GLOBAL CHANGE IMPACTS

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THE CURRENT SCENARIO OF GLOBAL CHANGE

Humans have attained a status not merely of dominance on planet Earth, they are the most drastic force of biological disruption. Global change underpins all those cumulative effects that humans have been inducing since the last millennia, and actually keep inducing at even higher rates, on the Earth system (Dirzo and Raven 2003).

Global science faces the formidable task of providing humanity with the conceptual and technological tools to forecast major threats, manage effective solutions to eliminate or mitigate them, and offer feasible alternatives to alleviate global change effects. Threats have been increasing in the recent time, particularly since the end of the Pleistocene, and are associated in most situations to the direct effects of humans on nature (Barnosky et al. 2012, Novacek 2001). Pollution, greenhouse-effect gas emissions, abuse of water and fossil resources, deforestation, erosion, overhunting and overfishing, loss of wetland areas, the spread of exotic/invasive species, etc. are all different but interconnected faces of what we know as the Anthropocene, i.e., the period when human activity significantly alters the atmosphere composition of our planet, modifies the biogeochemical cycles, shapes the landscape, and is witness to a new (the sixth) mass extinction event. Massive events of biodiversity loss have in common three aspects also shared with the Anthropocene: occur over large tracts of the Earth surface (both terrestrial and marine), span relatively short periods of time, and do affect most groups of biological species.

The recent IPBES (2019) report has described and diagnosed with precision the current situation of the Earth biota and the fast-paced trend to mass extinction that we are facing. Together with the IPCC reports (2018), they provide robust evidence for pervasive changes that humans are inflicting to the Earth system. What this diagnosis has in common with earlier mass extinction and biotic crises on Earth is the rapid and synergic action of multiple stressors on the biota (Brook et al. 2008). Present-day ecosystems are the legacy of a biotic turnover initiated by the onset of glacial-interglacial cycles that began ~2.6 million years ago, and evolved primarily in the absence of *Homo sapiens*. Rapidly changing atmospheric conditions warming above typical interglacial temperatures as CO_2 levels rise, pollution, overfishing and overhunting, invasive species, pathogens, and emerging diseases, and loss of habitats constitute the most extreme ecological stressors that most living species have previously experienced.

A common and successful action for preserving biodiversity, wildlands and oceans is legal protection. About 5,106 km^2 of land and almost none of the oceans were protected in the mid-1970s, and now the figures are close to 17,106 and 10,106 km^2, respectively, and vast marine no- take zones have been established annually since 2000. Large tracts of remote deserts, the Amazon, or the boreal forests are protected, but the current real challenge is to achieve a sustainable production and restoring capacity in or near cities: high demanding sinks of natural resources. As Humankind, a new contract with Nature is needed. If urgent action is taken and environmental policies are deeply revised, a large part of human impacts to nature can be reversed. But observed changes on the Earth system are that fast that even if science and research are put to full work power, they may fail to provide useful forecasts or effective solutions. For instance, the fast-paced changes that are occurring in the Arctic and the long-standing international disputes may block any initiative aiming to a sustainable use of its resources, or even the possibility of generating knowledge to revert these changes. Deep, transformative changes in resource use, international trading, agriculture, use of non-renewable resources, recycling technologies, reduction of emissions and other aspects of human environmental activities are urgently needed. These would require concerted actions at the highest international level, and action policies based on solid scientific knowledge.

The Spanish CSIC and its research groups working on Global Change issues are ready to boost research to forecast and mitigate the effects of ongoing global changes. On the one hand, CSIC research groups collectively have a great potential to carry out synergistic, multidisciplinary projects at large spatial scales. On the other hand, ICTS facilities, historical collections and Interdisciplinary thematic platforms provide an excellent opportunity to deploy medium- and long-term monitoring programs in terrestrial and marine ecosystems, from Mediterranean to polar latitudes, to estimate key environmental indicators and test efficient and natural-based solutions to environmental problems. All this makes CSIC a quite unique and exceptional network of human resources and facilities to carry out scientific projects dealing with the impacts of global change.

WHAT THIS WHITE PAPER CONTAINS

Here we examine some of the most important environmental challenges our society faces in the near future as a consequence of the impact of global change. We do not intend to make an exhaustive compilation of drivers, processes involved, effects and hazards, but to illustrate which of the main ones, and to what extent, can be achieved with CSIC scientists, infrastructures, and collaborations in national and international networks, and to demonstrate the high international visibility of Spanish science in this knowledge area.

Most chapters start by listing knowledge gaps in a conceptual framework, and then we discuss how the development of new technology and long-term monitoring programs involving observational and experimental approaches, together with modeling, might help to forecast future scenarios and better adapt and mitigate environmental problems.

We first start by framing the historical importance of human impact on Earth, in which it has been named "the Anthropocene" (Challenge 1). Knowing what happened in the past and potential causes is the only realistic way of building projections of future scenarios, and thus designing effective mitigation actions. This long-term perspective involves quantitative past reconstruction based on proxies of high resolution stored in paleoenvironmental archives, allowing us to determine, for example, the interaction between climate and human societies, how fast contemporary processes are occurring, potential "tipping points" when abrupt changes occur, and the sensitivity of different environments and geographic regions. The experts list here different challenges addressing the identification and characterization of the main processes involved in rapid climate change and environmental changes, the need to advance on methods and data processing to improve time resolution and space coverage, developing new proxies able to detect rapid changes in the past environments, and advancing in model-data integration at different timescales.

Then, we go through one of the main threats of our planet, tightly linked to the increased atmospheric concentrations of greenhouse gasses: climate change (Challenge 2). The potential impacts of global warming and concomitant socio-economic and environmental costs are well known, and include sea-level rise, polar and mountain glaciers melting, snow cover retreat, more frequent land and marine heatwaves, changes in animal and vegetation phenology and distribution, and more severe forest fires. There are, however, remarkable knowledge gaps and uncertainties, and further work is required to establish a robust and comprehensive assessment of climate change and climate variability, which affects the robustness of future climate projections. Five big challenges have been outlined in this context: 1) to improve the quantification of the rates of change in all physical components (including the rescue and analysis of available historical observations and proxy records to better contextualize and discriminate natural climate variability and the current anthropogenic forcing), 2) to assess the physical processes of climate change, including feedbacks between thermodynamics and dynamics, and interactions between the Earth System components (land-atmosphere-ocean-ice coupling), 3) to quantify the observed changes and identify the triggering factors of extreme events, 4) to reduce uncertainties of climate projections at global and regional scales (which requires sophisticated computational resources and the development of more comprehensive global and regional Earth System models with higher spatial resolution), and 5) to offer reliable and transparent climate services to user communities, since many economic and social activities, as well as policy decisions, depend on the availability of accurate climate information. Also, sustained international initiatives are required to support the continuity of existing analogical observational networks and standardized methodological approaches, which represent the fundamental pillars of climate change assessments.

The next block of key-challenges focusses on how to preserve the threatened biodiversity and its functions (Challenge 3). Biodiversity on Earth is countless, builds on very many interconnected layers of complexity (biological levels, spatio-temporal scales...), and the functional properties of ecological systems are multifactorial and interactive. The authors outline here nine challenges grouped in three major fronts. Firstly, filling knowledge gaps of the relationship between biodiversity and ecosystem services, ecosystem functions of microbial communities, and the evolutionary dynamics of communities. Secondly, advancing in technology like next-generation sequencing, artificial intelligence or remote sensing, which together with citizen science programs constitute a fundamental part of monitoring, both genetically (e.g. sequencing populations of endangered species, discovering microbial diversity) and environmentally (e.g. species presence or distribution shifts, landscape changes...). Emerging technologies have a great potential for massive, large-scale monitoring, but still need to be integrated with observational and experimental evidences, and realistic modelling. Last but not least, seeking solutions for biodiversity conservation, such as those addressed to mitigate the effect of invasive species, halting the loss of pollinators, or managing wild vertebrates. The success of conservation planning and ecosystem-based management depends on our ability both to anticipate species' responses to global change and to manage conflicts arising from ecosystem conservation and economic exploitation, but also on the coordinated implementation of tools such monitoring programs, laws and policies at national and international levels. In the meantime, scientists have to increase their interaction with managers and policymakers, through the implementation of long-term surveillance and monitoring projects addressing urgent questions before arriving to a non-return point of biodiversity loss or decay.

Then, we move to Polar regions (Challenge 4), which are considered the best preserved and natural places on Earth because of the low level of human activity they experience. Besides that, they are exceptional sentinels to monitor global change challenges: both the Arctic and the Antarctic Peninsula are the regions where temperature has raised most and faster than any other Earth's place; the rapid decline in Arctic sea ice extent and volume illustrates the sensitivity of polar regions to global warming; and the strong adaptations of polar wildlife to extremely cold environments makes species highly vulnerable to environmental changes considering their narrow range of tolerance. The remoteness of the polar regions and the complexity of polar research have resulted in many gaps of knowledge in the different spheres of polar systems functioning, interactions, and feedbacks (atmosphere, cryosphere, oceans, biosphere, geosphere). Nine key-challenges are presented here as possible ways for tackling them, aiming at better understanding ozone evolution and its effects on surface climate, polar climate variability and trends, polar changes with satellites (sea ice thickness and extension, glacier melting rate, permafrost…), past ocean dynamics and ice stability under warmer than present conditions, impact of anthropogenic pollutants in the polar regions, biogeochemical cycles of trace metals and their influence on the oceanic productivity in Polar Oceans, the pelagic-benthic coupling in the warming cold, the vulnerability and resilience of Polar aquatic and terrestrial microbial ecosystems to climate change, and finding the best organisms indicators of environmental change. Only by obtaining sound, detailed and long-term knowledge of the polar systems functioning we will be able to stablish efficient and environmentally friendly measures to mitigate the negative effects of current anthropogenic impacts and to protect polar ecosystems.

Unfortunately, human modification of natural systems for the production of food and goods is the norm and one of the major causes of global change (Challenge 5). To cope with the increasing problem generated by a growing and more demanding human population, we urge the development of actions towards more sustainable, climate-proof and resilient production systems. Our understanding of how climate change and land degradation affect current food production and security, and the extent to which they will do in the future is very limited and yet crucial to adopt adaptation and mitigation actions. For that reason, long-term observational and experimental monitoring programs including multiple stressors are necessary to understand complex dynamics, and assess cost and effectiveness of adaptation options. We need, for example, to increase our predictive capability in future environmental scenarios for crops and grazing systems sustainability, nutritional composition of forages, sensitivity of crops and livestock to heat and water stresses, spread and the life-cycle dynamics of pathogens…. A second key challenge deals with fostering resilient and better adapted food production systems: design crop adaptation to changing environments through the development of process-based models that can be used in Decision Support Systems, the use of soil biodiversity to maintain and increase yield production while minimizing ecological footprint, design water efficient production systems through the application of agronomic practices that reduce evapotranspiration losses and lower the water use, develop early warning systems of infectious diseases, aquatic pathogens, marine storms to avoid massive damage to infrastructures etc. The third set of key challenges are focused in mitigating and reducing emissions, by designing carbon efficient landscapes, enhancing soil carbon sequestration, or combining low and high trophic species in complementary cultures of aquatic systems. Finally, the last group of key challenges tackles questions, methods and approaches to foster adaptive management of forests, in order to minimize the direct and indirect effects of climate change, and to better manage wildfires (a major driver of Mediterranean landscape dynamics).

The book ends with the most "problematic and dangerous" part of environmental human legacy, and how the human society deals with environmental risks (Challenge 6). Our unsustainable use of nature, and our steadily increasing energetic demands are bringing the Earth system and its capacity to recover from global changes beyond the environmental boundaries that supported us as a society. Environmental hazards affect socio-economic development and human wellbeing, and constitute a major component of environmental risk management. And despite that the natural capital and the quality of the environment is essential to human wellbeing, there is an increasing number of individuals that live in urban environments, with high levels of pollution and lack of green and natural spaces. Here, the authors make list of challenges that should be addressed for the human species to live with undesirable products resulting from its development: sustainable use of nitrogen to counterbalance atmospheric deposition and the long-lasting effects of artificial fertilizers and pesticides, integrated watersheds management (natural and engineered wetlands) for preserving water resources and their quality, dealing with the environmental impact of the omnipresent plastics by increasing efforts in reducing, reusing and recycling them, and social awareness of the problem they cause, increase of the resilience of marine ecosystems, restoration of the deteriorated marine coastal ecosystems, or the early detection of emergence of zoonotic diseases associated with global change (environmental degradation, land use changes, and climate change). We need nature-based solutions to mitigate urgent environmental problems, and also consider subjective wellbeing issues in the governance of societies for preserving a healthy planet.

EXECUTIVE SUMMARY

The environmental sustainability of the Earth system is at risk, and so do human wellbeing because of our dependency on it. Global environmental changes are not new, but human society is now facing global impacts of anthropogenic causes at an unprecedent fast pace. This book reviews some of the most important environmental challenges created as a consequence of such impacts, and how they can be achieved with the aid of scientific research.

To do so, we first identify knowledge gaps, and then we examine how the development of new technology and long-term monitoring programs involving

observational and experimental approaches, together with modeling, might help to seek solutions and forecast future scenarios to better adapt and mitigate environmental problems. This analysis is preceded by the first challenge: framing current global changes into the **long-term reconstruction of natural changes and historical human impact on Earth** ("the Anthropocene"), as a way of improving projections. Then, we examine challenges related to one of the main threats for our planet, of dramatic socio-economic and environmental costs: **climate change** (contextualizing anthropogenic forcing and natural climate variability, interaction of physical processes, forecasting extreme events and climate change at regional scale, provision of climate services to different users). Next two challenges focus on **how to preserve biodiversity and its functions** (unveiling the structure and complexity between biodiversity and ecosystem services, the role of microbial communities, advancing in technology like next-generation sequencing, artificial intelligence or remote sensing, halting the loss of pollinators, reduce invasive species, and managing wild vertebrates), and **monitor biotic and abiotic processes in polar ecosystems**, one of the most remote but sensitive areas to global change (ozone evolution, polar climate variability and trends, current polar changes with satellites, past ocean dynamics and ice stability, impact of anthropogenic pollutants, biogeochemical cycles of trace metals, the vulnerability and resilience of microbial ecosystems, and finding out the most suitable indicators of environmental change). The last two blocks of challenges deal with the **need of developing more sustainable, climate-proof and resilient production systems** (forecasting the sensibility of crops, grazing systems, and the dynamics of pathogens under climate change scenarios, incorporating tools like soil biodiversity, designing water efficient production systems, enhancing soil carbon sequestration, fostering adaptive management of forests, managing wildfires...) and the **need to consider hazards for human wellbeing and look for natural-based solutions** (sustainable use of nitrogen, watersheds management to preserve water resources and their quality, reducing the omnipresence of plastics, increase the resilience of marine ecosystems, restoring deteriorated marine coastal ecosystems, early detection of emergence of zoonotic diseases).

Environmental challenges outlined above must be incorporated in the governance of societies, and the CSIC scientific community can provide knowledge, tools and solutions to design effective policies. The impact of global change is unavoidable, but our success in preserving the important services provided by nature, building sustainable and resilient productive systems, and incorporating risk management, will determine the future human wellbeing in a healthy planet.

PARTICIPATING RESEARCHERS AND CENTERS

82 researchers working at 31 CSIC Institutes, together with scientists working at five national and international Universities, one national research center and one company have participated in this volume (coordinators of the chapters and the with paper in bold).

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EXECUTIVE SUMMARY **REFERENCES**

Barnosky, A.D. et al. (2012). Has the Earth's sixth mass extinction already arrived? Nature 470: 51–57.

Brook, B.W., Sodhi, N.S. and Bradshaw, C.J.A. (2008). Synergies among extinction drivers under global change. Trends Ecol. Evol. 23: 453–460.

Dirzo, R. and Raven, P.H. (2003). Global state of biodiversity and loss. Annu. Rev. Environ. Resour. 28: 137–167.

IPBES (2019). Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. E.S. Brondizio, J. Settele, S. Díaz, and H.T. Ngo (eds.). IPBES secretariat, Bonn, Germany.

IPCC (2018). Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. [V. Masson-Delmotte, P. Zhai, H. O. Portner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, T. Waterfield (eds.)]. IPCC, in press. https://www.ipcc.ch/site/assets/uploads/sites/2/2019/05/SR15_SPM_version_report_LR.pdf

Novacek, M.J. (ed.) (2001). The Biodiversity crisis: losing what counts (The New Press)