations of epidemiological interest.

The advantage of including scientists in diagnostics and implementation through tools such as the LIFE Programme is that their results are often published, so that anyone will have the ability to replicate or discuss them publicly. Replicability and accessibility do not usually occur when activities are carried out exclusively by the technical world and are stored in the offices of local or national administrations. The following are examples of CSIC's work on some of the hot topics related to biodiversity management.

Species conservation

The media often report on the critical status or advances in the conservation of species such as brown bears, lynx, birds of prey, steppe birds, seagrass meadows, sea turtles and the Balearic toad (or *ferreret*), among other examples. Many of these owe their emblematic nature to their extreme rarity or imminent risk of extinction, which tends to favour the use of ex situ management strategies based on captive breeding and reintroduction, as opposed to the generally more successful **in situ strategies** aimed at combating the causes of population decline. Several CSIC teams have **carried out precise diagnoses for the classification of threats, developed criteria for conservation protocols and implemented plans**, all of which have been published in the scientific literature and, partially, incorporated into Spanish legislation. The results are not always encouraging, as, in general, ex situ projects are not always adequately designed, which explains their low effectiveness, which remains largely unknown because successes are published, but not failures. In addition, many of them target popular species whose endangerment should be resolved by in situ actions, while they leave aside other much more threatened but unpopular or unknown species; the latter, however, are key to the maintenance of ecosystems (many inland fish, reptiles, plants or invertebrates).

Nevertheless, **success stories** are important. The improvement in the situation of the Iberian lynx would not have been possible without the long and arduous programmes involving the CSIC. Nor would that of the Balearic shearwater, a seabird endemic to the Balearic Islands whose demographic diagnosis showed it to be critically endangered and which has come to be considered the most endangered bird in Europe. Another example is the case of the chytrid fungus, an amphibian pathogen from Asia which, thanks to the CSIC, was recorded in the Old World for the first time, changing the paradigm of chytridiomycosis as a disease of tropical areas and revealing its devastating effect in temperate zones. Similarly, the stable status of one of our continent's highest priority plants, *Borderea chouardii*, located only on the walls of a single pre-Pyrenean locality, has been demonstrated by patient monitoring over more than 20 years. Finally, some reintroduction projects, such as those of the bearded vulture in the mountains of southern Spain, have been designed and monitored with scientific advice that has contributed to their partial success, as there are still years to go before we can be sure that the reintroduced population is viable in the absence of continued human intervention.

Deep time view to understand biodiversity

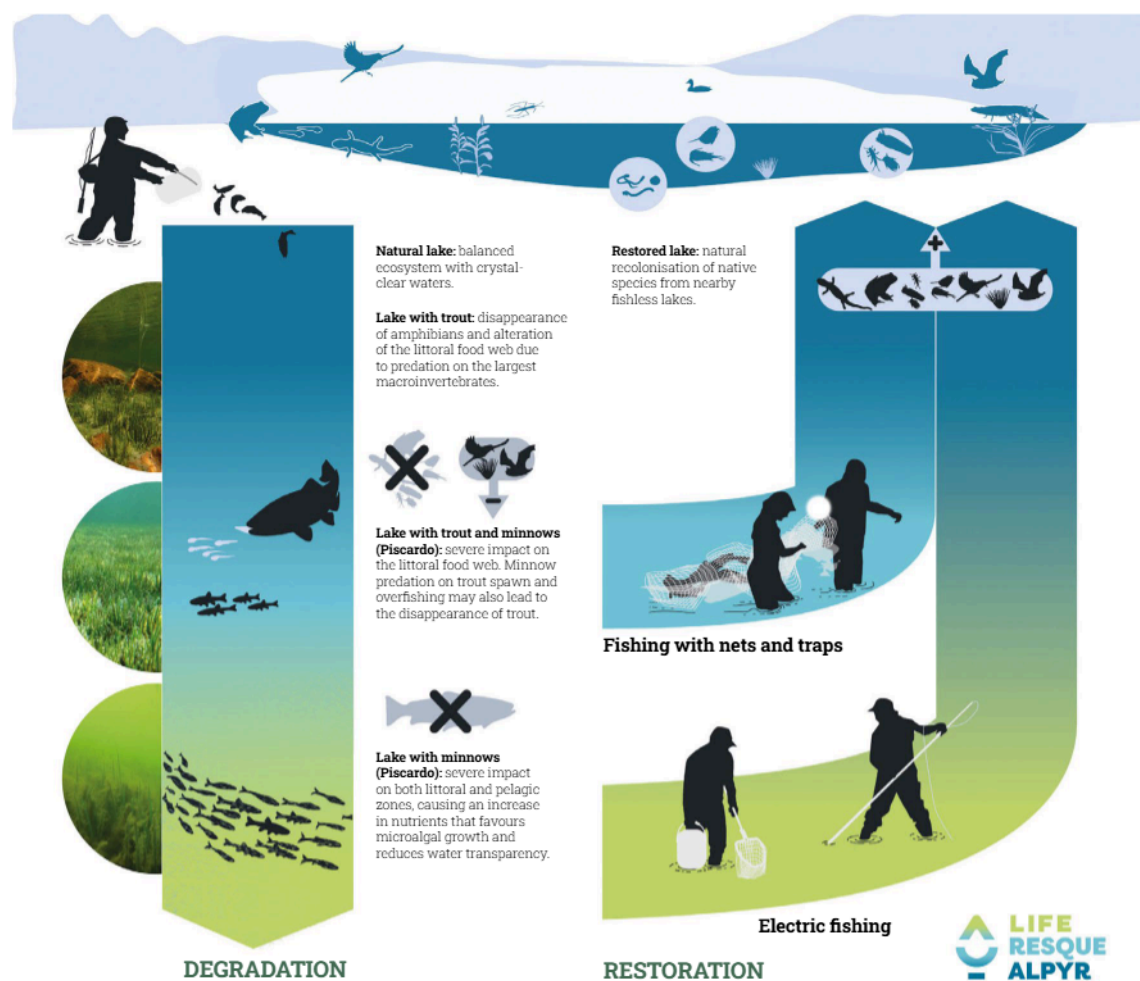
The CSIC leads numerous palaeontological and palaeoecological projects (both pollen records and fauna remains) that describe the flora and fauna of the past. This approach to evolutionary time scales is fundamental for understanding and studying the dynamics of biodiversity in our country. An example of this is the presence in the Balearic Islands of the *Myotragus*, a herbivore with no predators that inhabited the islands for more than five million years until the arrival of humans. Undoubtedly, the vegetation of these ecosystems co-evolved with this herbivore, which was later replaced by domestic animals (sheep and goats). The CSIC is currently investigating how rural abandonment affects the dynamics of vegetation on the islands and how these ecosystems should be managed taking into account the evolutionary past of their communities. Such broad biogeographical approaches, integrating broad temporal scales, are becoming common in several CSIC research groups.

Restoration to reverse trends

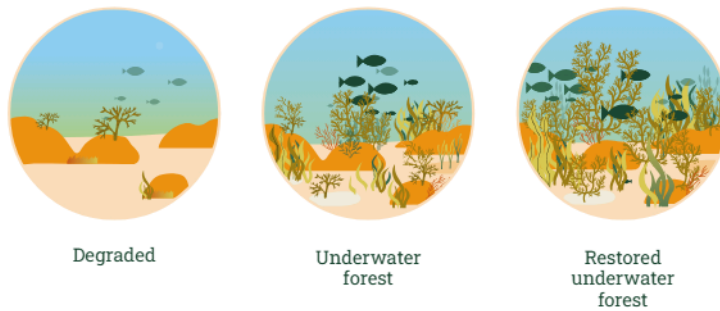
The CSIC leads or plays a definitive scientific role in numerous ecological restoration projects in our country, covering different ecosystems and agents of global change, such as the presence of invasive species or the loss of habitats due to human-related causes. These projects usually rely on the collaboration of the public environmental authorities, especially with regard to the logistical aspects of the restoration actions. These include projects to **eradicate invasive species on islands, in rivers and mountain lakes** (figure 9) or to **restore seagrass meadows affected by erosion due to nautical anchoring or macroalgae populations affected by coastal water pollution**.

As an example, CSIC conducted a study on the effects of the **successful eradication of the black rat on the island of Dragonera**, the largest island in the Mediterranean where this goal has been achieved. This study showed the historical dynamics of the effects of human action and how the vegetation is responding to the eradication not only of rats but also of other invasive species, such as goats, traditionally introduced by humans into the fragile island systems. Another example is the **eradication of fish introduced in mountain lakes**, where CSIC teams carry out management and monitoring actions after the restoration of the original conditions prior to the introduction of species for fishing. In the streams of the Peñalara massif (Sierra de Guadarrama), the eradication of an introduced fish was achieved, which, together with the captive breeding and subsequent release of more than 1000 specimens of the Iberian stream frog, allowed the return of this highly endangered endemic species to the national park. In the Pyrenees, the great effort through another project is enabling the removal of introduced fish from mountain lakes to preserve the original food web, the transparency of the water, and its valuable amphibian and macroinvertebrate fauna. The **restoration of a seaweed species**, *Gongolaria barbata* (also known as *Cystoseira barbata* and nicknamed Golden pine seaweed), in Cala Teulera (Menorca) represents the first example of restoration of a macroalgae forest, in which the

Figure 9 Conservation in action: ecological restoration



Source: LIFE_RESQUE ALPYR Project, which promotes conservation and recovery actions for high-mountain aquatic habitats and species.

Figure 10 Conservation in action: ecological restoration

Stages in the process of restoring a seabed with brown algae endangered by the *Gongolaria barbata* in Cala Teulera (Mahón, Menorca). This project is led by the CEAB Marine Forests Group.

associated ecosystem functions, such as biodiversity refuge and its potential contribution to blue carbon, have also been recovered (figure 10). In Mallorca, the CSIC managed, for the first time in the world, to **eradicate the amphibian pathogenic fungus** from a stream in the Tramontana mountain range where it was introduced by mistake and which, if it had spread, could have extinguished the world population of the *ferreret* or Mallorcan midwife toad, endemic to the island. This milestone was achieved with the essential collaboration of the Balearic authorities and, more recently, the method has been improved and applied in Andalusia to save the endemic Betic midwife toad from extinction. All these examples show the urgent need for research and management to work together.

Resolving conflicts between development and biodiversity preservation

Actions undertaken for the protection and restoration of biodiversity are generating conflicts with some rural societies that see them as a barrier to economic development. One initiative addresses the **recovery of large carnivores**. Spain is home to a very rich community of large predators, which were decimated

over the last century throughout Western Europe. These include **wolves, bears, and lynxes, as well as birds of prey such as the Iberian imperial eagle**. Spain also has **the highest density and variety of scavenger bird species in Europe**, thanks to extensive livestock farming and the abundance of native wild ungulates, such as deer, roe deer and mountain goats. Comprehensive monitoring of the bear in the Cantabrian mountain range provides detailed knowledge of its activity in highly humanised habitats.

Some CSIC teams have been researching the biology of these creatures for many years and the knowledge generated has a direct application in the resolution of conflicts with the rural world and the evaluation of current legal regulations governing the management of these ecosystems. For example, it has been shown that wolves, in the absence of human persecution (a process affected rural abandonment and new conservation laws), become more diurnal, so we can expect more interaction with man due to increased recreational use of mountains. Another example in which CSIC has played a relevant role is the **conflict between fishing fleets and the accidental capture of emblematic species such as turtles, seabirds, and other large marine predators**. In this regard, the cases of the Balearic shearwater and Audouin's gull stand out. The CSIC has estimated the impact of such by-catches and has intervened in scientific and inter-sectoral committees to resolve the conflict and harmonise European regulations with resource sustainability and economic activity.

Finally, conflicts may also arise between the goals set by different a priori conservationist policies, which require **scientifically informed debates** for their resolution. A recent example is the conflict between certain aspects of the **Animal Welfare Act and biodiversity conservation policies**, ranging from the need to control invasive alien species with methods in principle prohibited by the Act to the negative effects of certain pets on local biodiversity, especially if they are allowed to be kept in semi-freedom. Several groups of CSIC researchers are tackling these questions from strictly scientific approaches with the aim of contributing to the development of criteria to solve the debate locally, despite their unpopularity in certain animal rights circles.

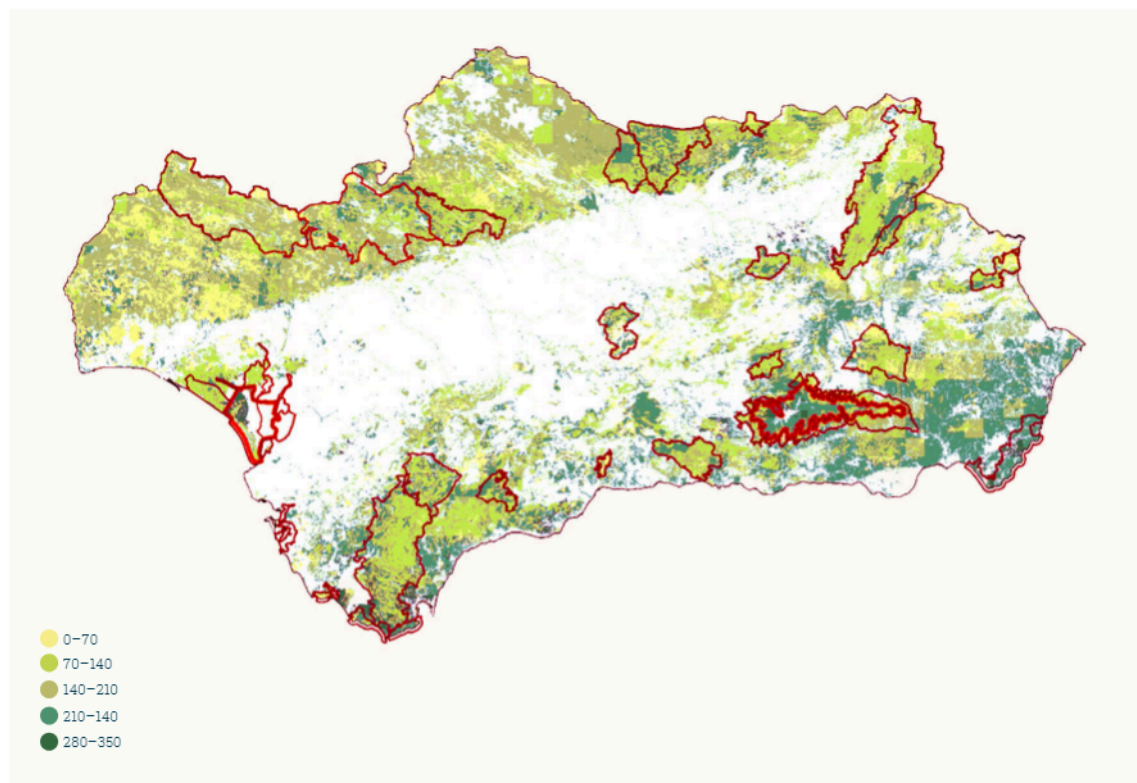
Quantification of ecosystem services

Since 2008, the CSIC has been leading an accounting proposal that combines environmental and social values. It was initially developed to account for environmental and social income and capital of Andalusian forests in 2010 (RECAMAN project). The results by municipalities and at global level were published both in the scientific literature and on a portal of the Andalusian government. At present, it is one of the few proposed accounting systems being evaluated by the World Bank for official use in environmental accounting. Basic research in this line focuses on the determination of the set of relevant environmental values for official quantification and on the rigorous evaluation of the intrinsic values of biodiversity (independent of its material, recreational, aesthetic or cultural use) (figure 11). In parallel, and in terms of international bodies such as the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES), research is being carried out, with the participation of the CSIC, on the inclusion of cultural and spiritual values in accounting systems. This research, which is still in its early stages, aims to ensure that the services maintained by less wealthy regions are valued fairly, so as to prevent undesired actions in more prosperous areas from being transferred to those where it is still cheaper to develop them, even with the incorporation of environmental values. The CSIC, for example, is studying the ecosystem services of traditional grazing to improve the quality of life of society, the conservation of natural resources and their sustainable environmental and economic use.

Spatial planning and the Natura 2000 Network as general conservation measures

It is impossible for the same areas to support all the needs of today's human societies, as there are conflicts between uses. Biodiversity conservation legislation has therefore identified areas where human-friendly use is limited or even banned altogether, in order to ensure the survival of species and habitats. The European Union has taken environmental conservation very seriously because of its vital importance for the well-being of its citizens and has obliged member countries to designate **the Natura 2000 Network of protected areas to halt the loss of biodiversity**. This

Figure 11 Index of the relative conservation value of forests in Andalusia



Source: Díaz, M., Concepción, E. D., Oviedo, J. L., Caparrós, A., Farizo, B. Á., & Campos, P. (2020). A comprehensive index for threatened biodiversity valuation. *Ecological Indicators*, 108, 105696.

network consists of special areas of conservation and distinct protection areas for birds, with the aim of ensuring the long-term survival of species and habitat types in Europe. Spain is one of the countries with the highest coverage of the Natura Network, 27%, and some 84,300 square kilometres of marine surface area. A total of 118 habitat types and 263 species listed respectively in annexes I and II of the Habitats Directive and 125 species from annex I of the Birds Directive are present in the whole of Spain's land and marine waters. Their conservation entails the obligation to designate Natura 2000 Network sites, to manage them and evaluate their effectiveness for conservation purposes. This is why scientifically based land-use planning, ranging in space and time from whole reserves to industrial estates, is essential to ensure the material, health, and spiritual well-being of modern societies and, in particular, the conservation of biodiversity in a highly humanised world.

Several CSIC groups are actively working on this management and are involved in the design of connectivity strategies, protected areas in current and future climate and land-use scenarios, as well as in the evaluation of the management actions needed to implement this management. The experience of numerous researchers, increasingly coordinated around specific conservation objectives, but that account for the inevitable footprint of the development of ever more demanding societies, is a guarantee of the institution's potential to tackle one of the biggest problems we face: the loss of biodiversity and its services and values, which we are still far from being able to do without.

2.3.

CSIC's contributions to major policy lines worldwide

THE European Union considers it important to work transnationally and share information in order to address major common challenges. This makes perfect sense, because Spain's wetland problems are probably similar to those of Italy or Greece, for example. This is why the Council mandated the **European Strategy Forum on Research Infrastructures (ESFRI)** to support a coherent and strategic approach to research infrastructure policy-making in Europe and to facilitate multilateral initiatives to improve the use and development of research infrastructures. ESFRI outlines strategies for the substantial financial investment required and makes a long-term commitment to its operation. Two initiatives led by the CSIC from the academic side and included in the ESFRI roadmap are **DISSCo** and **eLTER**. The former, mentioned earlier, undertakes the inventory of biodiversity through the network of collections and the second to the standardised monitoring of socio-environmental variables. Both are intended to be permanently included in the European Research Infrastructure Consortium (ERIC) as is **LifeWatch**, whose mission is to facilitate the use of information and to provide electronic services related to biodiversity research and ecosystem functions. Other major European infrastructures coordinated by CSIC or in which it participates at national level are ICOS, ACTRIS, DANU-BIUS-RI and AnaEE-ERIC.

- **ICOS (Integrated Carbon Observation System).** Its main objective is to establish a long-term systematic observation network to monitor greenhouse gas fluxes in terrestrial ecosystems and their concentration in the atmosphere, as well as CO₂ exchanges between the atmosphere and the oceans.
- **ACTRIS (Aerosol, Clouds and Trace Gases Research).** For the study of short-lived atmospheric constituents and their interactions, enabling reliable forecasts ranging from weather and health warnings to short- and long-term climate change assessments.

- **DANUBIUS-RI.** International Centre for Advanced Studies of River-Marine Systems.
- **AnaEE-ERIC (Analysis and Experimentation on Ecosystems).** Infrastructure for research and experimentation with ecosystems under conditions such as pollution and climate change. It focuses on collecting data to predict and mitigate environmental problems.

Very recently, CSIC has established a long-term agreement with the Ministry of Agriculture, Fisheries and Food to provide advice on the assessment and adaptive improvement of compliance with the environmental and social objectives of the **common agricultural policy**. Through an Interdisciplinary Thematic Platform, the aim is to integrate the knowledge and experience of Spanish research groups that have been working on these issues for several decades, both inside and outside the CSIC. Contacts are also being established for the CSIC to act as scientific advisor to Spanish administrations in the framework of the European project to develop an **office for monitoring** both endangered and common **biodiversity**. These recent initiatives are in addition to those already established for fisheries monitoring in the context of the **common fisheries policy**.

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Conclusions and Recommendations

Conclusions

Spain is home to an exceptional biodiversity in the European context, the result of its peripheral location, great climatic variability (from the humid Cantabrian coast to the semi-arid areas of the southeast) and a wide altitudinal range (from endorheic depressions to alpine ecosystems). Its socio-economic history, especially an Industrial Revolution developed unevenly across the territory and the change of a long tradition of land use based on extensive livestock farming, have also had diverse effects both on the loss of biodiversity due to anthropic factors and on the shaping of the current map of spaces aimed at preserving it, the Natura 2000 Network.

The CSIC manages the largest scientific collections related to biodiversity in the country and has dozens of research groups working on a wide range of topics linked both to the inventory and estimation of biodiversity loss, threat factors, and future projections, as well as advice and the implementation of applied recovery projects. Since the emergence of *conservation biology* in the 1980s, the CSIC has been an international leader in the advances of this discipline and has led numerous analyses on the dynamics of biodiversity. These include, due to their social resonance, cases of emblematic species such as the Iberian lynx or amphibians, as well as the restoration of alpine lake communities. It also carries out numerous knowledge transfer activities, such as the evaluation of monitoring actions or participation in the establishment of legal conservation actions (lists of threatened, invasive or extinct species, evaluation of reintroduction projects, ecological connectivity or restoration strategies, etc.).

Recommendations

For public decision-makers:

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A definition of priorities within the national biodiversity conservation strategy is required, establishing time frames and a system of assured funding to be able to develop monitoring programmes on a par with those of other European Union countries. Spain's participation in European infrastructures and initiatives will undoubtedly help in this regard.

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In a widely decentralised multilevel governance system, as is the case of the Autonomous State, it is necessary to improve coordination between the public administration and scientific and technical research, through advice and harmonisation of the respective actions.

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Another determining factor is the implementation of an effective workflow for data collection, validation, and analysis, leading to the proposal of scientifically based management measures. All this should lead to the participation of the scientific world in the evaluation of the conservation status, in the design and implementation of early warning systems, as well as in the improvement of the effectiveness of actions aimed at preservation, through a series of specific actions such as the following:

- Supporting groups of taxonomic experts for the identification, description, cataloguing and monitoring of biodiversity and of the infrastructures for its preservation (collections, germplasm banks) equipped with resources and specialised personnel.
- Listing of threatened organisms requiring long-term observation to diagnose their conservation status and of sentinels acting as bio-indicators of habitat dynamics or of the general effects of the drivers of global change.
- Design of science-based monitoring protocols (standardised field methods and use of new technologies), both for species and habitats of interest and for rapid detection of invasive species and pathogen proliferation. Likewise, for greater effectiveness, collaboration is needed in the training of implementing groups, such as NGOs, staff of public or private companies, protected areas, volunteers, etc.
- Data analysis and modelling to obtain robust conclusions and assist decision making with international validation.
- Review of protocols aimed at assessing the effectiveness of management measures with biodiversity conservation objectives, such as the recovery of populations or the restoration of degraded systems.

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At the same time, environmental legislation should be revised to take into account the balance between biodiversity conservation and rural livelihoods, as well as the participation of the inhabitants of the environments where it is managed and the establishment of compensatory measures.

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Priority should be given to those aspects that can help reverse climate change. These include the protection of mature forests, both as carbon sinks and as refuges for biodiversity and numerous other ecosystem services; the diversification of the landscape and the practices that maintain it; the recovery of wetlands, seagrass meadows, and blue carbon-generating macroalgae forests; and the promotion of pollinator biodiversity by reducing the use of chemicals.

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The incorporation of disciplines such as sociology, anthropology, archaeology or environmental economics can help to resolve doubts about the original landscapes or about which variables to modify in order to obtain better results in cases such as those affected by rural abandonment and conflicts with wildlife.

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The promotion of low-impact extensive activities (agricultural, livestock, and recreational events) can be an alternative to a model of protected areas or intensive use zones, so that the environmental values of these activities are evaluated and accounted for in the income of those who maintain them, whether individuals, administrations or companies.

For society:

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Coexistence between man and nature is not easy because the demand for resources is growing exponentially, leaving a growing footprint on biodiversity and on the necessary ecosystem resources that are increasingly difficult to recover. To persist as a species, we must be aware of our dependence on the natural health of the planet and care for it as we care for ourselves. The loss of biological diversity is the first warning sign of our own extinction, but fortunately we are still in time to take preventive measures.

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For all these reasons, it is necessary to encourage and promote the participation of society in data collection through efficient and well-calibrated citizen science programmes, as well as that of the third sector and companies with corporate social responsibility.

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Similarly, it is essential to move towards a food and consumption model that reduces the impact on biodiversity and favours sustainable production. Current systems are destroying ecosystems that are fundamental to the health of the planet, depleting water resources and altering the climate. There is an urgent need to switch to schemes that guarantee healthy diets for all, reduce food waste, the excessive use of fertilisers, uncontrolled and inefficient energy expenditure and consumerist tourism and, in short, promote the circular economy and good governance to achieve sustainable systems that respect biodiversity. The key, undoubtedly, will be to raise awareness at the individual level for responsible consumption and tourism and to demand from political decision-makers systems that ensure the enjoyment for future generations.

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List of Centres

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CENTRE	WEB PAGE	E-MAIL
Centro de Estudios Avanzados de Blanes [CEAB, CSIC]	www.ceab.csic.es/	direccion.ceab@csic.es
Centro de Investigación Ecológica y Aplicaciones Forestales [CREAF, CSIC-IRTA-UAB-UB-IEC-Generalitat de Catalunya]	www.creaf.cat/es	direccion.creaf@csic.es
Centro de Investigaciones sobre Desertificación [CIDE, CSIC-UV-Generalitat Valenciana]	www.uv.es/cide/	
Centro Oceanográfico de A Coruña [COAC-IEO, CSIC]	www.ieo.es/coruna/	ieo.coruna@ieo.csic.es
Centro Oceanográfico de Illes Balears [COB-IEO, CSIC]	www.ieo.es/baleares/	cob@ieo.csic.es
Centro Oceanográfico de Cádiz [COCAD-IEO, CSIC]	www.ieo.es/cadiz	contacto.cadiz@ieo.es
Centro Oceanográfico de Canarias [COC-IEO, CSIC]	www.ieo.es/canarias	ieo.canarias@ieo.csic.es
Centro Oceanográfico de Gijón [COG-IEO, CSIC]	www.ieo.es/gijon	ieogijon@ieo.csic.es
Centro Oceanográfico de Málaga [COMA-IEO, CSIC]	www.ieo.es/malaga	ieomalaga@ieo.csic.es
Centro Oceanográfico de Murcia [COMU-IEO, CSIC]	www.ieo.es/murcia	web.murcia@ieo.csic.es
Centro Oceanográfico de Santander [COST-IEO, CSIC]	www.ieo.es/santander	ieosantander@ieo.csic.es
Centro Oceanográfico de Vigo [COV, CSIC]	www.ieo.es/vigo	ieo.vigo@ieo.csic.es

CENTRE	WEB PAGE	E-MAIL
Estación Biológica de Doñana (EDB, CSIC)	www.ebd.csic.es/	direccion.ebd@csic.es
Estación Experimental de Zonas áridas (EEZA, CSIC)	www.eeza.csic.es/	direccion.eeza@csic.es
Estación Experimental del Zaidín (EEZ, CSIC)	www.eez.csic.es	direccion.eez@csic.es
Instituto Acuicultura Torre de la Sal (IATS, CSIC)	iats.csic.es/	direccion.iats@csic.es
Instituto Botánico de Barcelona (IBB, CSIC-MCNB)	www.ibb.csic.es/	direccion.ibb@csic.es
Instituto de Agricultura Sostenible (IAS, CSIC)	www.ias.csic.es	direccion.ias@csic.es
Instituto de Agroquímica y Tecnología de Alimentos (IATA, CSIC)	www.iata.csic.es/es	direccion.iata@csic.es
Instituto de Biología Evolutiva (IBE, CSIC-UPF)	www.ibe.upf-csic.es	direccion.ibe@csic.es
Instituto de Biología Integrativa de Sistemas (I2SYSBIO, CSIC-UV)	www.i2sysbio.es/	direccion.i2sysbio@csic.es
Instituto de Ciencias Agrarias (ICA, CSIC)	www.ica.csic.es/	direccion.ica@csic.es
Instituto de Ciencias del Mar (ICM, CSIC)	www.icm.csic.es/	direccion.icm@csic.es
Instituto de Ciencias Marinas de Andalucía (ICMAN, CSIC)	www.icman.csic.es	direccion.icman@csic.es
Instituto de Investigación en Recursos Cienéticos (Junta de Comunidades de Castilla-La Mancha)	www.irec.es	direccion.irec@csic.es

CENTRE	WEB PAGE	E-MAIL
Instituto de Investigaciones Marinas (IIM, CSIC)	www.iim.csic.es	direccion.iim@csic.es
Instituto de Políticas y Bienes Públicos (IPP, CSIC)	ipp.csic.es	direccion.ipp@csic.es
Instituto de Productos Naturales y Agrobiología (IPNA, CSIC)	ipna.csic.es	direccion.ipna@csic.es
Instituto de Recursos Naturales y Agrobiología de Salamanca (IRNASA, CSIC)	www.irnasa.csic.es	direccion.irnasa@csic.es
Instituto de Recursos Naturales y Agrobiología de Sevilla (IRNAS, CSIC)	www.irnas.csic.es/	direccion.irnas@csic.es
Instituto Español de Oceanografía (IEO, CSIC)	www.ieo.es	webmaster@ieo.csic.es
Instituto Mediterráneo de Estudios Avanzados (IMEDEA, CSIC-UIB)	www.imedeai.csic.es	direccion.imedeai@csic.es
Instituto Mixto de Investigación en Biodiversidad (IMIB, UNIOVI-Principado de Asturias-CSIC)	imib.csic.es/	direccion.imib@csic.es
Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria (INIA, CSIC)	www.inia.es/	direccion.inia@csic.es
Instituto Pirenaico de Ecología (IPE, CSIC)	www.ipe.csic.es/	direccion.ipe@csic.es
Misión Biológica de Galicia (MBG, CSIC)	www.mbg.csic.es/	direccion.mbg@csic.es
Museo Nacional de Ciencias Naturales (MNCN, CSIC)	www.mncn.csic.es/	direccion.mncn@csic.es
Real Jardín Botánico (RJB, CSIC)	www.rjb.csic.es/	direccion.rjb@csic.es

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Further Information

**CSIC. PTI Agriambio.****<https://pti-agriambio.csic.es>**

It brings together research teams from different disciplines to develop knowledge that will boost Spain's future agriculture. It seeks to generate knowledge that will provide the scientific basis for the adaptive improvement of the socio-environmental effectiveness of the common agricultural policy (CAP) in Spain.

**CSIC. PTI Agrofor.****<https://pti-agrofor.csic.es>**

Dedicated to the maintenance and recovery of plant genetic biodiversity in agricultural and forestry systems.

**CSIC. PTI Ecobiodiv.****<https://pti-ecobiodiv.csic.es>**

Its aim is the management of interdisciplinary collaborative infrastructures in the collection of ecology and biodiversity data and the unification and interconnection of natural science assets in scientific collections.

**CSIC. PTI HorizonteVerde.****<https://pti-horizonteverde.csic.es>**

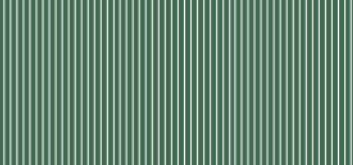
Aims to ensure the future sustainability of agricultural and forestry systems in the face of the impact of climate change.

**CSIC. PTI Oceans+.****<https://pti-oceans.csic.es>**

Develops research and innovation activities aimed at strengthening scientific knowledge on the environmental state of the marine environment in oceanic ecoregions located in the national territory and its response or adaptation to climate change.

**CSIC. PTI PolarCSIC. Polar Zones Observatory: Horizon 2050.****<https://polarcsic.es>**

This brings together the joint work in the Antarctic and the Arctic regions of numerous CSIC groups from various disciplines.



Science for Public Policy



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