CHALLENGE 5

IMPACT OF GLOBAL CHANGE ON MANAGED ECOSYSTEMS

Coordinator
Victor M. Castillo (CEBAS, CSIC)

Participating researchers
X. Antón Álvarez Salgado (IIM, CSIC)
J. Julio. Camarero (IPE, CSIC)
M Delgado-Baquerizo (UPO)
A. del Campo (UPV)
P. García Palacios (ICA, CSIC)
Ana Gómez Peris (IATS, CSIC)
F.J. Giráldez (IGM, CSIC - ULe)
Iñaki Hormaza (IHSM, CSIC - UMA)
D. S. Intrigliolo (CEBAS, CSIC)
Rafael M. Navarro Cerrillo (UCO)
Juli. G. Pausas (CIDE; CSIC-UV)
Jaume Pérez Sánchez (IATS, CSIC)
Ariadna Sitjà-Bobadilla (IATS, CSIC)
David Yañez (EEZ, CSIC)
Manuel Yúfera (ICMAN, CSIC)

1. INTRODUCTION AND GENERAL DESCRIPTION

Climate change, combined with other global stressors, such as a growing population, health, food and water security, soil degradation, and rising consumption in an ever more interconnected world, are posing significant threats to the integrity and functioning of natural and managed ecosystems and its capacity to support human livelihoods in a globalized world (Herrero and Thornton, 2013; Steffen et al., 2015, Marques et al., 2019). Critically important, impacts on food production systems (cropping, livestock and aquaculture) threaten our capacity to maintain food security and increase by 50 % food production to feed the growing population by 2050 (Porter et al, 2014).

Changes in global temperature and precipitation patterns, as well as extreme events are already affecting crop yield and quality of agricultural and forest systems worldwide. Besides these direct climatic impacts, indirect effects on water availability, land degradation and soil health, changes in crop suitability and shifts of cultivation areas, emergence and spread of pests and diseases, together with biodiversity decline and pollinators loss, will risk the capacity of crop and forest systems to sustain the growing demand of food over the last decades (Mbow et al., 2019). Livestock systems are also being impacted as consequences of global warming and changing patterns in precipitation.

Temperature affects most of the critical factors of livestock production, such as water availability, animal production and reproduction, and animal health. Moreover, increases in aridity will impact the production of pastures for livestock herbivores grazing in extensive systems in many regions across the globe. Climate changes are also expected to indirectly impact the livestock through changes in feed quality increases in CH_4 and antibiotic resistance genes, as well as through microbial pest and diseases outbreaks (Rojas-Downing et al., 2017). On the other hand, aquaculture is one of the fastest- growing food-producing sectors in the world, and this activity is tightly linked to freshwater, brackish and marine waters depending on the countries and water resources. Aquaculture production will be affected by both direct and indirect climate change drivers both in short and long terms. Increase in temperature, heat waves ocean acidification, toxic algae, diseases, and other drivers (sea level rise, more intense and frequent storm events, eutrophication and pollution) will pose an unprecedented risk to aquaculture systems (Blanchet et al., 2019, Froehlich et al., 2018) .These negative impacts could be partially offset by new development opportunities in areas where current production is low.

All these points claim for the development of effective, sustainable and resilient food production systems that ensure their capacity to support human well-being. Building production systems resilient to multiple direct and indirect climate driven impacts will be fundamental for humankind, and will require taking concerted adaptation and mitigation actions. Adaptation is highly context-specific, and no single approach for reducing risk is appropriate across all regions, sectors, and settings. Strategies for adaptation include, but are not limited to, higher quality impact assessment methods and the development early warning systems; optimizing the use of more tolerant species; harnessing genetic variability and biodiversity; water management including agronomic practices to reduce water losses, managing animal's diet and monitoring and managing the spread of pests and diseases (European Environment Agency, 2019). Mitigation in the Land related sector (AFOLU thereafter: agriculture, forestry and other land uses) is key to achieve ambitious goal of 2015 Paris agreement of limiting global warming 2 °C below of pre-industrial level, because it was responsible for about 10–12 % of global greenhouse gases (GHG) emissions in 2010. This sector is the largest contributor of non-CO_2 GHGs (including methane), accounting for 56 % of non-CO_2 emissions in 2005 (Tubiello et al., 2015). Mitigation pathways to reduce the carbon footprint of AFOLU sector are related to the improvement of production system and unlocking the potential of carbon sequestration in soil and biomass.

Biomass and soil carbon stocks in terrestrial ecosystems are currently increasing but they are vulnerable to loss of carbon to the atmosphere as a result of land use changes and the projected increases in the intensity of storms, wildfires and land degradation. Croplands store more than 140 Pg C in the top 30-cm soil depth, the most relevant layer for agricultural production (Zomer et al., 2017). This amount accounts for 19% of the global soil C stocks estimated at this depth (Jackson et al., 2017). Protecting and building C stocks in croplands is of paramount importance, as even subtle C losses may represent a substantial contribution to the build-up of the atmospheric CO_2 pool (~750 Pg C; Ciais et al., 2013). As an example, it is well known that the conversion of non-cultivated ecosystems such as forest to croplands typically causes a rapid decline in soil C stocks due to practices such as tillage or inorganic fertilization.

Forests are currently a net sink for carbon at the global scale. It is estimated that intact and re- growing forests currently contain 860 ± 70 Pg C and sequestered 4.0 ± 0.7 Pg C yr–1 globally between 2000 and 2007 (Settele et al., 2014). The future of the interaction between the atmosphere and forests is however unclear. Most models suggest that rising temperatures, drought, and spreads of wildfires and dieback episodes will lead to forests becoming a weaker sink or a net carbon source before the end of the century. Reforestation and deforestation processes over the next decades will play a key role in driving the future of C stocks worldwide (Roe et al., 2019)

The effects of the increase in the frequency of extreme weather events linked or not with other factors can be aggravated by a lack of, or erroneous management, which can expand the impact of climate change in already vulnerable forest ecosystems. For instance, wildfire activity is not only controlled by climate (Pausas and Keeley 2014), it requires ignitions and appropriate vegetation to spread, and these two factors are strongly related to human activities (land use, rural abandonment, afforestation, housing, etc.; Pausas and Fernández- Muñoz 2012). The necessary role of forest and landscape management on preserving forest goods and services in face of global change must be understood by the broad society.

2. IMPACT IN BASIC SCIENCE PANORAMA AND POTENTIAL APPLICATIONS

The effects of climate and others non-climate driven changes on natural resources and food production are already evident. The need to ensure food security in a changing world is recognized by the 2015 Paris Agreement of the United Nations Framework Convention on Climate Change (UNFCCC). Indeed, many countries have included food production systems under their mitigation and adaptation plans as found in their National Determined Contribution (NDCs) to Paris Agreement. The importance of soil C in mitigating climate change is currently recognized in international political actions such as the 4 per 1000 initiative. Governments committed by the 2015 Paris Agreement to limit global warming to less than 2°C above pre-industrial levels and to pursue efforts to limit the increase to 1.5°C and to adapt to unavoidable changes.

Pursuing effectively this ambitious goal will require to take actions to curb greenhouse gas (GHG) emission and to adapt to unavoidable changes that should be based on an improved understating of the links and causalities between climate events, ecosystems functioning and human-made decision on land and water resources management.

The research path proposed in this chapter aims to (i) identify and fill existing knowledge gaps on the global assessment of the impacts of different scenarios of global change on managed ecosystem, (ii) realize the potential capacity of the food production systems and land sector to reduce GHG emissions; and (iii) strengthen the resilience of the primary production sector to the impacts of global change.

In the next section we propose four key challenges. Each one addresses specific issues to further advance in the scientific understanding of the consequences of global change and how to cope with it. We expect that a successful response to the proposed key challenges will exert a positive impact on:

- Performing more reliable global impact assessment on food production systems by accounting for the combined effects of multiple stressors, and a better knowledge of the vulnerability of the species and the whole system to climate and non-climate related drivers.
- Developing early warning systems and other tools to forecast climate-sensitive events (storms, droughts, pest outbreaks) that allow to take up actions in advance.

- Devising approaches of mitigation based on more robust associations between climate-induced drivers and human-directed drivers of global change to avoid incorrect attribution.
- Boosting the use and management of biodiversity (genetic variability, soil diversity, gut microbes landscape heterogeneity) to adapt to climate change and reduce the footprint of production systems.
- Supporting the adoption of adaptation strategies that deliver co-benefits in terms of climate change mitigation, biodiversity conservation, prevention of land degradation, and water and food security.
- Fostering the adoption of integrated landscape management to deal with land competition issues while securing the provision of ecosystem services in a changing environment.
- Shifting from risk management adaptation practices (mainly at farming and exploitation level) to transformative projects of food production systems.

We also expect that the outcomes of this research have a strong impact on the development of policies and programs to tackle the environmental and development challenges across scales. Food, water and climate are three prominent elements in Sustainable Development Goals (SDGs). Eradicating hunger by 2030 (SDG 2) requires more sustainable food production systems and climate-resilient agricultural practices, which also offer active solutions to decreasing the negative effects of climate change. Food security and land sector (AFLOU) are also critical to other aspects of sustainable development, including poverty eradication (SDG 1), health and well-being (SDG 3), clean water (SDG 6), decent work (SDG 8), and the protection of ecosystems on land (SDG 15) and below water (SDG16).

At European level, dealing with climate change is a key objective of the European Green Deal, the Common Agricultural policy (CAP) and the Farm to Fork Strategy. The proposed new CAP for 2021-2027 has adaptation as a clear objective, and the achievement of the objectives of net zero GHG emissions in the EU by 2050 will be required an increase in carbon sequestration in agriculture and forestry sectors.

Finally, the 3rd work programme of the Spanish National Plan of Climate Change seeks to promote actions to adapt to climate change and reduce vulnerability of sectors. The plan recognizes that knowledge of climate changes impact on primary sector is copious but scattered and with gaps that need to be effectively implemented in plans and programmes.

3. KEY CHALLENGING POINTS

3.1. Understanding the impact of global change on food production systems: cropping, livestock and aquaculture

Advancing modelling of the impact on agricultural systems

Understanding how climate change and land degradation affect current crop production and food security, and the extent to which they will do so in the future is crucial to develop and adopt actions to mitigate and adapt to global change impacts. Our understanding of the relationship between climate change and land degradation with agricultural production is still very limited, in particular when impacts are multiplied or combined with other socio-economics consequences of climate change. On the other hand, attribution of any observed changes to climate trends are further complicated by the fact that models linking climate and agriculture must, implicitly or explicitly, make assumptions about farmers' behavior.

Consequently, we need to increase our knowledge and to improve our capacity to assess current and projected impacts of global change on agriculture and food security (Elbheri et al., 2017). The following lines of research can be identified as a priority:

- Developing complex impact assessment models that (i) evaluate cumulative impact by integrating direct (raising temperatures, changes in rainfall patterns, increase CO_2 concentration in the atmosphere) and indirect (water availability including aspects related to both quantity and quality land health or land use changes) climate impacts (ii) appraise crops suitability, and (iii) simulate multi-crops.
- Incorporate biophysical and socio-economic drivers of crop production and land use on complex integrated assessment models so to (i) enhance the capacity of attribution of projected changes to climatic and anthropogenic changes, and (ii) forecast agricultural land abandonment and land use changes resulting from decrease on profitability and shifting of production locations (cascade effect).
- Modelling the impact of the occurrence of weather extreme events (drought, frost and heat waves) during critical phenological periods and their impact on crop yield and its components.
- Improve our assessments of the impact of future climatic scenarios on crop quality. Although there are growing evidence suggesting a decline in proteins and nutrient content of the crops due to the increase CO_2 concentration, modelling impact on quality is well behind than on

quantity (weights) aspects.
- Ensuring long-term monitoring programs to collect temporal data aiming to understand complex dynamics in climate change and yield production, which are further needed to validate and test impact global change cropping models.

Improving our knowledge on the sensitivity and vulnerability of livestock system to global change

The impact of global change on livestock has received comparatively less attention than the impacts on crop production. Moreover, there is a need of a deeper understanding on the sensitivity of the different factors and the whole production system to individual and combined changes of climatic variables. To advance on this knowledge, we should address the following objectives:

- Assessing the impact of climate change on production and nutritional composition of forage and other fodder crops. It is crucial to map the impact of global change by different geographical areas and crop types to forecast feed yield.
- Assessing the impact of climate change on trophic interactions and sustainability in grazing ecosystems from a comprehensive perspective, including farmers' operational decisions
- Understanding the sensitivity to heat and water stresses of species and breeds at different physiological stages through the identification of the molecular basis of the adaptive mechanisms and their links with reproductive and food efficiency, immunological competence and quality of animal products.
- Understanding the impact of climate change on spread and the life-cycle dynamics of pathogens outside of the livestock host species
- Assessing the cost and effectiveness of adaptation options to the combined impacts of climatic changes. There is a strong need for additional research on integral multifactorial impact assessments

Integrated assessment of multiple stressors on aquatic species

Evidence of the impact of global change, and particularly climate change, on the aquaculture systems is still limited compared with that in other food production systems. Future is needed to progress in an integrated knowledge of the effect of water temperature, dissolved oxygen, acidification, pollutants, and salinity on the growth, nutrition, metabolism, reproduction, immune status and adaptability of the aquatic species. There is a need for long-term experimental studies with multiple stressors, including analysis of different generations and life stages, to assess basic questions such as the role of phenotypic plasticity (within one generation) and also trans-generational adaptation. All already known stressors affect different aspects of the reproduction, growth and health, but in many cases the underlying molecular mechanisms are not known yet. Accurate determination of thermal tolerance on different stages (larvae, juvenile, and broodstock) and the consequences of increased temperature on behaviour and productive traits affecting digestion and feed conversion, health and welfare, stress resilience, nutrient requirements and the use of new raw material as main components of new aqua-feed formulations have not been completed for the main farmed species. Likewise, reproductive capacity is highly dependent on water temperature, and most environmental stressors including raising temperature affect sex steroid profile, which also has an impact on the quality of the progeny through the involvement of epigenetic mechanisms.

In order to predict the impact of climate change on aquaculture the development of coupled climate – biological /ecological models are also necessary. Advances and development of these models will not only contribute to produce early warning systems able to support decision making under the current climate change conditions, but also to predict the impact of climate change on aquaculture activities on the medium and long-term, to evaluate future risks and opportunities and to elaborate adaption plans to ensure food security.

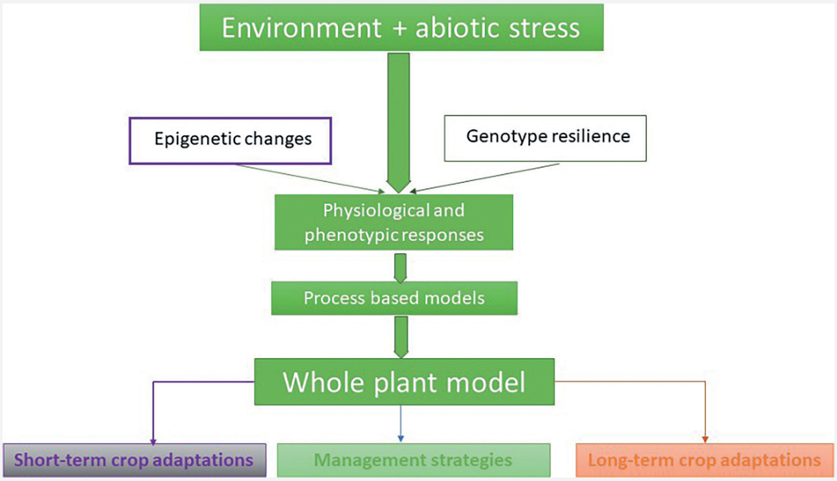
3.2. Fostering resilient and better adapted food production systems

Innovative tools for building resilient agricultural systems: crop management modelling and harnessing soil biodiversity

Adaptation options at farm level combine the use of current genetic resources and breeding programs for obtaining more tolerant crop species and varieties, the development of new crop diversification and rotation strategies, the adoption of advanced agronomic practices including precision farming and modifying crops calendar, and the better management of natural resources. Challenges associated to development and operational implementation of these responses (sustainable intensification, agro-ecology, sustainable land management) are discussed in thematic 6.

Here, we will focus on additional challenges regarding on the development of process-based models (PBM) aimed to design crop adaptation to specific

FIGURE 1–Innovative tools for building resilient agricultural systems: crop management modelling



changing environments and to the use of biodiversity to maintain and increase yield production while minimizing ecological footprint. This framework should result in a combination and integration of biology, technology and computation sciences applied to the whole farming system under study (Figure 1).

Crop strategies are ecosystems context-dependent. Therefore, results obtained for a given Genetic (G) × Environment (E) interactions are often only valid for the local conditions where in these strategies are developed. However when results are extrapolated to other sites many times contrasting results are reported. PBM are increasingly being used for research and application purposes in plant sciences and natural resource management (Holzoworth et al. 2014). Such models integrate the complex interactions of crop eco-physiological processes as they respond to environmental drivers and predict their impact on productivity. The ability of crop models to capture cultivar (or genotype) differences within a crop species in response to environment and management drivers enables simulating the outcome of the complex interactions among genotype, environment, and management (G×E×M), thus allowing phenotypic attributes to emerge as a consequence of model dynamics. PBMs can be applied at different levels, from genes to whole plants. PBM are tools to make physiology and genetics more predictive by bridging the gap between genotype and phenotype. The physiological and adaptive responses of plants to environmental changes are the result of complex interactions between genetic and epigenetic mechanisms that are translated into changes to specific functional traits. By using PBMs, it is also possible to integrate genetic information into plant physiological responses. In addition, PBMs have the advantage that they can be used in Decision Support Systems to simulate crop behaviour and take decisions on crop management practices.

Harnessing the microbiome associated soil and crop species in agricultural ecosystems (i.e., the crop microbiome) will be of paramount importance to promote future healthy and productive agricultural ecosystems in a changing world. In order to unleash the full potential of the crop microbiome aiming to promote healthy and productive crops under future scenarios of climate change and extreme climatic events (e.g., drought) we need (i) to characterize the structure and function of the major crop species (e.g., wheat, rice, corn, potatoes etc.) across wide climatic and vegetation global gradients (e.g., https://www.globalsustainableagriculture.org), and to identify the components and functional capabilities of the crop microbiome; (ii) a better understanding about what, how and why keystone species influence crop production; (iii) to identify what microbial species are cultivable and able to team up with other microorganisms as to create plant probiotics capable of promoting yield production in a global change context, and (iv) to know more about the evolutionary changes in the microbiome of crop species during the domestication process that could help us to identify particular keystone microbial species and traits, which were lost during the domestication process, but that, could now be used to promote plant production under stressed environments.

Agriculture in a drier world: Increasing the efficiency and sustainable use of water resources

Increasing the efficiency and sustainability of the water use by agricultural systems is needed to cope with the double challenge of meeting a higher water demand with less available freshwater resources.

Designing water efficient agricultural systems through the application of agronomic practices that reduce evapotranspiration losses will lower the water consumptive use. Woody perennial crops have often incomplete ground cover leaving part of the soil directly receiving a high radiation regime that increases the evaporative component of the orchard evapotranspiration.

Sub-surface drip irrigation systems eliminate most of the soil evaporation component from the system water balance, and they could be used in cases of water scarcity. In addition, when the volume of applied water needs to be restricted in relation to potential evapotranspiration, decreasing the volume of soil wetted by the drip system, by reducing the number of emitters per tree, can be a useful way to increase the irrigation efficiency.

In fruit trees, there is evidence that high fruit load may enhance the sensitivity of fruit growth to water stress (Berman and DeJong, 1996). Hence, reducing fruit load has been used to mitigate the negative effects of plant water stress, though with important yield penalties. Under low crop demand conditions, a reduced plant photosynthesis rate due to water stress is less detrimental since fruit are the major sink for carbohydrates, particularly during stage III of fruit growth. In addition, lowering fruit load has been shown to reduce plant water use because of a reduction in stomatal conductance via feed-back mechanisms.

Eliminating part of the actively transpiring canopy surface area (such as whole branches) can be also used to help fruit tree survival under extreme drought conditions. It is obvious that this practice has major consequences on the current year tree performance, but at least can guarantee plant survival. In addition, innovative canopy forms should be designed to optimise light interception reducing tree transpiration under soil water limiting conditions. Under a future scenario of reduced water availability, new orchard and vineyard designs might alleviate the impact of drought stress. In this sense, the use of shading nets has been proven to be useful for increasing water use efficiency and even crop performance.

The improvement of water use efficiency at field, or farm level, (maximizing "crop per drop") should be aligned to the optimized sustainable use of water resources at basin level as an element of Integrated Water Resources Management (IWRM). IWRM is a coordinated process focusing on both economic and social issues while protecting ecosystems and ecosystem services at the same time. The IWRM approach has been accepted internationally as the way for efficient, equitable and sustainable development and management of the world's limited water resources and for coping with conflicting demands. This IWRM approach is required for coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems.

Methodologies for integrating climate change adaptation (CCA) into IWRM should be investigated, developing innovative approaches and/or testing existing ones. The IWRM-CCA approaches should be implemented and tested by involving all the potential stakeholders in experimental sites representative of Spanish water conditions in terms of water scarcity, water use efficiency, use of non-conventional irrigation waters (saline and waste), changing climatic conditions, different crops, conflicting use of available waters, as well as need for governance by different authorities, and other relevant factors. Existing simulation models predicting the impact of climate change can be useful tools for developing adaptation strategies. Calibration and validation of these models is necessary to obtain site-specific results in terms of climate change impact and adaptation. These results should be incorporated in the IWRM-CCA approach to develop water allocation strategies aimed at meeting various sectorial water demands under future climate change scenarios and with different socio-economic assumptions.

Better adapted livestock production systems to climate change

Livestock production systems have proved to be resilient to disturbances because of their technical and biological adaptive capacity. None of the less, the magnitude, intensity and pace of projected impacts of global change will make necessary to strengthen the adaptive capacity of the different elements of the system. To devise better adapted livestock systems, we need additional research on:

- Developing early warning systems (EWS) on stresses driven by climatic change and infectious diseases. Increasing the capacity of forecast climate-sensitive diseases outbreak, and the application of responsive measures at the proper time are key factors for a more effective prevention and control.
- Reassessment of current production systems to identify the species, breed and crosses most adapted to local environmental conditions and the production objective and increase diversity. The improvement of animal rearing conditions (shading and sprinkles, ventilation systems) could mitigate the projected impacts of growing of heat and water stresses in arid and semiarid zones. However, an integral assessment of the system will be necessary, including risk analysis and the evaluation of the efficiency in the use of resources (water energy) needed. Some authors argue for using local less productive species but more tolerant to stresses instead of more tolerant strains by breeding non-adapted species.

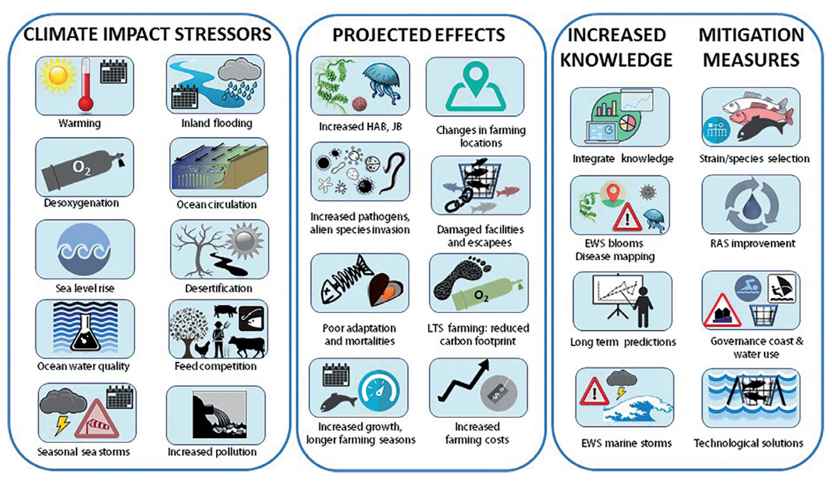
- Advancing our knowledge on: (i) the relationships between genome and epigenome and the tolerance to diseases and heat and water stresses, and (ii) the role of the gut microbiome in tolerance to heat stress and resistance to diseases.
- Assessing nutritional, reproductive and management strategies to mitigate the impact of climate change, in particular the effects of heat stress.
- Advancing in the knowledge of epidemiology of prevalent and emergent diseases and developing tools to diagnose, prevent and control. On-farm monitoring of animal behaviour and physiological parameters based on nanotechnology and new developed ITs tools will bring about early detection of ill animals. The development of vaccines and programs of vaccination is of primary importance to improve the capacity of prevention and control.

Adapting aquaculture systems: from anticipating the impacts to planning and optimizing management

Aquaculture systems are vulnerable to gradual change of climatic conditions and extreme weather events often resulting in severe loss of stock and infrastructure. Possible adaptation and coping measures require additional research into:

- Modelling towards early warning systems (EWS) of water temperature effects on aquatic pathogens and harmful biological blooms. Harmful algal blooms can lead to the loss of bivalve stocks, which have been estimated to cause losses globally of €200 million in one year and can also lead to illness in humans who consume effected shellfish. Jelly fish blooms have also been identified as a risk in the Mediterranean finfish farming due to oxygen depletion in sea cages and skin erosions (Bosch-Belmar et al., 2017). Fish and mollusc pathogens are also important economic drivers of aquaculture production. Thus, progress in the development of early detection systems of harmful blooms and aquatic pathogens, including the integration of diverse methodologies from image detection to on-site methods with light sensors and smart devices is imperative.
- Developing EWS of marine storms and development of technological solutions to avoid massive damage to marine infrastructures. Increased storminess (increases in wind velocity and changes in direction, water currents and waves) and increased frequency of extreme events (such as

FIGURE 2—Climate impact stressors affecting aquaculture activities, their projected effects and the needs to increase the knowledge that will make possible to implement mitigation measures



storms, floods, and droughts) are expected to have a negative impact on offshore mussel raft and fish cage aquaculture in the Atlantic and Mediterranean basins.

- Devising integrated spatial planning for aquaculture farm setting that consider governance strategies for the coastal use and preservation of water quality. Because of high risk of a reduction of aquaculture suitable areas and more stringent legal conditions for the establishment of new facilities we need of better site selection methods that balance resources conservation and production.
- Advancing in new technologies to reduce water use and increase biosecurity. Recirculation aquaculture systems (RAS) reduce water needs, improve the production and reduce the impact of pathogens in inland and marine cultures. RAS will allow the delocalization of fish farming from pristine waters, and will compensate the disappearance of inland open flow and coastal ones impacted by climate change.

3.3. Mitigating the impact and reducing emissions: negative emission options and low-carbon footprint primary production systems

The land-based mitigation pathway: Towards a carbon efficient use of the land

Global models predict that meeting the ambition goal of the Paris agreement of limiting warming to 1.5 °C above pre-industrial level will be only possible with negative emission. Among the negative emission technologies, land-based options are gaining the attention. Land based mitigation options include among others measures: (i) afforestation/reforestation; (ii) sustainable forest management (see section 3.4.1); (iii) biomass energy with carbon capture and exchange (BCSS); (iv) soil carbon sequestration (see section 3.3.2) and biochar application. It is estimated that land sector could deliver up to 15Gt CO_2 eq year-1 (about 30% of the mitigation) up to 2050 while contributing to several sustainable development goals (Roe et al., 2019). The feasibility and suitability of implementing large-scale land-based carbon dioxide removal technologies have been however questioned because of their water and footprint that would result in an increasing demand and competition for land and adverse impacts on biodiversity and food production.

Further research is needed on the affordability, reliability and sustainability of land-based mitigation pathways. This will address the following key issues: (i) incorporate environmental and social safeguard in integrated assessment models (IAM) of land-based mitigation pathways; (ii) evaluate how future climatic conditions could eventually affect the potential capacity of land-based mitigation option; and (iii) deploy integrated landscape planning to design and build carbon efficient landscapes. A carbon efficient landscape is that maintains or increases land–based carbon while delivering co-benefits such as for example enhancing biodiversity, soil fertility, halting desertification and land degradation, promoting water retention or diversifying livelihoods (Searchingeret al.,2018).

Enhancing soil carbon sequestration as a natural based solution for climate change mitigation

Protecting and rebuilding soil C is a powerful Natural Climate Solution to increase carbon sinks and deliver negative emissions. Soil C sequestration comprises up to 47% of the mitigation potential for the agricultural sector (Bossio et al., 2020), and delivers important ecosystem services in addition to climate mitigation such as soil fertility, water retention and pathogen control.

However, despite its great potential in agricultural systems, the practical implementation of climate mitigation strategies focused soil C lags behind its potential.

We have identified four research lines devoted to meet the key challenge of building soil C as a natural climate solution to mitigate the climate change contribution of agriculture and forestry. First, soil C sequestration may be promoted via multiple agricultural practices (improved residue management, reduced tillage, cover cropping, biochar), but their potential varies across climatic and soil conditions. Second, soil C is stored in a mixture of organic matter fractions (mineral-associated vs. particulate) that differ in their stability against microbial decomposition, determining the vulnerability of soil C stocks to climate warming and agricultural practices. Third, there is a trade-off between soil C storage and the emission of greenhouse gases with high warming potential, as agricultural practices increasing soil C sequestration can also enhance CH_4 and N_20 emissions. Finally, climate warming may stimulate the loss of soil C to the atmosphere, reinforcing climate change, and these losses may be fuelled or compensated with agricultural practices.

Generalizing soil C sequestration as a management goal in agricultural systems requires the design of monitoring programs at the farm level coupled with the increasingly more available remote sensing measurements. To do that, methods allowing a cost effective and straightforward quantification of soil C are needed

Deploying low carbon footprint aquaculture

All aquaculture systems should contribute to mitigate global change by optimizing every step of the cultivation process (from hatchery to harvest) to reduce their carbon footprint (net greenhouse gas emissions) and environmental impact (e.g. eutrophication, metal, organic and emerging pollutants). But further research is needed to foster the mitigation potential of aquaculture activities. Low Trophic Species (LTS) aquaculture (i.e. microalgae, macroalgae and bivalves) is a low carbon footprint activity with potential to sequester atmospheric CO_2 and, therefore, contribute to global warming mitigation. LTS aquaculture also contributes to the good environmental status of coastal ecosystems. Conversely, as LTS are fed by the environment, these aquaculture systems are more sensitive to climate and global change than high trophic species (HTS). Combining complementary cultures of LTS and HTS, as in the Integrated Multitrophic Aquaculture systems, also contributes to reduce the carbon footprint and environmental impact of HTS aquaculture activities. Eventual inclusion of LTS aquaculture in the international carbon trading market implies proposing algal biomass and bivalve shells applications that ensure the long-term preservation of the trapped CO_2.

3.4. Maintaining and enhancing carbon stocks and the provision of ecosystem services in threatened forests

Fostering adaptive forest management to climate change

Lack of forest management (in a gradient from non-intervention to intensive silviculture) to adapt forests ecosystems has resulted in high-density stands vulnerable to recurrent disturbances (e.g. pest and diseases outbreaks, wildfires, drought-induced dieback, and mortality). Forests need new planning tools and solutions to predict and forecast the influence of management practices on disturbance regimes and associated dynamics (Vilà-Cabrera,et al., 2018). Such tools must explicitly address the margin for manipulation, including among others the structure of the ecosystem, current and potential range of variation in stand composition, history of disturbance or disturbance suppression, and stand dynamics over time. Additionally, this conceptual advance must be accompanied using new technological tools (e.g. remote sensing, big data analysis, modelling, TIC, etc.) without which it is not guaranteed the future sustainability of forest ecosystems.

Items to be addressed to develop these tools are, among others:

- Identifying structural, ecophysiological or functional traits and related processes that are most sensitive to forests dynamics, in particular new stress conditions (e.g. global change, droughts, pest and diseases, pollution, etc.).
- Establishing traceable methods, based on eco-hydrological processes and mechanistic models, that explicitly relate forests ecosystem services (in particular water and C cycles) with forest management, paying special attention to the context of global change.
- Determining what are the management options applicable in the short and long term (e.g. when and where management adaptation strategies should be employed) to adapt Spanish forests to extreme climatic events as droughts and the analysis risks that intervention will make effective, given various ecological, economic or social scenarios.
- Integrating the objectives for managing forest at landscape scale to alleviate climate- related stresses and to enhance forest capacity to

resist, tolerate and adapt to a dynamic environment. Mosaic-liked landscapes that include agro-silvopastoral systems must be part of the forest management approach focused on resilience.

- Incorporating the current technological paradigm (e.g. remote sensing, wire-less sensors, IoT, etc.) into the silvicultural adaptive approaches/strategies that can address a complex ecosystem-specific climate change adaptation treatment in a gradient from field to big data integration and decision support.

Coping with wildfires: Managing landscapes for generating ecologically and socially sustainable fire regimes

Wildfires are currently one of the most important sources of variability, heterogeneity, and dynamism in our landscapes. They alter plant and animal population occurrences (extinction) and sizes, modify community and landscape structure, affect biotic interactions and open opportunities for new species including invasive ones. Wildfires within the historical variability of the fire regime are an evolutionary pressure that may generating biodiversity (He et al. 2019) and ecosystem services; but abrupt changes in fire regime may be detrimental for biodiversity (Keeley and Pausas 2019). Thus, understanding how species and biotic interactions respond to wildfires (at ecological and evolutionary scales) is a key step for setting appropriate land management and conservation programs. Traditionally wildfires have been viewed as an external factor, a "forest problem". The research in the last decades suggest that wildfires needs to be viewed as an intrinsic factor to ecosystems and societies, so that once it is integrated in the system, we can better understand it and managed it. In order to enhance our understanding for a better management of wildfires, we need to know:

- What are the fire regime thresholds that generate abrupt changes in biodiversity?
- What is the adaptive capacity of the species to changes in fire regime?
- What are the ecological (biodiversity, biogeochemistry) consequences of fire regimes changes?
- What are the ecological consequences of managing landscapes for protecting people and infrastructures?
- What is the proportion of variability in species distribution and biodiversity explained by fire regime?

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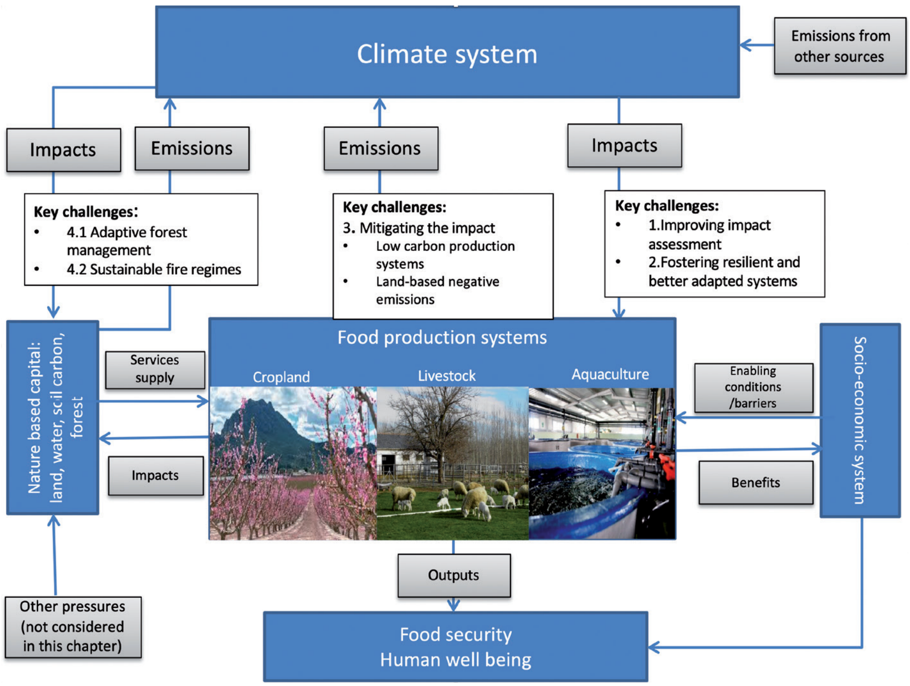
ACADEMIC SLIDE



Climate system

Emissions from other sources

Impacts

Emissions

Emissions

Impacts

Key challenges:
- 4.1 Adaptive forest management
- 4.2 Sustainable fire regimes

Key challenges:
3. Mitigating the impact
- Low carbon production systems
- Land-based negative emissions

Key challenges:
- 1.Improving impact assessment
- 2.Fostering resilient and better adapted systems

Nature based capital: land, water, soil carbon, forest

Services supply

Impacts

Food production systems

Cropland

Livestock

Aquaculture

Enabling conditions /barriers

Benefits

Socio-economic system

Outputs

Food security
Human well being

Other pressures (not considered in this chapter)

CHALLENGE 6

ABSTRACT

Our unsustainable use of nature is bringing the Earth system and its capacity to recover from global changes beyond the environmental boundaries that supported us as a society. Here, we discuss some urgent challenges that should be addressed for the human species to live with undesirable products resulting from its development: sustainable use of nitrogen, watersheds management for preserving water resources and their quality, environmental impact of plastics, increase of the resilience of marine ecosystems, restoration of the deteriorated marine coastal ecosystems, or the early detection of emergence of diseases. We advocate for the use of Nature based solutions to mitigate environmental problems, and also consider subjective wellbeing issues in the governance of societies for a future healthy planet.

KEYWORDS

Sendai Framework
nitrogen cycling
watersheds management
plastisphere
bioengineering
resilience
marine ecosystem restoration
zoonotic diseases
natural capital
social capital

CHALLENGE 6

HEALTHY PLANET: HAZARDS, RISK MANAGEMENT AND SOLUTIONS-ORIENTED RESEARCH

Coordinators
Emilio O Casamayor (CEAB, CSIC)
Fernando Valladares (MNCN, CSIC)

Participating researchers
Txetxu Ausín (IFS-CCHS, CSIC)
Frederic Bartumeus (CEAB, CSIC)
Susanna Bernal (CEAB, CSIC)
Lluís Camarero (CEAB, CSIC)
Mikel Becerro (CEAB, CSIC)
Emma Cebrian (CEAB, CSIC)
Jordi Catalan (CREAF, CSIC – UB - UAB)
Ada Ferrer i Carbonell (IAE, CSIC)
Joaquim Garrabou (ICM, CSIC)
Helena Guasch (CEAB, CSIC)
Aurora Nogales (IEM, CSIC)
John RB Palmer (UPF)
Albert Sorolla (Naturalea SL)
Jorge Terrados (IMEDEA, CSIC - UIB)

1. INTRODUCTION AND GENERAL DESCRIPTION

A 10,000 year-long period of stability of the earth system has provided the necessary conditions for agriculture to develop and for us, as a society, to thrive. This stability is now challenged by our unsustainable use of nature, exacerbated by the fossil fuels dependency of our steadily increasing energetic demands, with negative impacts of humans on both the Earth system and its capacity to recover from change. With a degraded resilience capacity, the future of Earth may go beyond the environmental boundaries that supported us as a society. It seems paradoxical that the same development that allowed us to thrive is now jeopardizing our future. The Sendai Framework for Disaster Risk Reduction 2015–2030 was one of three landmark agreements adopted by the United Nations in 2015, together with the Sustainable Development Goals of Agenda 2030 and the Paris Agreement on Climate Change. In May 2019, the UN Office for Disaster Risk Reduction (UNDRR) and the International Science Council (ISC) jointly established a technical working group to identify the full scope of hazards relevant to the Sendai Framework as a basis for countries to review and strengthen their risk reduction policies and operational risk management practices. The hazard list provided by the technical working group identified >300 hazards grouped in eight clusters: (i) meteorological and hydrological hazards, (ii) extraterrestrial hazards, (iii) geohazards, (iv) environmental hazards, (v) chemical hazards, (vi) biological hazards, (vii) technological hazards, and (viii) societal hazards. The way these hazards interact and the complex interactions between natural, social and technological systems, and how those interactions affect, across time and space, the planet's life support systems, socio- economic development and human wellbeing are fundamental issues that need to be properly addressed for global sustainability.

Hazard information when combined with exposure, vulnerability and capacity is fundamental to all aspects of disaster risk management, from multi-hazard risk assessments for prevention and mitigation to warnings and alerts, to disaster response and recovery, long-term planning and public awareness. A successful understanding of hazards for a healthy planet needs to move from managing disaster events to managing risks, by addressing the systemic drivers of risk in relation to climate change, health, sustainable development, and resilience building.

This chapter focuses on some challenging points combining natural and social sciences selected as snapshots of the complexity, multidisciplinarity, and potentials of the approach at CSIC.

2. IMPACT IN BASIC SCIENCE PANORAMA AND POTENTIAL APPLICATIONS

Addressing the risks for human well-being that are associated with environmental degradation requires an extensive collaboration among contrasting scientific disciplines. Risks spread from climate change to pollution and from pandemics to the deployment of crucial resources such as fresh water. To anticipate these risks, to handle and correct them and to restore degraded ecosystems can only be achieved by multidisciplinary teams including biologists, physicists, modelers, medical scientists and veterinaries but also economists and a wide range of social scientists. This is in fact the spirit of the One Health program of the World Health Organization of the United Nations that CSIC is particularly well suited to tackle.

3. KEY CHALLENGING POINTS

3.1. Environmental Risk Management and Nature Based Solutions

Sustainable Nitrogen use

Nitrogen cycling through the biosphere rapidly doubled when abundant and cheap energy provided by the mobilization of oil reserves allowed the massive artificial fixation of nitrogen. A planetary boundary of still unknown consequences was crossed when humans became the stewardshipers of the nitrogen cycle. Reconciling high nitrogen demand for food supply with a safety biosphere became a primary challenge (Galloway et al 2008).

Shortly after the First World War, the Haber-Bosch chemical method for converting molecular nitrogen into ammonia was discovered. Roughly, the production of fertilizers accounts for 30% of all the nitrogen that circulates through the biosphere. The leguminous crops contribute another 15%, and 7% combustions in air; altogether more than half of the reactive nitrogen in the biosphere. Unfortunately, this acceleration of the nitrogen cycle leads to serious environmental problems because of the low use efficiency and the release of nitrogen contaminants to waters and atmosphere. Some of the early consequences, such as acid rain resulting from the emissions of sulphur and nitrogen oxides, were striking and corrective measures upon the main focus of pollution provided quick results. However, since then, little has changed because action on more diffuse and extensive sources is exceptionally complex. The global nitrogen scenery has changed little; for decades, estimates have been similar and hardly reducing uncertainty (Fowler et al. 2013).

Between 1900 and 2000, the application of methods of fertilization in agriculture (manure, commercial fertilizers and extension of the cultivation of legumes) increased > 100-fold. Nonetheless, the efficiency of use — understood as the nitrogen in harvest compared to the applied — decreased from > 60% to < 50%. This low yield results in increasing nitrate levels in waters and the emission of ammonia and nitrogen oxides into the atmosphere. Thus, pollution is transported far away from the fields. In hot spots of fertilizer use, the contribution of ammonium to total nitrogen deposition is increasing, becoming the majority form over large rural and remote areas. On the other hand, the metabolism of cities also returns large amounts of nitrogen to wastewater, generating a high treatment cost. There are health and environmental problems related to both scarcity and excess of nitrogen. Therefore, the balanced use of nitrogen is one of the main challenges for a sustainable society.

In present days, atmospheric transport and subsequent deposition have become the dominant nitrogen distribution process on a global basis, equivalent to about one-fourth of the total global nitrogen flux. The release of nitrous oxide (N_2O, a gas with 300-fold more greenhouse capacity than CO_2) is also a major concern. The amount of N_2O in the atmosphere has been increasing, with no signs of slowing down, over the past decades. It becomes essential to understand which factors control the N_2O:N_2 ratio. This question concerns wastewater treatment systems but also large areas of the planet affected by the atmospheric deposition of reactive nitrogen. Research based on molecular biology techniques, use of stable isotopes as tracers, and skills on simulating the complex nitrogen cycle may foster a required transition from heuristic knowledge to knowledge based on process understanding. Sustainable use of nitrogen by society necessarily implies increasing scientific knowledge to efficiently manage the nitrogen processes in which the natural and the human cycle are inevitably intertwined.

Integrated watersheds management

Diffuse and point source pollution in human-impacted watersheds has been increasing over decades. Simultaneously, the acceleration of the hydrological cycle is leading to an increase in the frequency of floods and droughts. The interaction between watershed pollution and climate variability can have devastating consequences for ecological and societal systems, and compromises the availability of freshwater resources in the future (Kaushal et al., 2018). The challenge is especially difficult in Mediterranean regions, where water is scarce and the management of freshwater resources is critical.

Water quality has been a priority for the European Union for many years. In 2000, the Water Framework Directive envisioned a good status of all EU waters by 2015. This aim was accomplished only by half of EU water bodies in 2012. Since then, water quality has improved, but only slightly. The 22% of EU water bodies still suffer of diffuse and point source pollution, while nutrient excesses precludes a good status of waters in about 30% of water bodies. Restoration and mitigation actions are complex and expensive. In most cases, interventions are conducted at individual sites, and they are focused on resolving either diffusive or point source pollution, one contaminant at a time. This strategy has appeared to be insufficient, and leads only to small improvements on the overall water quality. Managing water pollution needs to move beyond individual chemicals and individual sources. Evidence is growing that biogeochemical cycles of essential elements such as carbon and nitrogen are strongly linked to each other, and that human impacts lead to the formation of 'chemical cocktails', this is, groups of pollutants with similar fate and transport pathways that can originate from multiple sources (Kaushal et al. 2018).

Watersheds and their associated drainage networks are fundamental landscape units. Freshwater resources and water quality are ultimately determined by the combination of natural and anthropogenic processes that influence storage, transport, and transformation of solutes through the drainage area. Analogously to the different organs of a living organism, the impact of different land uses and human activities within a watershed cannot be dissociated from each other. They need to be taken as whole in a holistic manner if we are to understand water quality signatures and warrant freshwater resources. Watersheds can be seen as sieves and filters of particulate and dissolved organic matter, mineral solids and colloids, many times bounded to organometallic complexes and other organic contaminants. Watersheds can be also seen as chromatographic columns capable of eluting ions from soils and sediment exchanges sites. Finally, watersheds are powerful bioreactors capable of transforming solutes such as carbon, ammonium, nitrate, phosphate, and sulfate. Thus, watersheds can act as important control points of point source and diffuse pollution when environmental conditions favor biogeochemical reactivity. The formation, storage, and transport of these different families of 'chemical cocktails' through soils, groundwater, and sediments depend on the size and density of particles, the location of watershed sources, the frequency and characteristics of storm events and hydrological connectivity, and in the case of bioreactive solutes, on the redox conditions and biological demand within the watershed and along the drainage network.

Cities and urban areas keep growing, and so do water demand and wastewater production. While waste water treatment plants are essential for keeping freshwaters within reasonable limits of healthiness, point source effluent inputs strongly impact stream water quality and functioning. This is especially noticeable when mean discharges are low and streams have a low dilution capacity. Decades of channel engineering and 'dammification' have ensured water and energy supply, but at the same time, have altered natural flow regimes and hydrological connectivity, decreasing the hydrological resilience of fluvial networks, floodplain productivity and altering sediment dynamics in deltas and coastal areas (Nilson et al., 2005). In agricultural watersheds, the application of artificial fertilizers and pesticides has led to unprecedented levels of nutrient excesses and contaminants in groundwater and superficial waters.

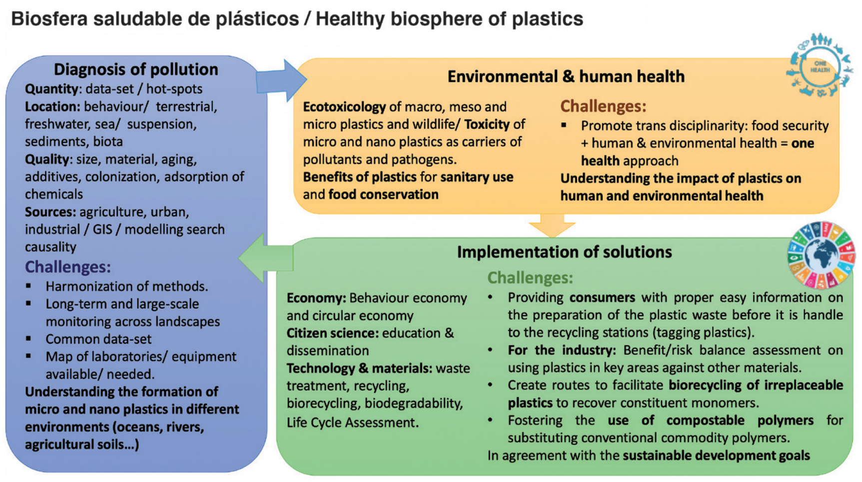
This type of diffuse pollution is extremely difficult to revert. Humanity is now starting to foreseen the long-lasting effects of these impacts on freshwater resources.

Given that watersheds are highly heterogeneous landscapes and that many different actions can be taken to protect water resources and reduce water pollution, it is crucial to carefully plan integrated management strategies that maximize benefits while reducing socioeconomic costs. The implementation and maintenance of long-term monitoring programs of surface and subsurface waters from headwaters to lowlands is fundamental. High-temporal resolution sensors are becoming increasingly affordable and widespread in national monitoring worldwide. Hydrological and physicochemical variables that can be used as proxies of water quality such as dissolved oxygen, temperature, turbidity, and electrical conductivity should be prioritized. A systematic monitoring program based on scientific criteria is perhaps the most important action that can be taken by public administrations, and without no doubt, the wisest investment at the long term. The reduction of impervious covers and the use of green infrastructures such as green roofs and permeable pavements can help to increase the transport of sediments and solutes while reducing nutrient loads in urban areas. Managing water diffuse pollution by protecting and restoring riparian buffers and wetlands is also key. Natural and engineered wetlands can contribute to reduce nutrient loads, but also remediate contaminants, pharmaceuticals, and metals. Moreover, plants in riparian zones contribute to reduce soil erosion and preserve natural flooding areas, which increases hydrological resilience during extreme hydrological events.

Management of the environmental impact of plastics

Plastics have become essential to our societies in less than a century, especially because they combine low cost and excellent functional and structural properties. Citizens from developed countries are increasingly worried about the impact on their health and on the environment of every day products made of plastics. Current investigations reveal that plastic pollution is not only widespread in the oceans, but also in the atmosphere, and in terrestrial and freshwater ecosystems. Most plastics constitute highly recalcitrant pollutants and act as long-lasting reactive surfaces, containing additives and/or absorbing organic matter and toxic substances. However, the complex nature of plastic pollution, including a large set of compounds, forms and sizes is poorly understood, with a lack of standardized analytical methods. Additionally,

FIGURE 1—Workflow for dealing with plastics: from diagnosis till solutions



Biosfera saludable de plásticos / Healthy biosphere of plastics

Diagnosis of pollution

Quantity: data-set / hot-spots
Location: behaviour/ terrestrial, freshwater, sea/ suspension, sediments, biota
Quality: size, material, aging, additives, colonization, adsorption of chemicals
Sources: agriculture, urban, industrial / GIS / modelling search causality

Challenges:

- Harmonization of methods.
- Long-term and large-scale monitoring across landscapes
- Common data-set
- Map of laboratories/ equipment available/ needed.

Understanding the formation of micro and nano plastics in different environments (oceans, rivers, agricultural soils…)

Environmental & human health

Ecotoxicology of macro, meso and micro plastics and wildlife/ **Toxicity** of micro and nano plastics as carriers of pollutants and pathogens.
Benefits of plastics for **sanitary use** and **food conservation**

Challenges:

- Promote trans disciplinarity: food security + human & environmental health = **one health** approach

Understanding the impact of plastics on human and environmental health

Implementation of solutions

Economy: Behaviour economy and circular economy
Citizen science: education & dissemination
Technology & materials: waste treatment, recycling, biorecycling, biodegradability, Life Cycle Assessment.

Challenges:

- Providing **consumers** with proper easy information on the preparation of the plastic waste before it is handle to the recycling stations (tagging plastics).
- **For the industry:** Benefit/risk balance assessment on using plastics in key areas against other materials.
- Create routes to facilitate **biorecycling of irreplaceable plastics** to recover constituent monomers.
- Fostering the **use of compostable polymers** for substituting conventional commodity polymers.

In agreement with the **sustainable development goals**

plastics themselves form specific niches for microbial life what has been defined as "The Plastisphere". Understanding of the sources, fate, transformations, occurrence and impact of plastics (from macro- to micro- and nano-plastics) remains very limited, particularly in terrestrial and freshwater environments.

The huge unintended impact of plastics in the environment is a crucial challenge of linear plastics economy. There is a need to understand the benefits of plastic but we have to balance them against its health and environmental costs. It is a complex issue that demands interlinked research covering a large variety of environmental, social-political, educational and economic challenges in line with the one health and the sustainable development goals approaches (Figure 1). In this context, the European Commission has fostered the circular economy policy, that applied directly to plastics. Single used plasticsare to be minimized and, for example, there is a European mandate to ban the popular single use plastic cutlery, plates and strokes. Educating citizens in responsible behaviors related to plastic used would help to take profit of using plastic materials while minimizing the environmental threats. New generations are more and more conscious on the problem of plastic waste. Challenges in educating the society on this issue should cover citizens and industry. Initiatives to inform the citizenship are, for example, providing consumers with easy information on how to prepare plastic waste at home before it is handled to recycling stations (tagging plastics) to boost circular economy. This education of the citizenship would demand on industries to become more efficient in the use of plastic specially on packaging.

Another fundamental issue is related to the carbon footprint of using alternatives to carbon, that in some cases is extremely higher than that of plastics. The alternatives are related to the way we use plastics, and basically centering efforts in reducing, reusing and recycling existing plastics. From a scientific point of view, challenges include the seek for alternative materials that could not threat nature, either in the form of waste or in the form of carbon footprint. Also, understanding the formation of microplastics (for example in oxo-degradable polymers) to recover them and exploiting the possibility of reusing them in the manufacturing of recycled plastic materials. And finally, promote the understanding and application of biorecycling through bacteria that may allow the recover the constituent monomers of the plastic materials.

Bioengineering and Nature Based Solutions

Evidence is growing that small ponds, temporary wetlands, or even wetlands geographically disconnected from the fluvial network contribute to decrease loads of nutrients and other contaminants at the landscape scale. In the case of nitrogen, for instance, substantial load reductions (up to 40%) can be achieved if wetlands occupy areas as small as 5% of the total drainage area (Verhoeven et al., 2006). The construction of reactive vertical barriers and horizontal beds filled with materials such as organic matter can help to remove groundwater metals and nitrate via denitrification, an action especially important in those places with chronic groundwater pollution. The protection of natural flow regimes, flow spatial heterogeneity and stream-floodplain connectivity is essential, from headwaters to lowlands, and facilitates retention of water, solutes, sediments, and particulate organic matter, and resilience to disturbance (Palmer and Ruhí, 2019). Headwaters are especially important because these areas drain up to 70% of the watershed, and thus the benefits of protecting headwaters on water storage and quality, cascade down through the whole fluvial network. Finally, stream restoration activities such as channel reshaping, wood addition, or enhancement of natural flow regimes can help to manage sediment transport and nutrient transformation along particular sections. In addition, towns and cities must take a step forward with an absolute change of criteria in relation of the management of the environment. Creating modern urban areas means, among other things, improving the quality of life by improving the quality of the urban environment. Towns and cities must restore green areas and manage some of their problems within their own urban area. These are essentially Nature Based Solutions (NBS), so the design of these green areas with tools like Soil& Water bioengineering should have specific objectives added to landscape improvement. A few examples follow.

Stormwater management and improvement. The management of urban runoff has been characterized as primarily a hydrodynamic phenomenon related to high levels of waterproofing and rainfall patterns, in this sense, urban runoff will be managed, both in Mediterranean regions because of his regime torrential rainfall intensity and in continental areas for its periodicity. It was not until recently that it has become clear that the management and treatment of pollutants present in runoff load is a critical control point that should also be contemplated. Green areas should act like rain gardens, improving aquifer recharge, reducing runoff and making flooding less intense. These areas should be especially active at improving the quality of the first flow.

Improving air quality and controlling wind and temperature. Similar NBS criteria can be applied for air improvement and oxygen production, temperature and wind control, and CO_2 retention in towns. The future gardens, parks, roundabouts and roadsides should be functional ecosystems. We should give architects and engineers clear tools for the new cities. Smart cities are made with NBS.

Biodiversity criteria in the design of structural protection systems. In urban rivers, in road slopes, in drainage, etc., engineering solutions have been created to achieve security. In the XX century these spaces have been solved using concrete, stones, and similar hard materials. Nowadays, bioengineering solutions are introduced to gain in landscape quality and resilience against natural impacts. NBS, in addition to consider the mechanic stability, have positive influences on the environment such as introduction of biodiversity, capacity of biodepuration of water and air, friendly landscape, among others, providing additional ecosystems services.

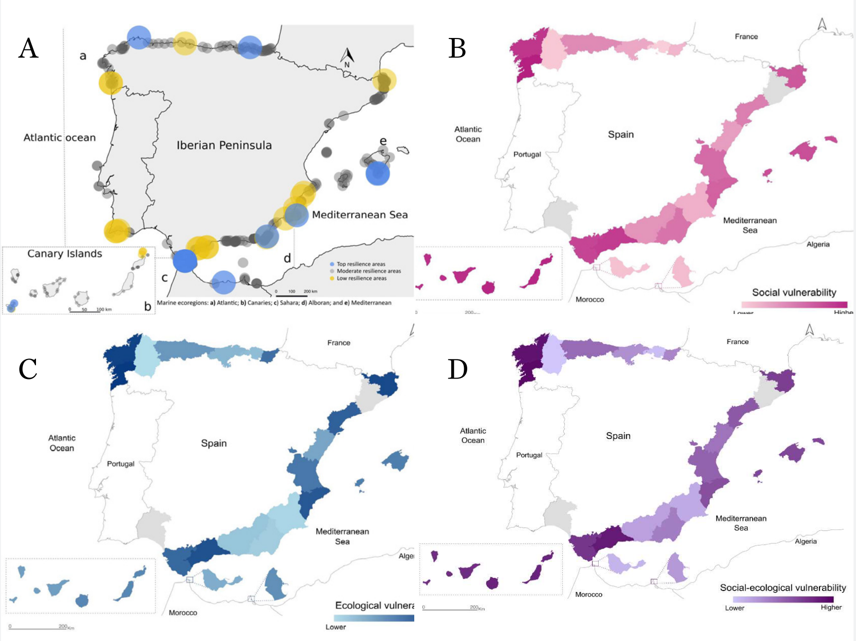
River improvement to reduce diffuse pollution from WWTP effluents. Southern Europe rivers are very vulnerable to human pressure since they usually have low flows or are even dry during certain periods of the year, and therefore their ecological quality depends on the contribution regime of effluents from wastewater treatment plants (WWTPs). Due to this low flow, they have a low capacity to dilute the contributions, mainly nutrients, emerging pollutants and pathogens. This fact means that, although the WWTPs legally comply with the parameters set by the states and the European regulations on the quality of the effluents, the low dilution capacity in Iberian rivers for example, leads to overwhelming pressure on their biodiversity and functional capacity, and their optimal purification implies a high economic cost. The present and future climate change scenarios exacerbate these effects. NBS can substantially improve the river habitats by adapting the riverbed, the banks and the effluent path of the WWTP. Bioengineering based in autochthonous plants increase rivers bioreactivity and a large potential exist in this research field. Further investigations will certainly solve these problems in a cost- effectiveness way.

Sustainability and resilience in marine ecosystems

The global environmental crisis is now rooted in a society that demands profound changes to reach sustainability. A decade ago, the Convention on Biological Diversity specifically addressed the need to enhance resilience (Aichi Biodiversity Target 15). Seven years later, the International Union for the Conservation of Nature established the Resilience Thematic Group to clarify the concept of resilience and to demonstrate the value of tools for resilience-based natural resource stewardship, disaster risk reduction, and ecosystem- based adaptation. The truth is painful. A decade after the establishment of the Aichi Biodiversity Target 15, data on resilience remains elusive and our empirical understanding of resilience is still in its infancy. As a complex concept, quantifying resilience is a challenge that needs the integration of numerous biological, environmental, and anthropogenic factors (Maynard et al, 2010). In tropical marine regions, the resilience assessment framework established an approach to calculate a site-specific resilience indicator with strong management implications (Maynard et al, 2010). This approach has been adapted and used to assess resilience in several tropical locations and it could be instrumental in gaining knowledge about the resilience of the oceans. For a better environmental management, accurate but simplified resilience indicators are needed that provide baseline resilience data to help track natural patterns of resilience and, also, the consequences that human actions have on the resilience of the oceans.

Multiple biological, environmental, and anthropogenic factors are known to regulate the resilience of temperate marine systems. The need for data is large

FIGURE 2–Rocky reefs in Spain (A) with high (blue) and low (yellow) resilience values as measured by the IRIS. Social (B), Ecological (C), and Social-ecological (D) vulnerability of the Spanish provinces to tourism and fishing (unpublished data by JA Sanabria&N Lazzari)



and could benefit from validated protocols of citizen science (e.g., the Reef Life Survey program www.reeflifesurvey.com) to gather biological data. In turn, massive environmental data can be obtained from publicly available repositories (e.g., Bio-Oracle marine layer dataset www.bio-oracle.org). Finally, anthropogenic data can be obtained from multiple sources supported by social scientists. Overall, high-quality data provide a huge array of possibilities to advance science and to inform policy-makers (Sanabria-Fernández et al. 2019). Objective resilience values can be generated and areas that would benefit the most from specific management actions, such as regulation of fishing activities can be identified. In a recent study carried out in Spain, over 5% of the rocky reefs investigated had low resilience values, suggesting that their capacity to recover from disturbance is at risk (Figure 2). The resilience of some of these sites could be increased by over 20% through adequate management actions. Overall, pollution management would provide the largest benefit to the resilience of the Spanish rocky reefs, with regulation of diving and fishing activities in second and third positions (Figure 2).

Restoration of marine habitats

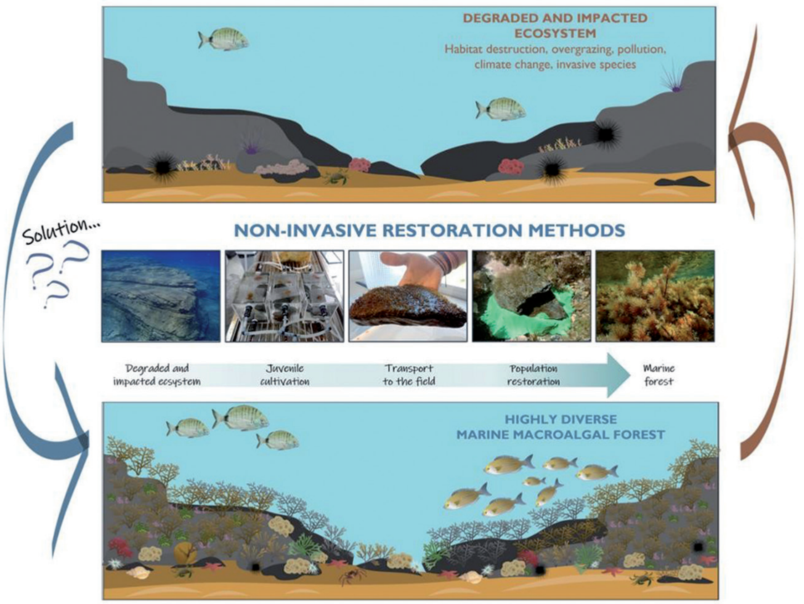
Marine coastal ecosystems are among the most impacted systems by human stressors (Bevilacqua et al., 2020), and ensuring the provision of essential ecosystem services requires not only the protection of native habitats but also effective restoration through new approaches (Brancalion et al. 2019). The final goal for restoration and conservation is to shift from the traditional, narrow, species-focused plans to broader approaches incorporating seascape-scale perspectives to achieve multiple objectives, including reducing species extinctions, mitigating injurious climate change and promoting sustainable livelihoods (Figure 3). There is widespread agreement that monitoring is fundamental for successful restoration (Guariguata and Evans, 2019), but it needs to be reframed and include different habitat types to provide integrated knowledge of ecosystem functioning and ecosystem services. Then, conservation and restoration actions should embrace habitat variability and support adaptation to local circumstances to increase ecological resilience in a rapidly changing world. Among biological and ecological features, life-history traits, population connectivity, spatial distribution, structural complexity, and the potential for regime shifts are identified and scored as the main biotic factors contributing to the successful accomplishment of habitat restoration (Bekkby et al. 2020). However, at present most of these features still remain unknown for many assemblages and species.

Viability of ecological restoration could be strongly compromised by accelerated environmental modifications associated with climate change. A promising, but as yet untapped, opportunity for enhancing the climate-resilience of restoration investments rests in the exploitation of natural genetic variability of key species (Prober et al. 2015). While the capacity of plants to adapt to environmental change through plasticity, selection, or gene flow has been intensively explored (Prober et al. 2015), for marine habitats and species the available knowledge is scarce or null. In addition, the impacts of climate change are highly variable geographically, and a place-based understanding of climate change threats to marine ecosystems is needed. Combined modeling approaches considering intrinsic adaptation of habitats and species together with predictions of climate change trends and impacts, are essential to properly assess the fate that species, habitats and sites will follow when restored.

Emerging diseases: zoonoses and arboviruses

Zoonotic diseases are infections that humans catch from other animals. They can be caused by viruses, bacteria, parasites and fungi. Some examples of

FIGURE 3—Steps for integrated actions to restore deteriorated marine coastal habitats



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zoonotic disease are: Anthrax, Ebola, avian influenza, rabies, Zika, and a number of coronavirus diseases, including SARS, MERS, and probably Covid-19 (Ahmad et al. 2020). Vertebrates hosting pathogens that can spillover to humans include bats, cats, birds, pigs, camels or horses. For some zoonotic diseases, non-human animals serve primarily as vectors, meaning that they transmit the disease between humans more than serving as host reservoirs. A special case of vector-borne diseases of current concern in Europe involve viruses transmitted by arthropods (e.g. certain species of ticks and mosquitoes), the so- called arboviruses. Diseases caused by mosquito-borne viruses, such as dengue, Zika, chikungunya, West Nile fever, Usutu, and yellow fever, are emerging and reemerging globally. The causes are "multifactorial and include global trade, international travel, urbanization, water storage practices, lack of resources for intervention, and an inadequate evidence base for the public health impact of mosquito control tools" (Roiz et al. 2018). In other cases, zoonotic diseases are transmitted among humans without requiring a vector, often transmitted by air, as is the case of infectious diseases originated by coronaviruses.

The emergence of zoonotic diseases is being shaped and intensified in complex ways by a variety of factors associated with global change, including biodiversity loss, environmental degradation, land use changes, and climate change (Franklinos et al. 2019). For example, there is mounting evidence that increased virus spillover events from animals to humans can be associated with biodiversity loss and environmental degradation, as humans further encroach on wildlands to engage in agriculture, hunting and resource extraction they become exposed to pathogens which normally would remain in these areas (Christine et al. 2020). Such spillover events have been tripling every decade since 1980 (Shield et al. 2020). Another study concludes that the anthropogenic destruction of ecosystems for the purpose of expanding agriculture and human settlements reduces biodiversity and allows for smaller animals such as bats and rats, who are more adaptable to human pressures and also carry the most zoonotic diseases, to proliferate. This in turn can result in more pandemics (Gibb et al. 2020). Both air-borne and vector-borne emerging zoonotic diseases are currently challenging the existing global health infrastructure and organization.

The digital revolution coupled with data science, and the use of breakthrough multi- analytical data sources and technologies (e.g. social networks, global databases, active smartphone data collection) offers opportunities for infectious disease detection and management. Rapid identification and scalable management are essential to reduce the impact and costs of outbreaks. As a major part of emerging infectious diseases come from animals, a true shift in ability to detect would come from a deep understanding of the factors governing their emergence, focusing on the complex interplay of environmental and human factors that drive disease dynamics, and using those insights to develop scalable and actionable early warning systems. Future epidemiological research needs to combine and model data from a wide range of sources that reflect and track changes in drivers of (re)emergence and transmission of infectious diseases at almost real-time. Open and participatory science approaches together with novel technologies such as the internet of things (IoT) and smartphones, are essential to generate actionable connections between public health management, science, and citizenship, providing scalable and flexible data on vectors and infectious diseases that can be used together with traditional surveillance and management tools (Shepard et al. 2016).

Novel observational and computational laboratories should be designed to be used in 'interepidemic' mode' (i.e. in the absence of actual threats) as well as of immediate use in actual outbreak events (i.e. outbreak response mode). They may be able to reveal critical changes in the drivers of disease, (re)emergence and spread at a much earlier phase of an outbreak curve (when is the risk increased?), predict hot-spots for (re)emergence and spread of known and novel pathogens (where should we investigate?), and assess potential public health or animal health risks (how do we interpret and detect risk?). Technological innovation in public health including contact tracing and social distancing measures also raises however various challenges from multiple perspectives. Policymakers and public health managers aim to predict and control outbreaks faster with novel technologies, but often public health systems are not ready to accept innovative tools that require prior investment in IoT architecture and human resources. In addition, technology-focused responses often reinforce existing power structures and patterns of inequality, while at the same time masking the political considerations that underlie decision-making processes. As a consequence, an ethical, legal and societal perspective is required to solve tensions and risks of the use of novel technologies and big data approaches in the public health context.

3.2. Preserving human wellbeing and promoting good governance practices

Environment & Subjective Well-Being

The subjective wellbeing literature has empirically shown that the natural capital and the quality of the environment is essential to individuals wellbeing. Individuals are not necessarily happier living in high income countries, but rather if they live in cohesive societies with a sustained and stable economic development, with less poverty and inequality, and higher levels of employment and respect for the environment. Individuals subjective wellbeing depends not only on their objective personal situation (such as, their health, job conditions, and income), but also on their personality as well as on their surroundings (such as regional inequality and unemployment rate, environmental quality, and institutions and social capital in their region). Current evidence shows unequivocally that satisfaction with life depends, among others, on the quality of the environment. The natural capital and the overall environmental quality and the level of nature conservation is not only the base for sustaining life on earth and our economy, but it is also key for our health and wellbeing. It is crucial for policy making to understand the determinants of reported wellbeing not only to design policies that are welfare improving, but also to take into account individuals' reactions to policies.

With the increasing urbanization all around the world, there is an increasing number of individuals that live in urban environments, with high levels of pollution and lack of green and natural spaces. Pollution decreases life quality through health deterioration, lower productivity, and worse educational performance, but also decreases life satisfaction (van Praag and Baarsma, 2005). Nature becomes crucial in cities. Being close to natural or green areas within the city is correlated with both better physical and mental performance (individuals close to natural areas have a better social life and are more physically active) and higher life satisfaction (e.g., White et al., 2013). It has already been shown that hospitalized patients who were in rooms with views to a green space recovered earlier and stayed shorter days in hospital (Ulrich 1984). MacKerron and Mourato (2013) found that individuals were substantially happier in green spaces or natural areas compared to when they were in an urban environment. White et al. (2013) found that people were reported to have higher levels of wellbeing if living in cities with larger green areas. Thus, the increasing urbanization puts physical and mental health at risk and needs of proper risk management policies and actions.

Climate change and environment deterioration also affects individual wellbeing indirectly through anxiety about future uncertainty. This is known as eco-anxiety, a term accepted by the American Psychological Association since 2017. This term refers to the anxiety caused by the environmental problems, notably climate change and loss of diversity, and the risk that this has for future generations. Social reports show that a large percentage of the population sees climate change as an important threat. In 2016 the European Social Survey (ESS) reported that 74% of all respondents from the 23 countries were worried about climate change, but only 33% of the ESS respondents were in favor of increasing taxes to fossil fuels in order to reduce climate change. This survey revealed a need for enhancing scientific communication and social discussion on climate change threats and the best measures, actions and practices that should be committed for sustainability and human well-being.

Environmental change, risk, trust and governance

Since the end of the 20th century, our era has been characterized as a "risk society" (Beck 2011). The concept of risk is truly polysemic and is used both to refer generically to an undesirable event and to its causes, its probability or its expected statistical value. The terms dangers and threats have been used interchangeably to refer to these new anthropogenic risks that are beyond a probabilistic determination and which, linked to human action, can acquire a catastrophic and global character. For this reason, the term "danger society" is more appropriate to refer to our time. The uncertainty about facts, disputed values, enormous challenges (systemic risks) and urgent decisions, altogether calls for ethical debate, public deliberation, transparency and policies (social control with participation of non-experts in deliberation and decision). In other words, it calls for "good governance".

At a time of great uncertainties and risks, with global pandemics, economic crisis, mistrust, suspicion and fear of the future refer, a "special fear" arises as the fear that the society in which we live will collapse, the sensation of sinking and a feeling of loss of identity (Marina 2006). The antidote to fear is trust. Trust accumulates as a kind of capital that offers more opportunities for further action. In this sense, trust is a key element of the concept of "social capital", widely used in economics and social sciences, and which can be defined as the connections between individuals and social networks and the norms of reciprocity and trust that arise in this interaction. Social capital consists of the stock of active connections among people: the trust, mutual understanding, and shared values and behaviors that bind the members of human networks and communities and make cooperative action possible.

Mistrust and discredit are lethal for organizations, companies and institutions and undermine the basis of the political organization of society. Several OECD reports have identified a decline in the legitimacy of governments and a fall in confidence in public institutions in many countries since the 1990s, with a negative effect on the legitimacy of such governments and institutions. We therefore urgently need a "good governance" of risks and uncertainties. Governance basically means the management of public affairs and is characterized by a multi-centered type of decision-making, structured in complex networks through which relations between relatively autonomous but at the same time highly interdependent actors are organized. The idea of governance connects with a vision of democracy that is more open, more direct and more interactive as opposed to a closed, hierarchical and unidirectional practice. The concept of governance promotes co- responsibility and designates rules, processes and behaviors that influence the exercise of power. Five principles characterize "good governance" (which is what generates citizens' confidence in the institutions and the political system): openness, participation, responsibility, effectiveness and coherence (European Governance. White Paper 2001, https://ec.europa.eu/commission/presscorner/detail/en/DOC_01_10).

In short, governance aims at a form of coordination between political and social actors characterized by regulation, cooperation and horizontality. Governance is based on the principle that the solution of social problems is not carried out exclusively through a supreme authority but through the joint action of different actors and organizations. And it requires the administration and politics to recover a strategic capacity to be able to face the future challenges of society and its democratic configuration. There is an inability to anticipate the future that is of a structural nature. Only if politics recover strategic capacity will it succeed in moving from the world of repairs to that of configurations (Innerarity 2011), especially in the current context of major environmental and social changes.

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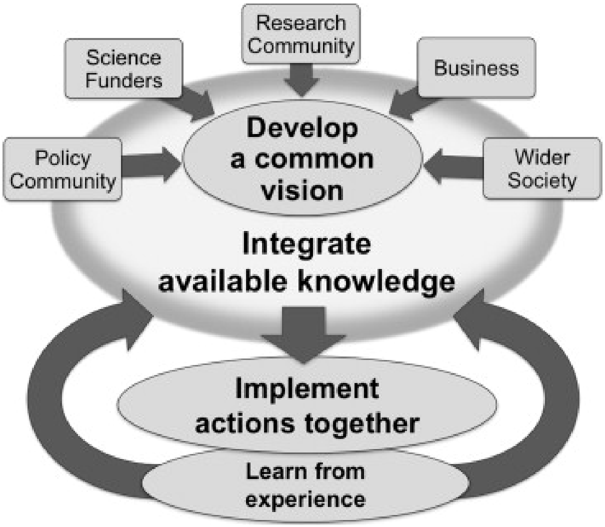
ACADEMIC SLIDE



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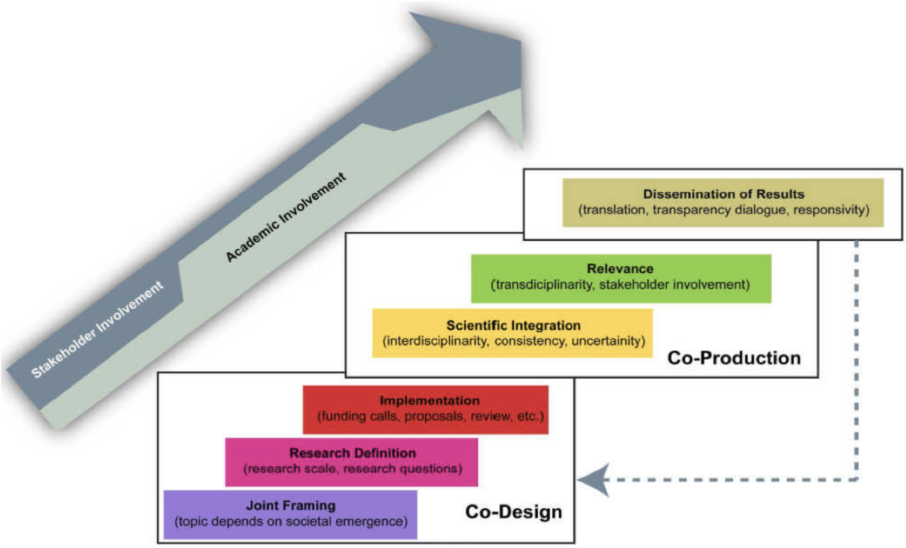
DISSEMINATION SLIDE



The environmental sustainability of the Earth system is at risk, and so do human welfare because of our dependency on it. Here we present challenges dealing with the understanding of how drivers of global change work, and how to minimize their effects on natural and human managed systems, with the aid of new concepts and edge-cutting technology. Their achievement should allow us to detect, understand, forecast and mitigate global change impacts related to climate change, the biodiversity crisis, polar regions, and managed ecosystems, and to improve the health of our planet in the coming decades.

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