REPORT TO THE NATIONS

The Anthropocene in Chile:
evidence and ways forward

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Foreword

In the 21st century, Chile's development is at stake because of the threats posed by the Anthropocene. This epoch is characterized by human influence on the Earth System. However, if faced boldly, it offers an opportunity for a sustainable development. Regardless of whether we have entered a new geological era, the Anthropocene questions our way of living on the solar system's blue planet. Or, in other words, the way to understand progress and development. In a country with high social inequalities, highly vulnerable to global change, meeting this challenge is of crucial importance and can offer new opportunities.

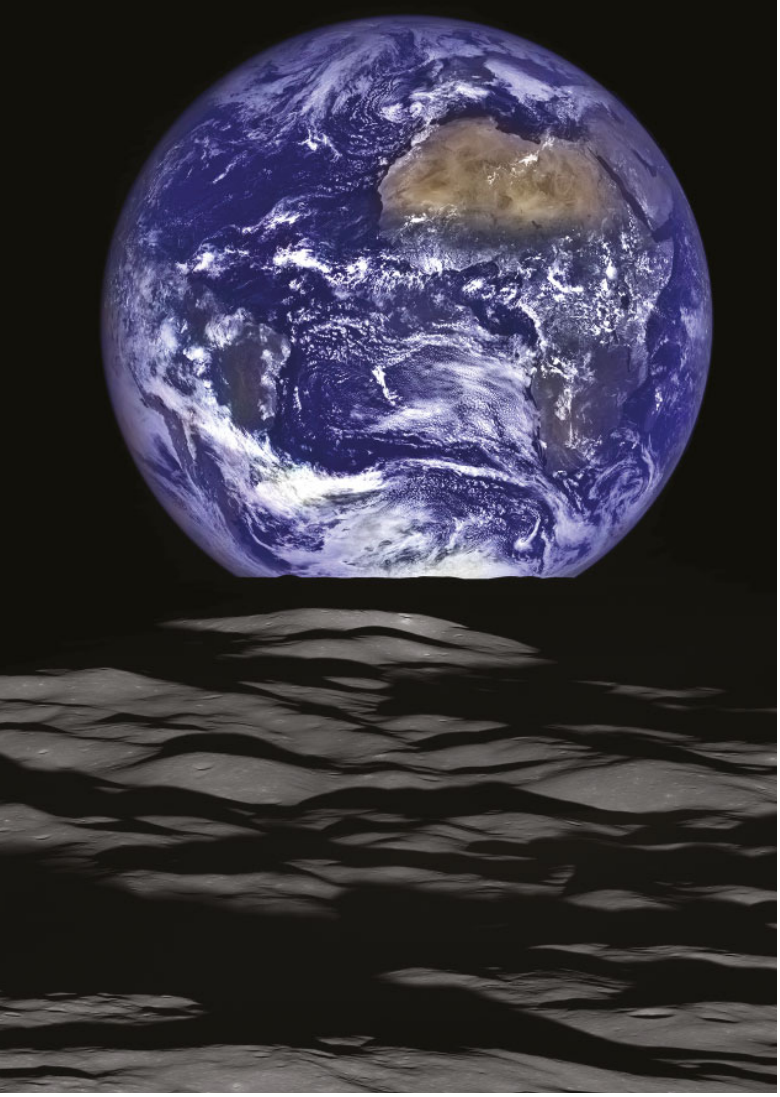
At the Center for Climate and Resilience Research (CR(2)), we decided to use the framework of the Anthropocene to develop our integrative research efforts. Thus, we have studied some of the regional manifestations of this new era in Chile, in order to contribute to identifying paths towards a greater resilience. Firstly, we review paleo-geo-historical records showing human influence in Chilean territory since pre-Hispanic times. We suggest that these records offer crucial "baselines" to delineate safe operating spaces for future Chilean socio-ecological systems. Then we show the co-evolution of air quality and the mobility of Santiago's residents over the last 30 years. This study demonstrates that science-based policies were successful in adopting new technologies but that there is a need for new public policies that promote, not just technological advances, but rather on changes in behavior and social transformations. Another CR(2) study assesses the causes of the variability of precipitation in central and southern Chile based on more than five decades of observations (1960-2016), as well as on climate projections. It found that the observed changes are largely anthropogenic, and that we can expect these trends to continue during the 21st century, albeit also modulated on annual-to-decadal time scales by natural variability. Moreover, as the consequences of a drying and warming climate are multiple and often intertwined, facing drought in the Anthropocene will require new, holistic approaches to water governance and climate change adaptation. The latter is illustrated for a watershed in central Chile where we evaluate the way in which water resources are allocated under existing legislation. Another study addresses how changes in large-scale climate have resulted in clearer skies (more

Foreword

solar radiation), stronger upwelling-favorable winds, which generates more concentration of nutrients in superficial waters and, therefore, more phytoplankton biomass and less dissolved oxygen concentrations. These changes affect the marine food web and, finally, fisheries production, which requires better monitoring (observations) and governance. Land use and land cover changes, and fire regimes are also analyzed in the framework of the Anthropocene. It is imperative to design a new forestry, and more generally, a land use policy to assure the preservation of biodiversity, to face new fire regimes, and to assure water provision in central and southern Chile. Finally, we present an analysis of governance in relation to climate change in Chile, which suggests ways for improvement through greater citizen participation and integration of knowledge. Most of the papers are part of a special issue in *Elementa: Science of the Anthropocene*, which is a journal open to interdisciplinary research. Others were published, subject to peer review in other journals. Here, these findings are summarized, and policy relevant aspects highlighted.

Setting the stage

To face the Anthropocene, we must acknowledge the interconnectivity of the world we live in.



It has been recognized that human influence has become a principal agent of change on the planet [1]. Anthropogenic impacts are in fact manifold and they occur worldwide at unprecedented and accelerating rates, particularly since the 1950s [2]. The current rates of change by far exceed those driven by natural processes, and with consequences that exceed planetary boundaries [3–5].

EThese changes are shifting the world out of the relatively stable geological time known as the Holocene (last ~12000 years), over which humans have prospered as a species. Now, we are entering a new geological era called the Anthropocene [1,6–8]. Changes in temperature and precipitation patterns, sea level, polar and glacial ice cover, ocean acidity, etc. have been duly assessed in the reports of the Intergovernmental Panel on Climate Change [99]. But beyond that, more than half of the planet's surface has been transformed by human action with consequences on biodiversity, the nutrient cycle, the edaphic structure and the climate, and all these changes are characterized by exponential growth that occurred simultaneously and accelerated after the 1950s [2]. This entails risks for our present and future due to the magnitude and rate of the changes, and to their intertwined nature, leading to feedbacks and unexpected responses, and new risks [10,11]. All this affects our society as our institutions are overwhelmed by the accelerated rates of change and the magnitude of the emergent challenges [12–15].

Setting the stage

The case of Chile is no different. We analyzed mainly the central and southern zone of Chile where ca. 90% of the population lives. Drivers such as urbanization and land use land cover change show accelerating trends since the second half of the 20th century. The consequences are not localized but larger and go well beyond administrative limits. Similarly, remotely driven changes such as those affecting precipitation patterns in central and southern Chile, have regional and local consequences, which occur in cascades. For instance, precipitation decline over the Andes is linked to changes in streamflow that can be amplified by the presence of extensive plantations, which affect the provision of nutrients to coastal waters, leading to changes in primary production in the ocean. These chains of effects cannot be addressed separately due to their intertwined nature [10,16]. Moreover, the consequences do not necessarily propagate linearly from one subsystem to the next, i.e., the response may not be proportional to the cause. The systems that are being locally and remotely perturbed are changing, evolving –over multiple time scales– and interconnected. These characteristics are those that define complex dynamic systems. Hence, to understand and face these challenges one must not adopt static and reductionist approaches but adaptive and holistic ones [17].

To face the Anthropocene, we must acknowledge the interconnectivity of the world we live in, which has been recognized in the United Nations 2030 Agenda that set out 17 Sustainable Development Goals that are integrated and indivisible. Also, we must be aware of the need for fast and far-reaching action [1]. This, in turn, requires new ideas, perspectives, concepts and the inclusion of multiple actors. We need to change our paradigms for science and governance among others moving away from sectoral approaches. The new epoch questions what we have called development and progress up to now.

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Geohistorical records of the Anthropocene in Chile

CHAPTER

1

We review evidence of the human imprint on present day northern and central Chile during the last 3 millennia. Our review suggests that societies that have inhabited these regions over the last 3000 years played an active role in shaping natural environments. We verify the cumulative impacts of past human activities on the evolution of Chilean ecosystems. The results support the emerging notion that the Anthropocene derives from long-term processes that have operated continuously since prehistoric times. In this sense, we demonstrate that deep-time narratives have the potential to become science-based instruments for shaping better-informed public and political discourses about socio-environmental history in Chile. But more importantly, that these offer crucial “baselines” to delineate safe operating spaces for future Chilean socio-ecological systems as well as principles for the sustainable management of Chilean ecosystems.

Estimates for past demographic levels for northern and central Chile reveal an overall exponential population growth during the last 3000 years, with a marked acceleration at about 2000 years ago. This pattern of demographic increase and human activities occurred under relatively adverse climate conditions in both regions. Apparently, pre-Columbian societies were able to buffer this environmental scenario by continuously adjusting socio-cultural practices and/or incorporating new technologies that guaranteed resource access and social wealth. The deliberate clearing and burning of native forests either on offshore islands and on the mainland resulted in an inherent land management practice in central Chile.

Large-scale landscape opening strategies were absent from the northern region, most likely due to the limited vegetation cover. Conversely, Atacama Desert populations exploited ecosystem services through the management of water from watersheds or aquifers, and the implementation of agroforestry to create fields of fertile crops and artificial vegetation oases. Intensive exploitation of target shellfish and other marine resources was a key strategy for coastal populations from both Chilean regions, that resulted in overfishing, a profound transformation of the littoral morphology, and probably, altered the nutrient-cycling in nearshore habitats.

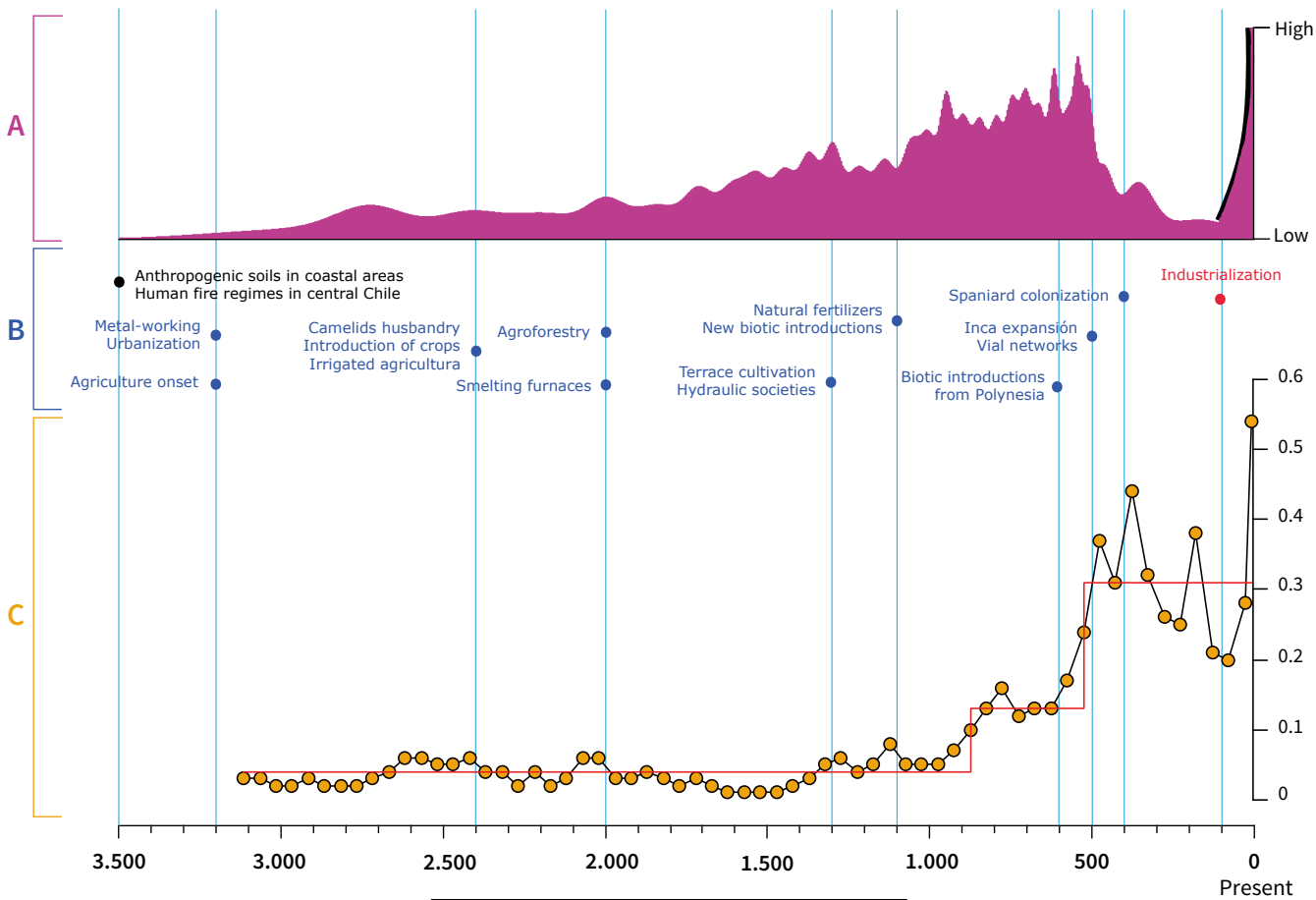
Recreation of the pre-Columbian practice of melting copper using high-temperature windmills.

We posit that past human behaviors modulated biophysical systems, precluding the view of virginity or unaltered environments before the Industrial Revolution. Moreover, the data analyzed suggest that most of present-day symptoms to describe the Anthropocene in Chile are rooted in pre-Columbian processes that were scaled up in intensity over the last 3000 years, and ultimately accelerated since Spanish colonization. Perhaps the most striking trend is the observed co-evolution between metallurgy intensity in northern Chile and atmospheric heavy metal pollution that is appearing in different south American and even Antarctic geochemical records.

Authors: Eugenia Gayó, Virginia McRostie, Roberto Campbell, Carola Flores, Antonio Maldonado, Mauricio Uribe-Rodríguez, Patricio Moreno, Calogero Santoro, Duncan Christie, Ariel Muñoz, Laura Gallardo
Publication in review

Figure

Panel A: Modeled demographic levels for chilean population over the last three millennia. The black line describes the population growth trend for the last 190 years. **Panel B:** Main socio-cultural and environmental transformations ocurred in the territory. The black dot denotes environmental disturbances that have induced by human activities since well-before the year 3500 BP. **Panel C:** Pollution index derived from metallurgical activities (black curve with orange circles). The red line describes regime changes in the anthropogenic emissions of heavy metals.



Evolution of air quality in Santiago: The role of mobility and lessons from the science-policy interface

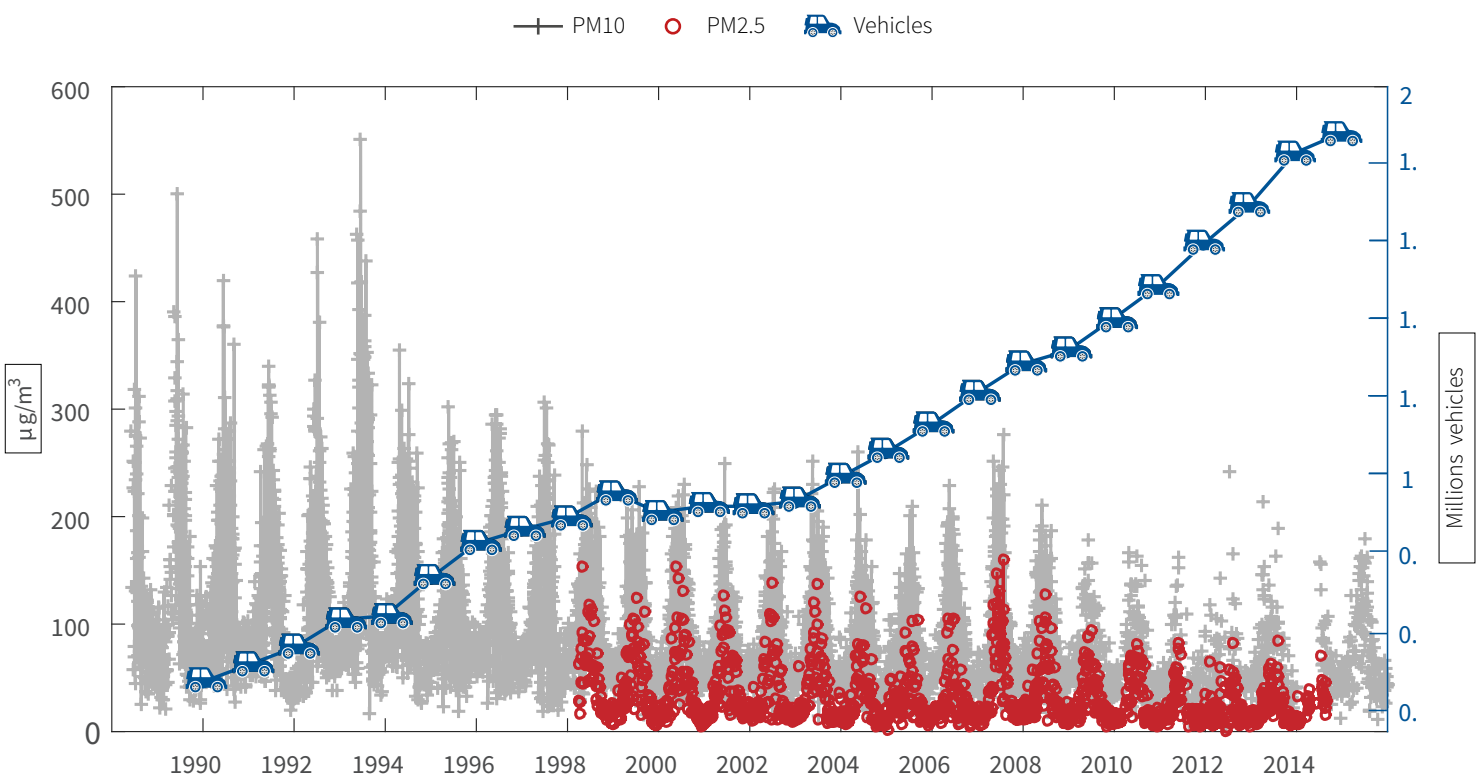
CHAPTER

2

The evolution of mobility and air quality over the past 30 years in Santiago, Chile, demonstrates the success of science-based policies, yet it also shows that technological changes are not enough. Sustainable urban development within the context of the Anthropocene requires integrated science and policy that address complexity, emphasizes behavioral changes, and moves beyond sectoral visions.

Over the past 30 years, urban sprawl has created segregated communities with poor connectivity, experiencing detrimental environmental and socio-economic impacts. A dramatic decrease in public transport use in Santiago has been observed, dropping from 83% in 1977 to 47% in 2012, with a corresponding increase in private car use. Nevertheless, there is evidence of a substantial decrease in coarse mode aerosol (PM10) concentrations in Santiago despite the urbanization rates described above. This reflects the success of policy measures adopted since the early 1990s. Policies have been mainly technological and operational. However, these efforts have been counteracted, in the case of fine mode particles (PM2.5), by increasing vehicular activity levels. Likewise, a transition to a more oxidative atmosphere, where secondary aerosol formation and photochemical pollution become particularly relevant, also emerges from our analysis. Thus, attention must be paid to the evolution of the transportation sector due to its emissions of nitrogen oxides, among others. The technological and operational measures will likely be insufficient if behavioral changes do lead to an increase in the use of public transportation. To this end, the incorporation of social scientists and communicators within the policy-making arena will be paramount.

PM10 & PM2.5 evolution and number of cars between 1988 and 2016

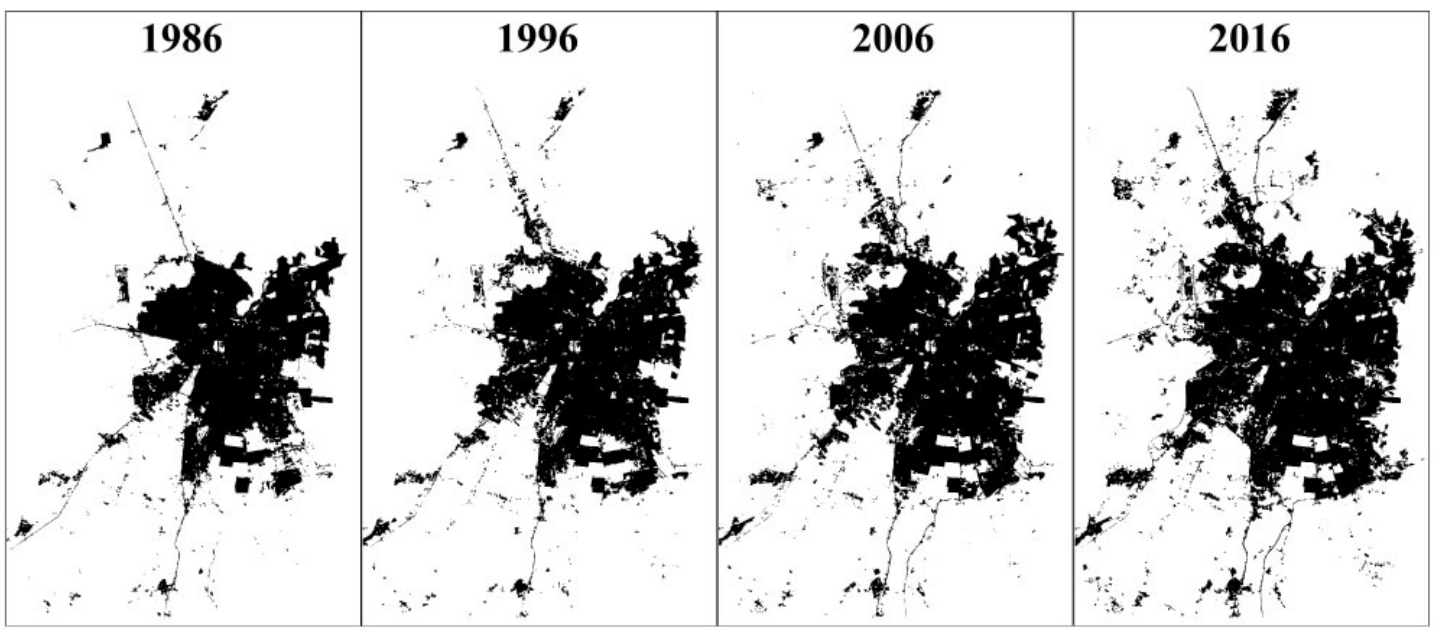


Along with that, current monitoring efforts must be enhanced, therefore we suggest the establishment of at least one monitoring supersite in Santiago, and, eventually, in all major Chilean urban centers. If undertaken jointly with an academic consortium, such an initiative would support long-term collaboration with the scientific community. Also, extending current greenhouse gas emissions estimates to include short-lived climate pollutants and its precursors, including black carbon, methane, nitrogen oxides and hydrocarbons, among others, is key. Cost-benefit analyses have been limited to health impacts, without considering other impacts such as visibility, crop damage, impacts on vegetation, food and water security, contamination of water bodies, and others. Likewise, a shift from short-term effects (acute) to long-term effects (chronic) appears necessary.

The context of the Anthropocene calls for bold and creative action. Many actions must occur within the city and be echoed and sustained by science, media and political will. Cities can offer opportunities for technological and societal transformations towards energy efficiency and decarbonization, in accordance with the Paris Agreement.

Authors: Laura Gallardo, Francisco Barraza, Andrés Ceballos, Mauricio Galleguillos, Nicolás Huneeus, Fabrice Lambert, Cecilia Ibarra, Marcela Munizaga, Raúl O'Ryan, Mauricio Osses, Sebastián Tolvett, Anahí Urquiza, Karina D. Véliz
Published in: http://doi.org/10.1525/elementa.293

Evolution contours of the city of Santiago from 1986 to 2016



Insight into anthropogenic forcing on coastal upwelling off south-central Chile

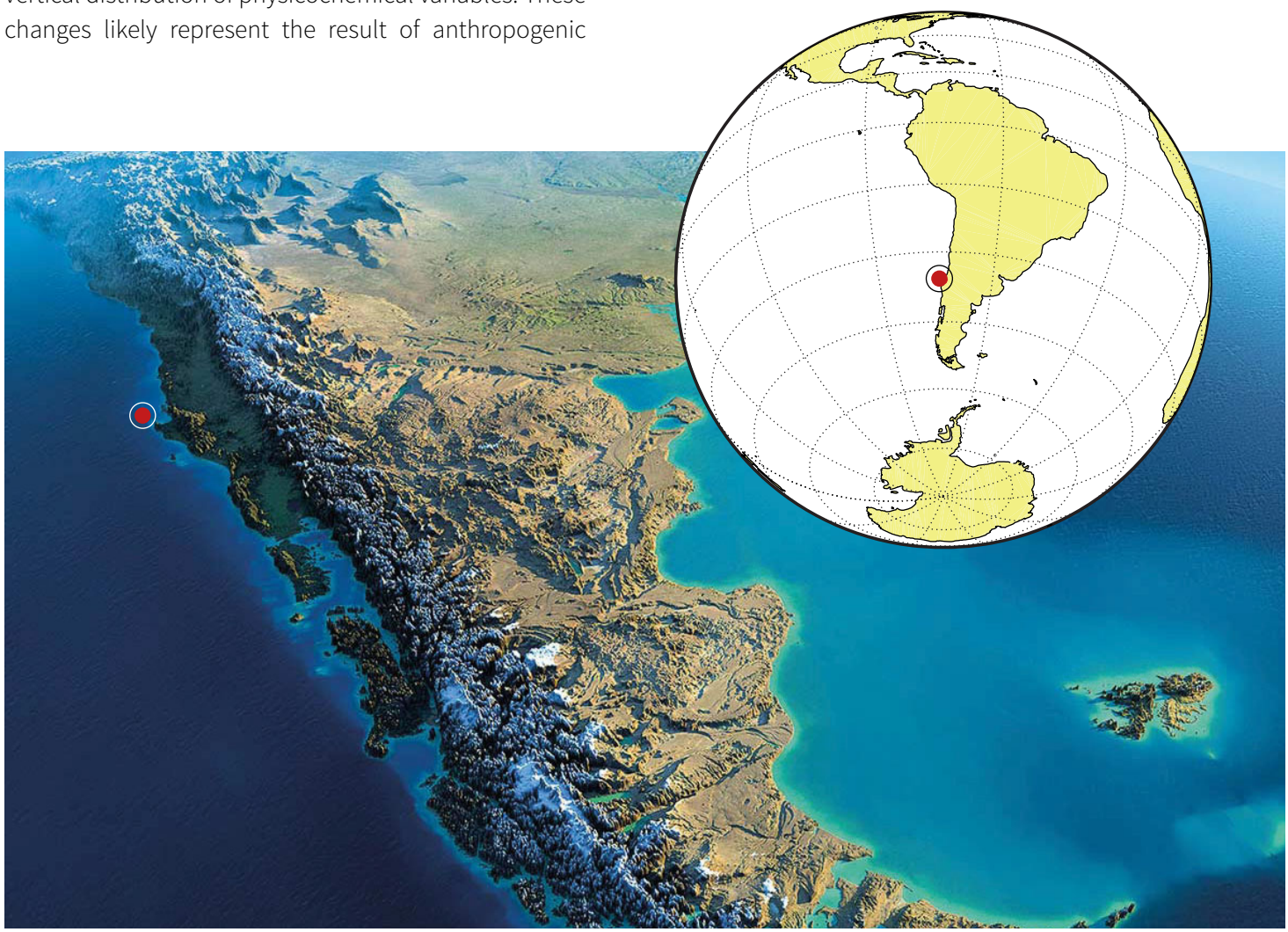
CHAPTER

3

Observed trends of environmental variables in the coastal ocean of south-central Chile during the last two decades appear to have been influenced by anthropogenic climate change and generating a chain of impacts on their marine ecosystems that affect fishing. This is key in coastal upwelling of Chile, systems with high biological productivity that are associated with important economic activities. Changes in intensity and frequency of the coastal upwelling system have numerous physical and biological consequences. Effectively addressing this issue will require better information to analyze the ocean through a representative observation system, for example, of oceanographic buoys, that operates effectively in the long term, which allows proposing measures to respond to adverse changes in the coastal ocean.

In the last two decades, an increase in sea-level pressure over the Southeast Pacific, as well as a southward shift of the Subtropical High-Pressure system, have been observed. These changes have resulted in clearer skies (more solar radiation in the surface), stronger upwelling-favorable winds, process by which cold waters, with low concentration of oxygen and rich in nutrients, rise to the surface. This translates into a coastal cooling and a greater contribution of nutrients to the surface layer which, in turn, affects the increase in phytoplankton biomass, and less dissolved oxygen concentrations. A shoaling of the mixed layer depth is also apparent that influences the vertical distribution of physicochemical variables. These changes likely represent the result of anthropogenic climate change, as the spatial configurations of these trends are consistent with those projected by climate change scenarios for the 21st Century. However, natural variability at interannual and interdecadal scales also play a key role.

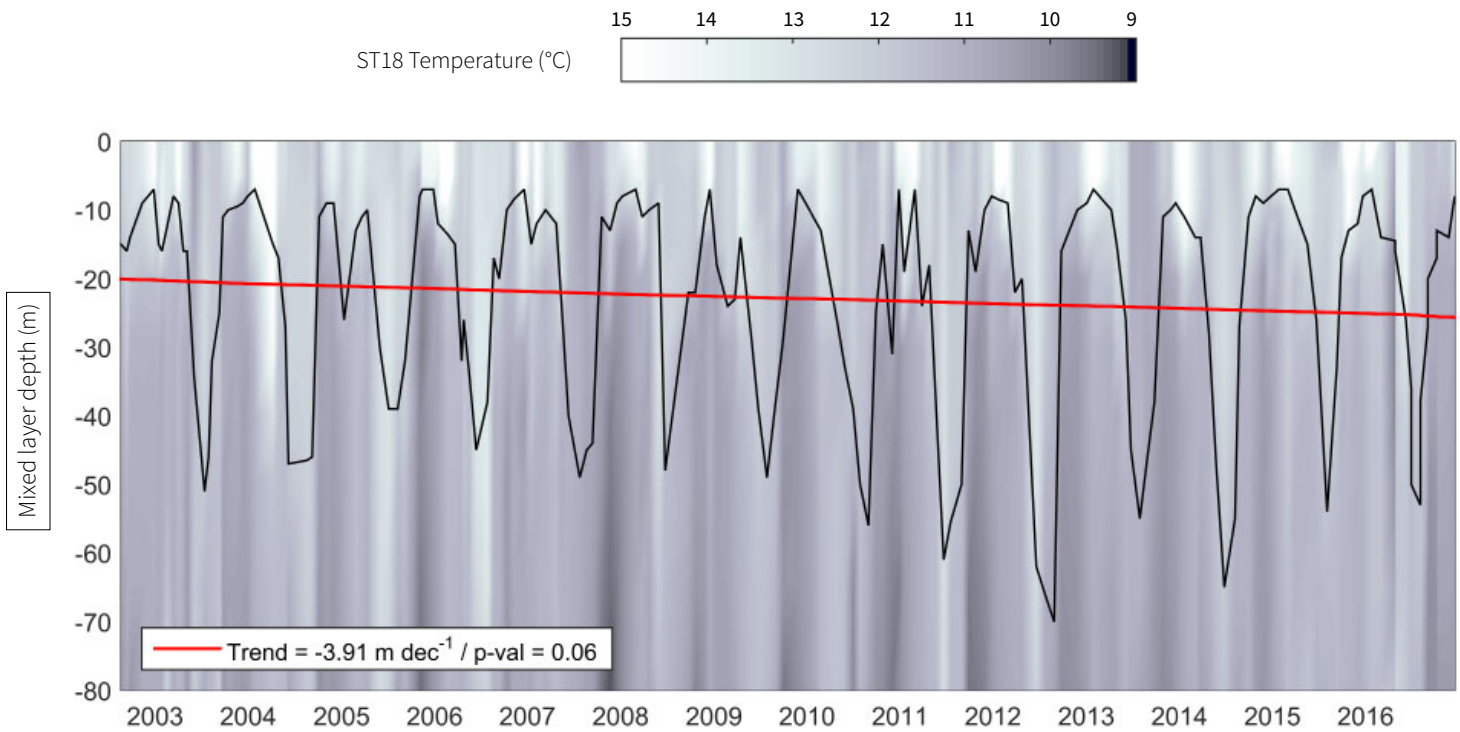
Sea color satellite image and/or location of station 18



The evidence summarized in this work illustrates the rapid rate of change and the complexity of the biophysical system defined by the coastal upwelling system along central and southern Chile. Observed trends are influenced by anthropogenic climate change, and the chain of impacts affects marine ecosystems that sustain fisheries, in turn, human well-being. Changing coastal upwelling systems and their consequences therefore represent a clear regional manifestation of the Anthropocene. Decision making must better integrate policy and science and use an ecosystem approach. To this end, it is vital to increase the level of certainty attached to the attribution of causality to past and future change by broadening the observational basis and developing long-term monitoring.

Authors: Catalina Aguirre, Sebastián García-Loyola, Giovanni Testa, Diego Silva, Laura Farías.
Published in: http://doi.org/10.1525/elementa.314

Evolution of mixed layer depth as inferred from water temperature offshore Concepción (2003-2017)



Anthropogenic drying in central-southern Chile evidenced by long-term observations and climate model simulations

CHAPTER

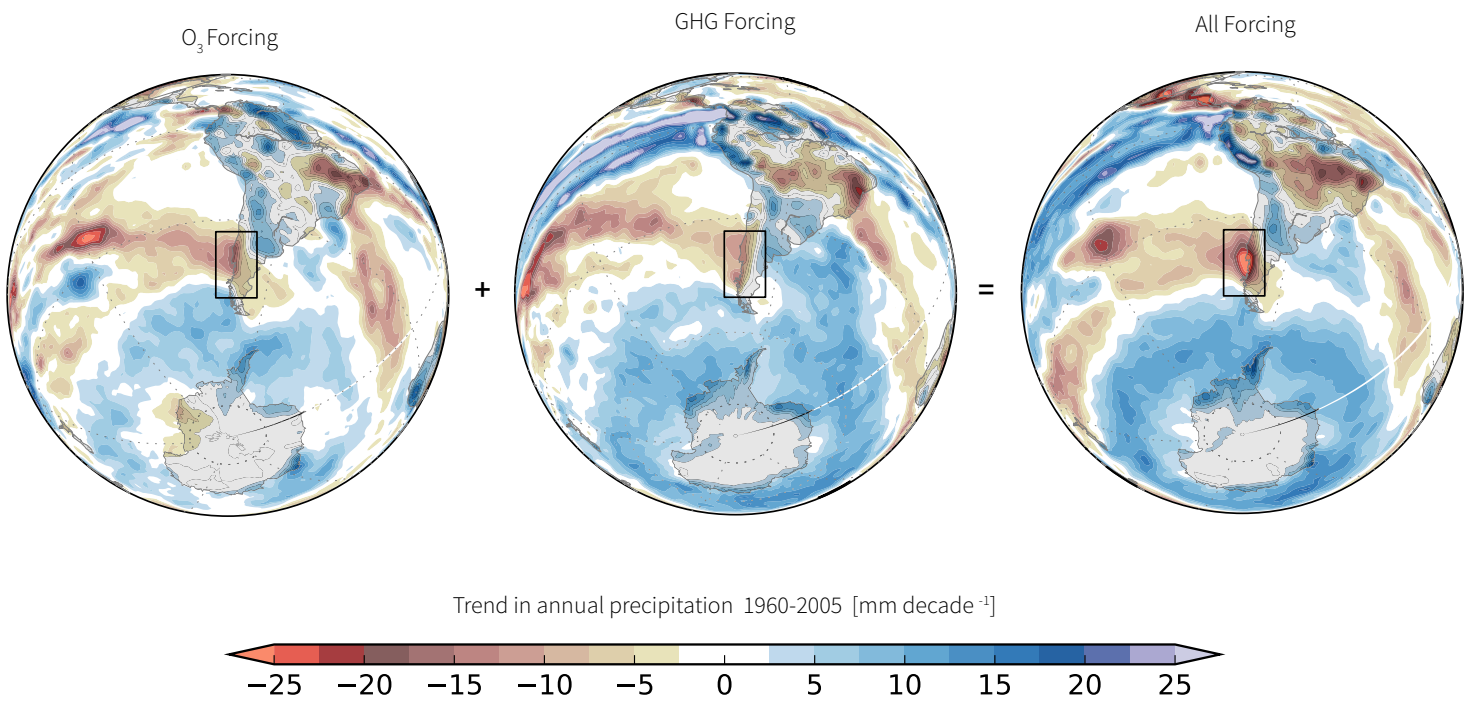
4

The observed long-term drying signal in central-southern Chile is mostly attributable to anthropogenic forcing. Without strong measures to reduce global emissions of greenhouse gases, we can expect this trend observed over the last decades to continue, albeit modulated on annual-to-decadal time scales by natural variability. The long-lasting and extended drought experienced in Chile in recent years serves as an analog for future climate. In addition to the direct impact on water availability, the rainfall deficit has resulted in multiple often linked impacts affecting vegetation, coastal marine biogeochemistry, and the intensity of forest fires, stressing mutually-dependent effects of the drought on Chile's socio-ecological systems.

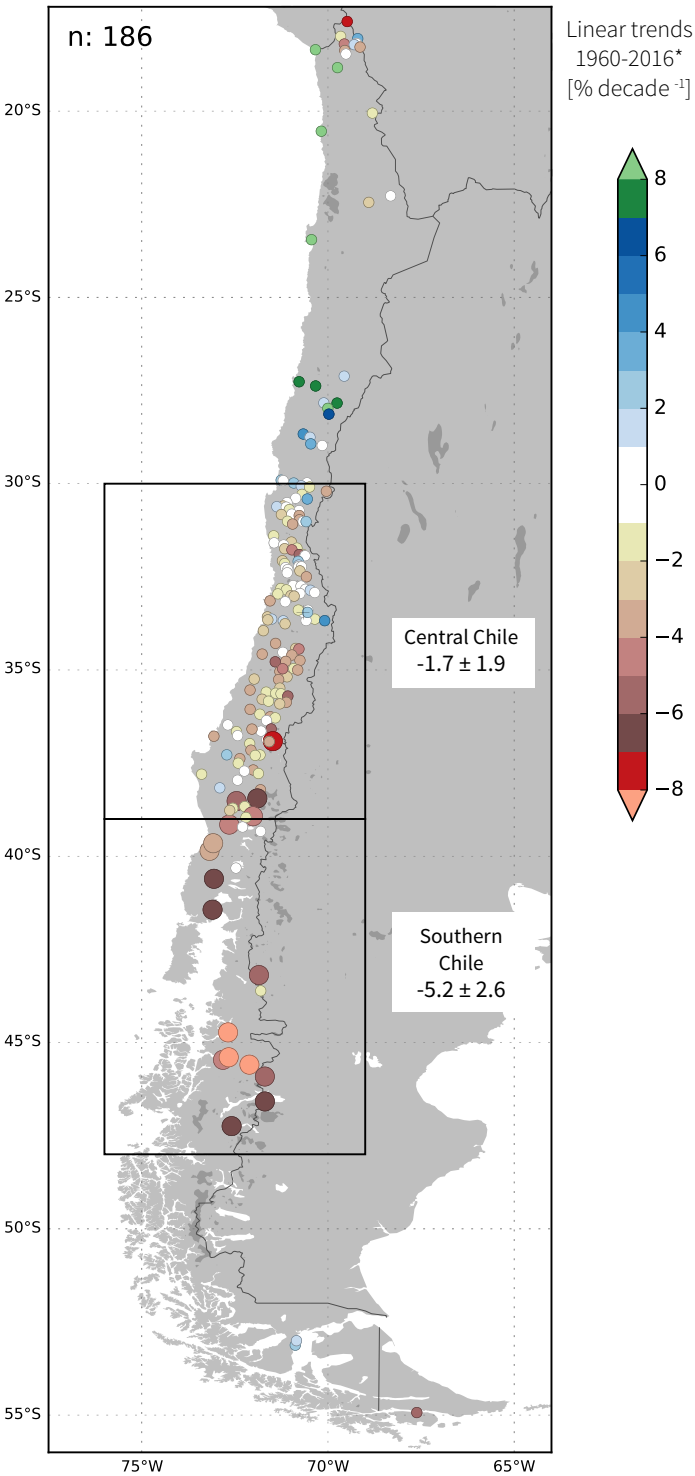
Changes in Chile's hydrological regime is recognized as a major risk for the country's future development. The analysis of recently assembled observations confirms a robust drying trend over the period 1960–2016 in central and southern Chile a climate signal that very likely emerged above natural variability during the last decade. The observed seasonal behavior of the rainfall decline agrees with the modeled response to multiple anthropogenic forcings in this region, which is consistent with a drift in hemispheric-scale atmospheric circulation known to be driven by anthropogenic factors. Hence, we conclude that the observed long-term drying signal in Chile is, to a large extent, attributable to anthropogenic forcing. The strong summer drying observed south of 38°S, of about 8% per decade, is associated with the depletion of stratospheric ozone, amplifying the drying effect forced by the greenhouse gas increases in all seasons.

Since the stratospheric ozone content is expected to recover throughout the 21st century as a result of the Montreal protocol, one can expect a lessening of the summer drying in southern Chile due to this forcing mechanism. In central Chile the rainfall decline is more significant in winter and is now perceptible over a large background of natural variability. The precipitation trend and, notably, the recent mega drought that affected this region, has a larger ocean (natural) forcing but also an anthropogenic component. The El Niño-Southern Oscillation (ENSO) and ENSO-like decadal modes of natural variability (e.g., Pacific Decadal Oscillation) will modulate precipitation on top of the centennial anthropogenic drying trend.

Simulation of sea level pressure and precipitation trends



Changes in annual precipitation



Notwithstanding the general coherence between the observed and simulated changes in the precipitation regime in Chile, the magnitude of the actual drying quantified in this study is substantially larger than that modelled. This bias is unlikely to be fully explained by natural variability, implying that the current climate simulations may be underestimating the drying amplitude in central-southern Chile. Further research is needed to constrain the uncertainties of the anthropogenic drying in Chile.

As changes in the precipitation regime are superimposed on a warming trend, other aspects should be considered, notably the increasing evapotranspiration and changes in the annual cycle of snowmelt and runoff. Changes in temperature, freezing level height and rainfall extremes should also be accounted for when assessing the risk of flooding or drought. Regarding water availability in the coming decades, we can expect the anthropogenic drying trend to continue, although modulated on annual-to-decadal time scales by natural variability.

Authors: Juan P. Boisier, Camila Álvarez-Garretón, Raúl R. Cordero, Alessandro Damiani, Laura Gallardo, René D. Garreaud, Fabrice Lambert, Cinthya Ramallo, Maisa Rojas, Roberto Rondanelli
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Anthropocene and streamflow: Long-term perspective of streamflow variability and water rights

CHAPTER

5

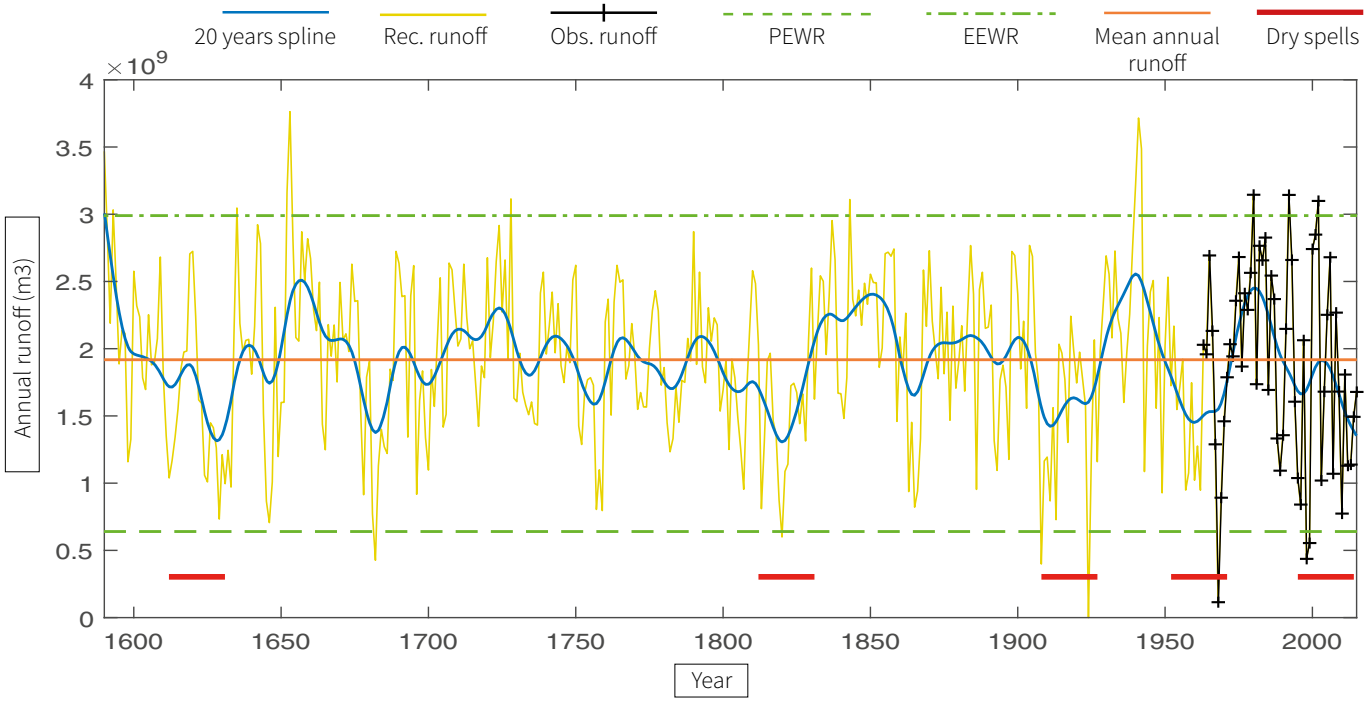
Aquí se analizan las asignaciones de los derechos de uso de agua considerando la variabilidad natural de largo plazo (1590–2015) y los escenarios futuros de los recursos hídricos del Perquilauquén, un afluente de la cuenca del Maule, ubicado en Chile central. Enfatizamos la necesidad urgente de una revisión de las metodologías actuales de asignación de derechos de agua y su legislación, que no concuerdan con la dinámica y la naturaleza no estacionaria de los procesos hidrológicos. La escasez de agua y su gobernanza son dos de los temas clave que debe enfrentar Chile en el Antropoceno.

Since 1981, water allocation in Chile has been based on a water use rights market, with limited regulatory and supervisory mechanisms. The volume to be granted as permanent and eventual water use rights is calculated from streamflow records, if stream gauge data are available, or if not, from data from similar catchments, usually having fewer than 50 years of records.

To test the performance of this allocation system, while analyzing the long-term natural variability in water resources, 400 year-long (1590–2015) tree-ring reconstruction of runoff and historical water rights was investigated for the Perquilauquén, a tributary of the Maule River in Central Chile. Furthermore, we assessed how the current legislation would perform under a projected climate scenario, based on historical climate simulations of runoff calibrated against observed data, and future projections.

Research assistants of the Dendrochronology and Global Change Laboratory of Universidad Austral de Chile taking samples of growth rings of ancient cypress trees of the Andes (Austrocedrus chilensis) to reconstruct the climate of the last 1,000 years. Place: Serranía El Ciprés, El Asiento, Valle del Aconcagua, Región de Valparaíso.

Observed runoff of the Perquilauquén river taking account the instrumental record and the reconstruction since 1590



Our analyses indicate that the allocation methodology currently applied by the Water Authority in Chile is very sensitive to the time window of data used, which leads to an underestimation of variability and long-term trends. According to the water use rights database provided by the Chilean Water Directorate, water use rights at river Perquilauquén are already over-allocated.

Considering regional climate projections, this condition will only be exacerbated in the future. Furthermore, serious problems regarding the access and quality of information on already-granted water use rights and actual water usage have been diagnosed, which further encumber environmental strategies to deal with and adapt to climate change. We emphasize the urgent need for a review and revision of current water allocation methodologies and water law in Chile, which are not concordant with the dynamics and non-stationarity of hydrological processes.

Authors: Pilar Barría, Maisa Rojas, Pilar Moraga, Ariel Muñoz, Deniz Bozkurt, Camila Álvarez-Garretón
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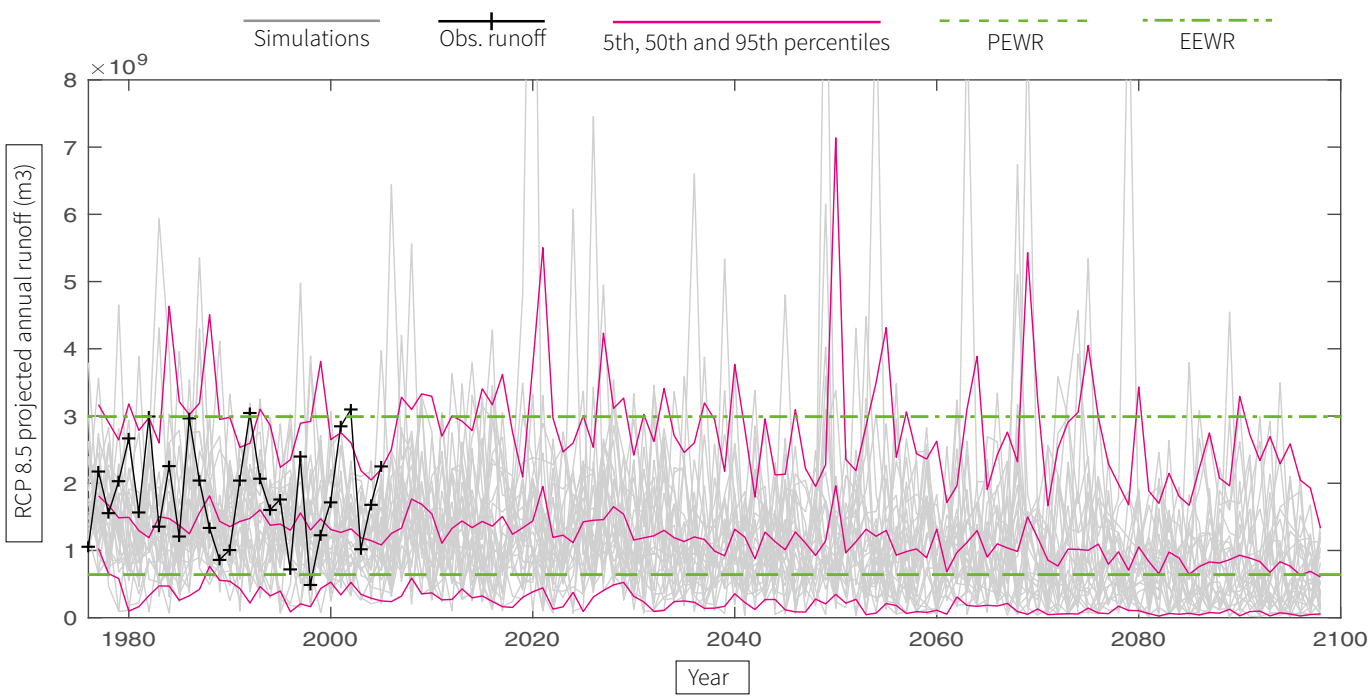
Annual runoff projections (m3) of the Perquilauquén river for the historical and future period (2006-2080)



Land use and land cover change in the Anthropocene

CHAPTER

6

From the Maule Region to the Los Ríos Region, forest plantations are the main contributor to native forest loss. This has adverse consequences on biodiversity, fire regimes, and water provision. It is imperative to design a new forestry policy to assure the conservation of one of the most unique biodiversity hotspots worldwide, to face new fire regimes and to assure water provision in central and southern Chile.

In central and south-central Chile, native forests and shrublands were the main land cover during the pre-European period. Since then, native forest loss has manifested itself as the main land use and land cover change, having been reduced by more than 50% of its original area through their conversion to pasturelands, shrublands, agricultural land and forest plantations of exotic species. Native forests in central and southern Chile are considered one of the 35 world biodiversity hotspots.

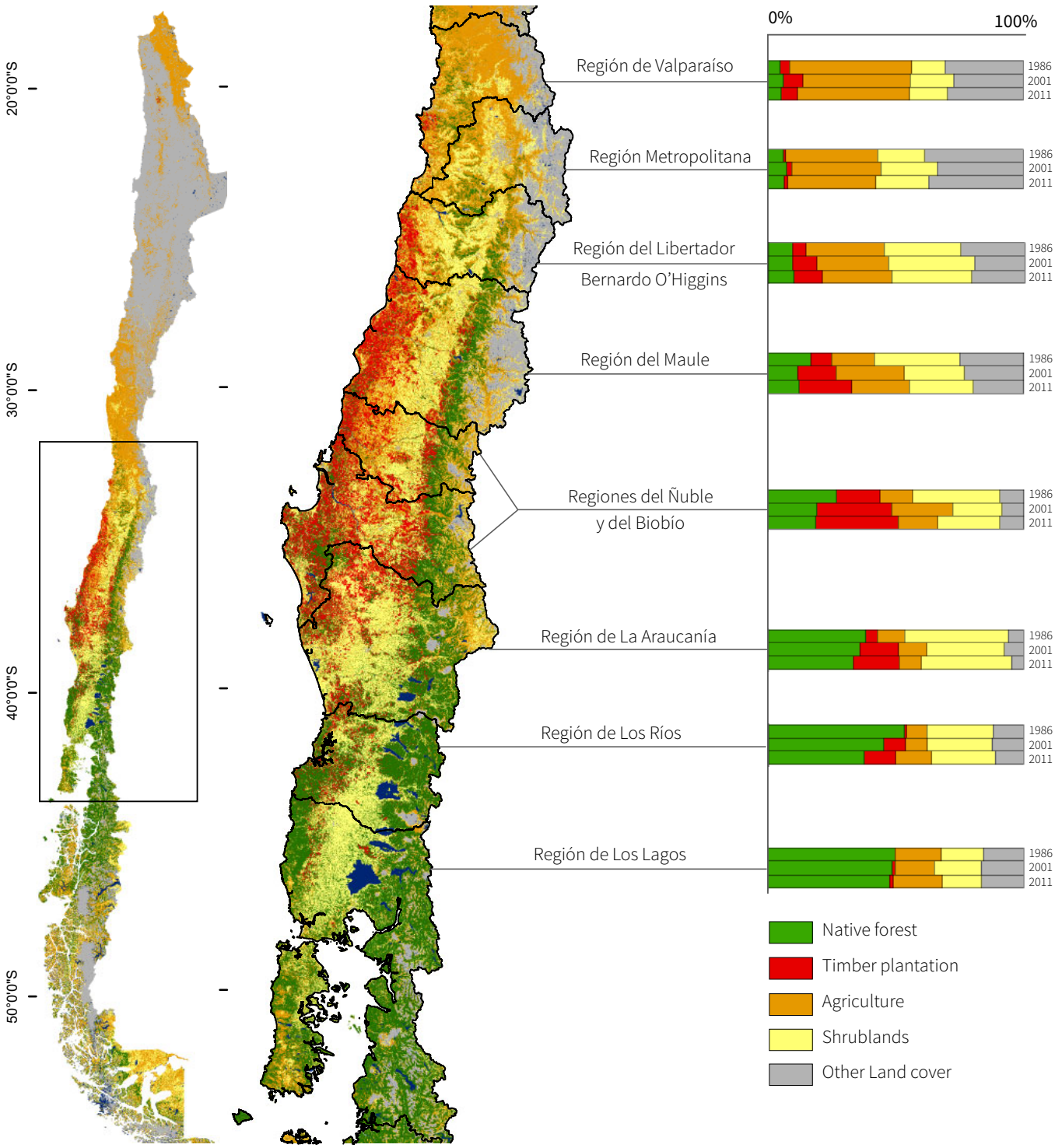
The main underlying drivers of land use and land cover change since the mid-nineteenth century are human-made fires and forest clearing for the expansion of agriculture and pasturelands by the Euro-Chilean colonization that has been promoted by the government. In recent decades, a major driver of land use and land cover change were the substantial incentives for forest plantations by Decree Law 701 passed in 1974. Forestry Policy and incentivizing plantations were renewed as Chile moved to a democracy and continued to operate until 2012.

Decades of intentionally produced fires to clear native forests for agriculture and cattle ranching triggered catastrophic soil erosion. The development of extensive homogeneous and continuous exotic plantations very prone to fire have contributed to human caused fires. Another important impact of landscapes highly dominated by exotic plantations is the decrease of water provision (quantity and quality) as an ecosystem service, due to their higher evapotranspiration rates compared to native forests.

Native forest loss in the Chilean biodiversity hotspot: revealing the evidence
Authors: Alejandro Miranda, Adison Altamirano, Luis Cayuela, Antonio Lara, Mauro González
Published in: https://doi.org/10.1007/s10113-016-1010-7

Forests and water in South America. Hydrological Processes
Authors: Julia Jones, Auro Almeida, Felipe Cisneros, Andres Iroumé, Esteban Jobbágy, Antonio Lara, Walter de Paula Lima, Christian Little, Carlos Llerena, Luis Silveira, Juan Camilo Villegas
Published in: https://doi.org/10.1002/hyp.11035

Geographical distribution of the main land cover and land uses



Fires in the Anthropocene

CHAPTER

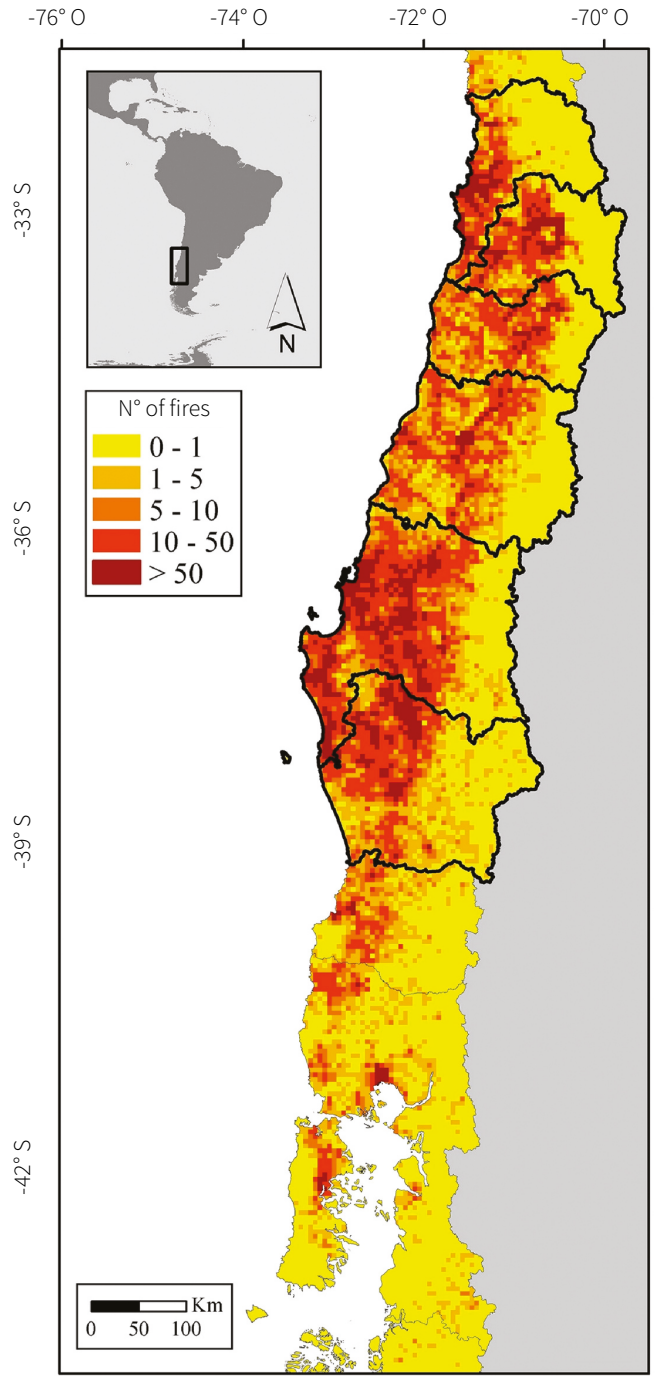
7

The agricultural areas with annual crops, grazing areas, as well as extensive forest plantations, are more prone to fire than native temperate forests. This implies that the adequate management of fuel and the design of landscapes will be key elements in reducing the impact of fires in the global change scenario in which we are already immersed.

In general, for a fire to start, only one source of ignition is required, when the fuel (leaves, branches, wood, fine grass, among others) is dry and flammable. However, once the fire has started, the intensity of the fire will depend on the load of that fuel and its speed of propagation will depend on the continuity of that fuel in the landscape, its flammability, the topography and the meteorological conditions at the time of the fire. On a global scale, both climate change and the change in land use are responsible for the increase in the occurrence of fires.

In recent decades, the landscape of central and southern Chile has undergone a strong transformation: large areas of native forest have been replaced by agricultural areas and exotic forest plantations. The mega fires that occurred in Chile in the summer of 2017 occurred after an extended period of drought, with deficits of around 30% in the Maule and Bío-Bío regions. In addition, a strong heat wave was observed with temperatures exceeding 32.6 ° C for 3 weeks. Forest plantations were the most affected land use (~ 286 thousand ha). Thus, the conjunction of, on the one hand, exceptional meteorological conditions and, on the other hand, the availability of fuel that is distributed in an extensive, homogeneous and continuous way in the landscape -as is the case of forest plantations- allowed the propagation of fires. These fires were exceptional in terms of intensity and speed of propagation, reducing the capacity to placate the fire. Therefore, the diversification of land use and the generation of heterogeneous landscape mosaics will be a fundamental tool to protect us from mega fires in the future.

Total number of fires per grid-cell
(5 × 5 km; Projection system WGS84 UTM 19S)
during the period 1985–2015



It is crucial that forestry and fire prevention policies incorporate the scientific knowledge available in relation to the optimization of fuel management based on risk analysis, in order to begin to implement efficient management tools at the landscape scale. This is particularly necessary in urban-rural interface areas, where the safety of people is a priority. We still can change towards more intelligent landscape arrangements, which reconcile the conservation of biodiversity, the delivery of ecosystem services and protection against fires.

Temperature and agriculture are largely associated with fire activity in Central Chile across different temporal periods. Forest Ecology and Management
Authors: Susana Gómez-González, Mauro E. González, Susana Paula, Ignacio Díaz-Hormazábal, Antonio Lara, Manuel Delgado-Baquerizo
Published in: https://doi.org/10.1016/j.foreco.2018.11.041

The 2010-2015 Megadrought and its influence on the fire regime in central and south-central Chile
Authors: Mauro E. González, Susana Gómez-González, Antonio Lara, René Garreaud, Ignacio Díaz-Hormazábal
Published in: https://doi.org/10.1002/ecs2.2300

Portugal and Chile: Longing for sustainable forestry while rising from the ashes.
Authors: Susana Gómez-González, Fernando Ojeda, Paulo M. Fernandes
Published in: https://doi.org/10.1016/j.envsci.2017.11.006

Climate change governance in the Anthropocene: Emergence of Polycentrism in Chile

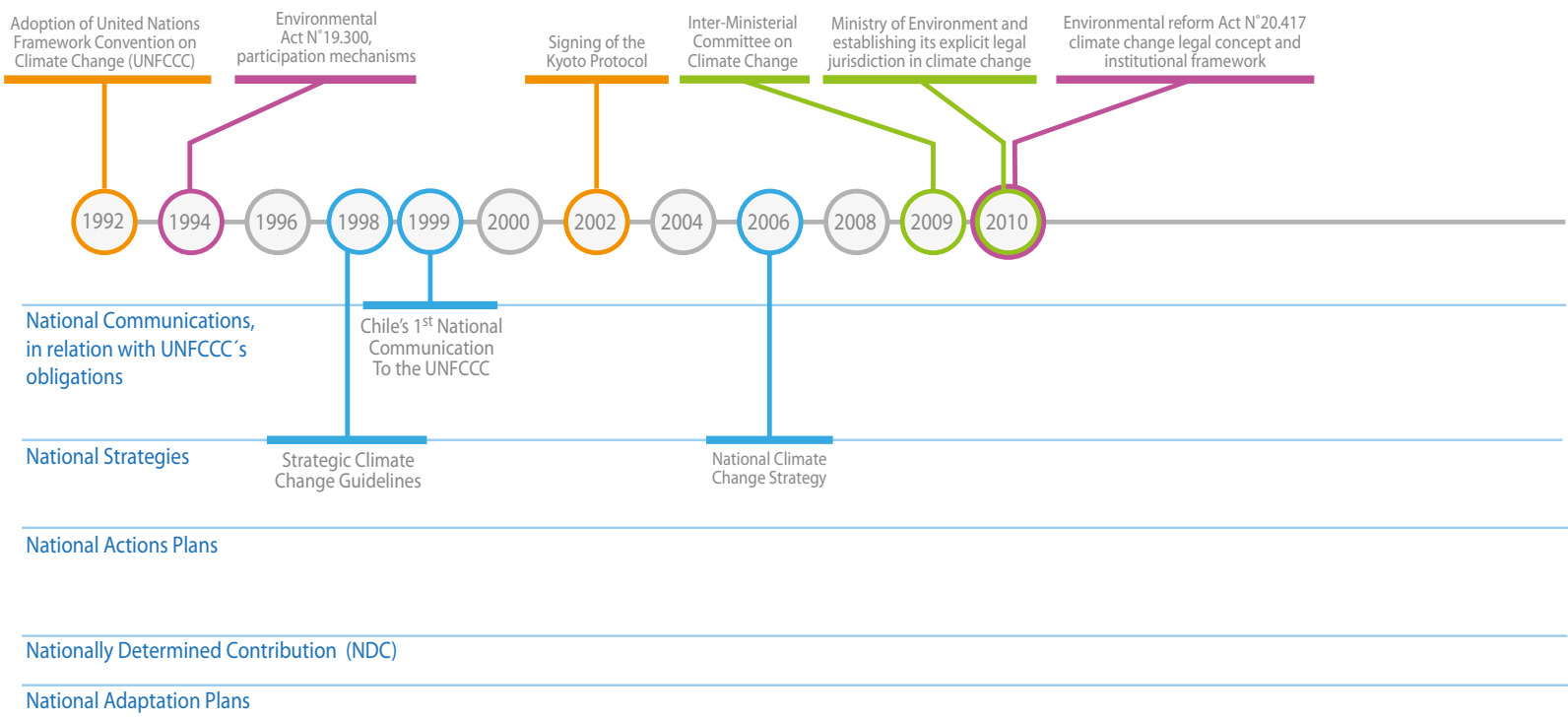
CHAPTER

8

Polycentrism –understood as a governance approach that coordinates multiple centers of semiautonomous decision-making, involving a diverse array of public and private actors– may provide an appropriate strategy for addressing the many challenges of climate governance in the Anthropocene. Two Chilean case studies were reviewed: Chile's Nationally Determined Contribution on Climate Change (NDC) and the Chilean National Climate Change Action Plan (PANCC). Our examination demonstrates that Chile has taken the first steps towards polycentrism but is still a long way from fully achieving it. Also, the national government coordinated both processes, showing the key role of interventions at higher jurisdictional levels in orienting institutional change to improve strategic planning and better address climate change.

A conceptual framework has been proposed to explore opportunities for polycentric climate governance in our country, understanding polycentricity as an approach that encompasses the potential for coordinating multiple centers of semiautonomous decision-making. We assert that polycentrism engages a diverse array of public and private actors for a more effective approach to reducing the threat of climate change. In this way, polycentrism may provide an appropriate strategy for addressing the many challenges of climate governance in the Anthropocene. We identified evidence (or lack) of emergence of polycentric governance by reviewing Chile's NDC and PANCC. To this end we considered four domains of polycentrism: (i) relevant governance levels and corresponding roles; (ii) actors and their roles (both formal and informal); (iii) cross-scale institutional linkages between multiple actors; and (iv) knowledge production. These case studies reveal a political commitment to open, participatory processes aiming to legitimize decision-making, avoid conflict, and produce robust commitments to international agreements by moving from often-symbolic social participation toward more active multi-stakeholder involvement. Our assessment also reveals a need to strengthen participatory processes and integrate multisector and multilevel actors throughout the entire political cycle, from policy design to implementation and evaluation.

Timeline of legal and institutional aspects of chilean climate governance since 1992



In terms of knowledge production, emerging institutional arrangements intend to build knowledge within the context of uncertainty and establish a common understanding of problems. It is necessary to institutionalize knowledge production and co-creation and document the strengths and weaknesses of this process to achieve adaptive management that learns from previous experiences, avoids mistakes, and effectively addresses knowledge gaps.

Efforts to overcome the weaknesses of the climate change policy arena in Chile should focus on strengthening current institutional structures for climate change response, encouraging institutional reform, fortifying communication channels and promoting decision-making that incorporates a wider group of organizations and social actors, as well as multiple levels of governance.

In particular, inclusion of local level actors presents an opportunity for enhancing polycentric governance modes, especially considering local administrations' unique role as key sources of knowledge, both directly affected by climate change and at the front lines of the climate change response. Nevertheless, case studies suggest that the central government also plays a key role in developing and implementing an effective and coordinated response to climate change.

Authors: Rodrigo Antonio Arriagada, Paulina Aldunce, Gustavo Blanco, Cecilia Ibarra, Pilar Moraga, Laura Nahuelhual, Raul O'Ryan, Anahí Urquiza, Laura Gallardo
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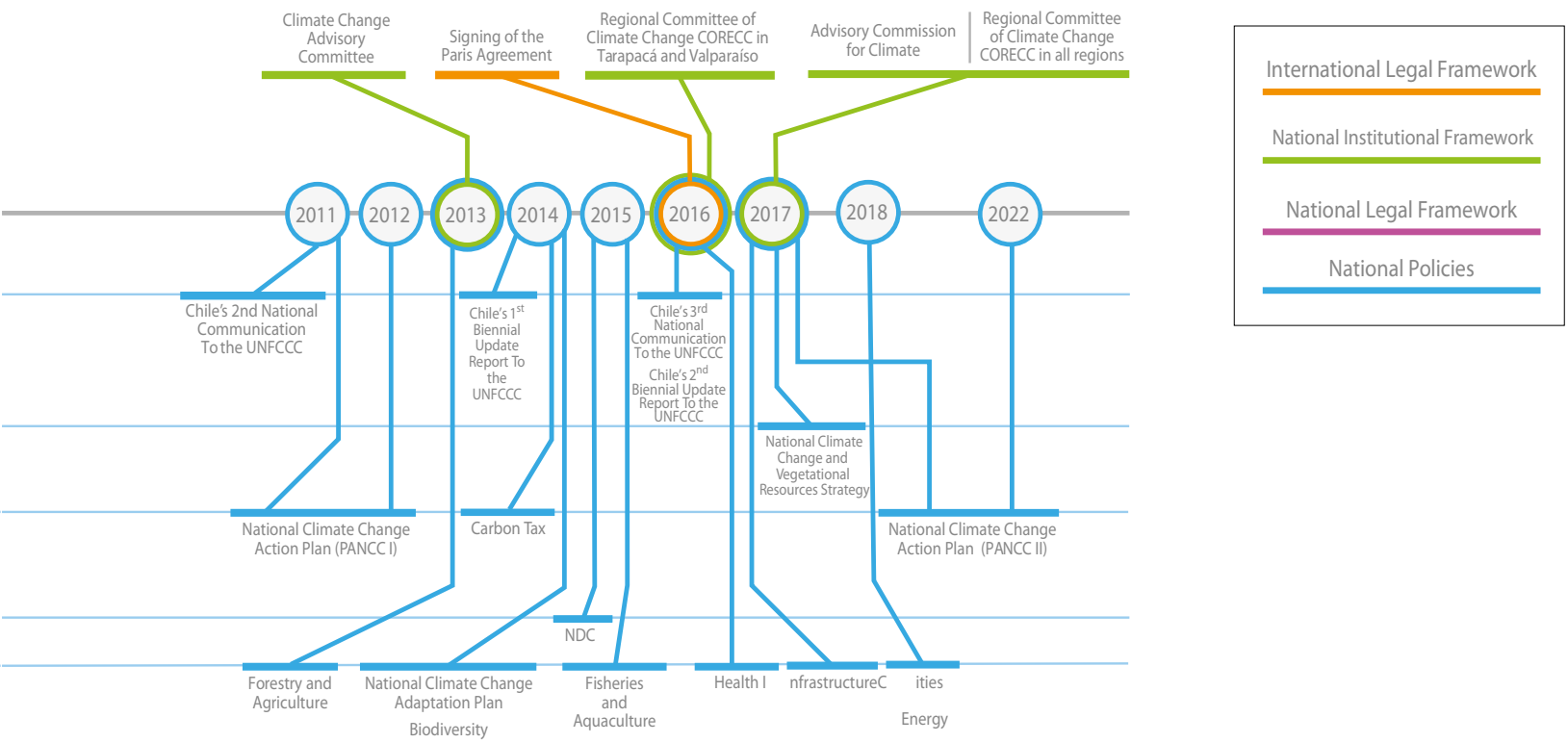
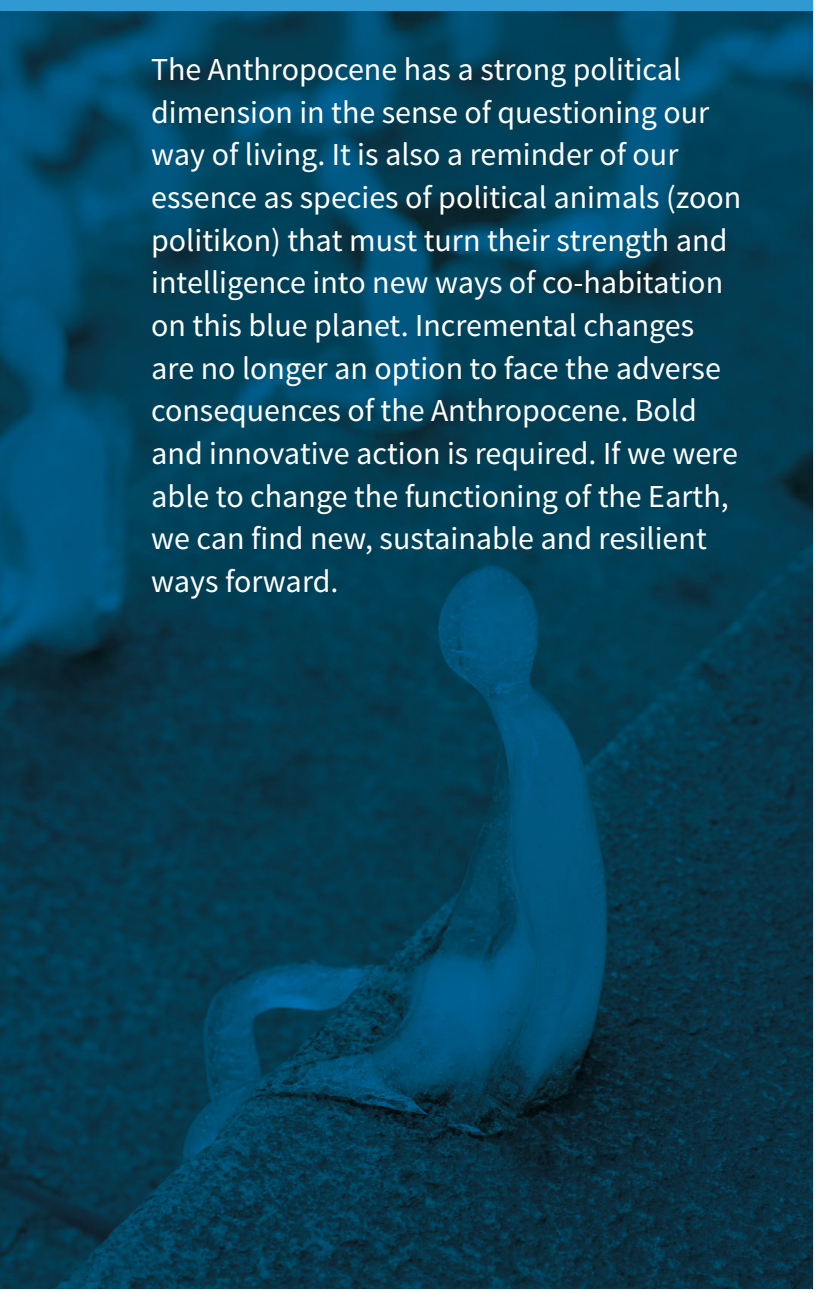


Recommendations



The Anthropocene has a strong political dimension in the sense of questioning our way of living. It is also a reminder of our essence as species of political animals (zoon politikon) that must turn their strength and intelligence into new ways of co-habitation on this blue planet. Incremental changes are no longer an option to face the adverse consequences of the Anthropocene. Bold and innovative action is required. If we were able to change the functioning of the Earth, we can find new, sustainable and resilient ways forward.

The Anthropocene –the epoch dominated by the human imprint on the planet– and its regional manifestations pose numerous threats both for Chile and the world at large. Facing those challenges requires an improved understanding of local and regional aspects, as well as of a new mindset able to adopt rapid and far-reaching measures, as strongly recommended by the international scientific community, and increasingly demanded by citizens, particularly younger generations, around the world. In doing so we will be building a more sustainable, equitable and prosperous future.

The Chile experienced by our ancestors is very different from the one we are experiencing now and probably more so from the one people in the near-future will face. All the issues addressed hereby stem from human environmental perturbations that affect the living conditions of Chilean society and most of our population. Drastic changes have been observed in air temperature, biodiversity, coastal ocean stratification, air quality, precipitation and stream flow, among others, over periods of less than a few decades, i.e., in roughly one generation. These changes bring strong challenges to governance as it must face intertwined issues, requiring a much stronger link between science and policy, more participation, with more diverse actors, under increased internal and external pressures, growing expectations, and accelerated rates of change.

Recommendations

Here we have examined geo-historical records of the human environmental impacts, including evidence of adaptative strategies adopted by pre-Columbian societies in central and northern Chile. Also, we have seen the records of accelerated urbanization and land use changes leading to changes in air quality, biodiversity, water availability, and fire regimes. We have discussed how human disturbances on climate that result in drying and warming trends over central and southern Chile pose challenges to the country's sustainability as water becomes scarce. This in turn, questions the way water rights are currently allocated, and are likely to be in the future.

Furthermore, we have analyzed changes in the Chile coastal upwelling system, and its consequences on fisheries. A set of conclusions and recommendations are drawn from our work and presented hereby to contribute to facing the challenges of the Anthropocene and building the roads to new opportunities for a sustainable near future.

1

From the geo-historical records left by pre-Columbian societies, we have learnt that human activities altered the environment well before the Industrial Revolution, although at a much slower rate than today. Pre-Columbian societies were able to buffer adverse environmental changes using adaptation strategies that combined adjustment of socio-cultural practices and the adoption of new technologies. Geo-historical records and their analysis offer "baselines" to delineate safe operating spaces for Chile today and tomorrow.

2

With an urbanization rate of nearly 90%, Chile must take the opportunities offered by cities to trigger technological and societal transformations towards energy efficiency and decarbonization, in accordance with the Paris Agreement and Sustainable Development Goals. The evolution of mobility and air quality over the past 30 years in Santiago demonstrates the success of science-based policies, yet it also shows that technological changes are not enough, emphasizing the need for behavioral changes, and integration across sectors with the overall objective of transforming Santiago and other urban areas, into livable cities.

Recommendations

3

Anthropogenic climate change is leaving an imprint on the physically, biologically and socially intricated upwelling system off the coast of central and southern Chile that sustains fisheries. The overall southward shift of upwelling favorable conditions is bringing nutrient rich but also oxygen poor waters to the mixed layer which may increase the risk for algae blooms.

These changes and risks require improved understanding, and governance. To this end, it is necessary to expand the observational basis and enhance long-term monitoring of the socio-ecological coastal upwelling system of central and southern Chile.

4

The observed long-term (1960-present) drying signal in central and southern Chile, which is already affecting agriculture and forestry, is, to a large extent, attributable to anthropogenic forcing. We can expect the anthropogenic drying trend to continue, although modulated on annual-to-decadal time scales by natural variability. The consequences of this phenomenon are manifold and often with linked impacts affecting vegetation and watersheds, the biogeochemistry of coastal water, as well as the intensity of forest fires.

Thus, facing a drying climate, and drought in the Anthropocene will require new, holistic approaches to water governance and climate change adaptation. In this vein, it is key to review and revise the current water allocation methodologies and water law in Chile, which are not concordant with the dynamics and non-stationarity of hydrological processes.

Recommendations

5

The development of extensive homogeneous and continuous exotic plantations, in combination with an extended drought, and the occurrence of heat waves led to unprecedented fires in the summer of 2017 with multiple adverse consequences on socio-ecological systems along central and southern Chile. This land use and land cover change has also contributed to the decrease of water provision (quantity and quality) as an ecosystem service, due to their higher evapotranspiration rates compared to native forests.

Thus, it is imperative to design a new forestry policy to assure the conservation of one of the most unique biodiversity hotspots worldwide, to face new fire regimes and to assure water provision in central and southern Chile. Intelligent landscape design and territorial planning will be paramount in this endeavor.

6

Phenomena in the Anthropocene are essentially intertwined. This calls for a governance that can engage a diverse array of public and private actors. We assert that polycentrism provides a way forward, particularly in the case of climate governance. This highlights the need to strengthen participatory processes and integrate multisector and multilevel actors throughout the entire political cycle –including social and natural scientists–, from policy design to implementation and evaluation, while strengthening the key role of interventions at higher jurisdictional levels in orienting institutional change to improve strategic planning and better address climate change action. This will better prepare us to appropriately address the climate and sustainable development challenges and opportunities that lie right ahead of us.



Glossary

Anthropocene: term proposed to designate the current geological time (post Holocene), which is defined by the alteration of the biophysical and geological conditions of the planet as a result of human activity. (Source: Manifiesto Antropoceno en Chile. Hacia un nuevo pacto de convivencia. Link: http://antropoceno.co/manifiesto.pdf)

Forcing: agent or phenomenon that generates a change. In the case of climate change, it occurs through natural internal processes, but also by external forces such as changes in solar cycles, volcanic eruptions or human actions on the atmosphere or soil that are maintained over time. The forces can be local or remote, orbital, among others. (Source: Glossary Intergovernmental Panel on Climate Change Link: https://www.ipcc.ch/site/assets/uploads/2018/08/WGI_AR5_glossary_EN.pdf)

Pacific Decadal Oscillation: temperature variations above the average that occur in the Pacific Ocean in certain periods of time. (Source: National Oceanic and Atmospheric Administration U.S Department of Commerce, Link: https://www.ncdc.noaa.gov/teleconnections/pdo/)

Atmospheric monitoring supersites: refers to a concurrent observation station of multiple parameters with more sophisticated instruments than those used in monitoring sites oriented to the verification of air quality standards. The supersites are oriented to the understanding of processes that affect air quality and to characterize its evolution. They contemplate the physical and chemical characterization of particulate material segregated by size and its gaseous precursors, as well as other relevant traces, including greenhouse gases and meteorological variables. These types of monitoring sites provide valuable information for atmospheric sciences and human health research and exposure communities. In addition, they provide reference measurements for the calibration of instruments used in common air quality stations. These sites require highly qualified technical personnel and can be operated in the context of consortiums between environmental authorities and academic entities. Examples of them are in the United Kingdom, the United States, Finland, etc.

Coastal upwelling: a process in which deep, cold, nutrient-rich waters emerge to the surface of the ocean, due to the wind that moves the surface waters. Cold water replaces pushed water, which occurs mainly along the coastline. These waters, being rich in nutrients, have a greater amount of biomass, which allows greater fishing activity. (Source: National Oceanic and Atmospheric Administration U.S Department of Commerce, Link: https://oceanservice.noaa.gov/facts/upwelling.html)

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