Comisión Nacional de Investigación Científica y Tecnológica - CONICYT

FONDAP CENTERS OF RESEARCH PROGRAM

CONTINUITY PLAN

Guidelines:

Both a printed (report and excel spreadsheets) and an electronic version must be sent to the following address:

PROGRAMA CENTROS DE EXCELENCIA FONDAP
CONICYT
Moneda 1375, Floor 9
Providencia
Santiago

E-mail: mcamelio@conicyt.cl
Phone: (56 – 2) 2435 43 27

For future inquiries, please contact:

María Eugenia Camelio
FONDAP Program Acting Director
E-mail: mcamelio@conicyt.cl

CONICYT
Ministerio de Educación
Gobierno de Chile

Comisión Nacional de Investigación Científica y Tecnológica - CONICYT

PRESENTATION

NAME OF THE CENTER **Center for Climate and Resilience Research**		**CODE** 15 11 00 09
DIRECTOR OF THE CENTER Laura Gallardo Klenner	**E-MAIL** lgallard@u.uchile.cl laura@dgf.uchile.cl	**SIGNATURE**
DEPUTY DIRECTOR René Garreaud Salazar	**E-MAIL** rgarreau@dgf.uchile.cl	**SIGNATURE**
SPONSORING INSTITUTION Universidad de Chile		
SPONSORING INSTITUTION REPRESENTATIVE Favio Salazar Onfray	**E-MAIL** vespinozasc@u.uchile.cl	**SIGNATURE**
ASSOCIATE INSTITUTION(S) (if applicable) Universidad Austral de Chile		
ASOCIATE INSTITUTION REPRESENTATIVE Oscar Galindo Villarroel	**E-MAIL** rectoria@uach.cl	**SIGNATURE**
ASSOCIATE INSTITUTION(S) (if applicable) Universidad de Concepción		
ASOCIATE INSTITUTION REPRESENTATIVE Sergio Lavanchy Merino	**E-MAIL** rector@udec.cl	**SIGNATURE**
CENTER WEBSITE ADDRESS http://www.cr2.cl/		

DATE: _18/_August_/_2017_

UNIVERSIDAD DE CHILE VICERRECTORIA DE INVETIGACION Y DESARROLLO VICERRECTOR

UNIVERSIDAD DE CONCEPCIÓN RECTOR REPUBLICA DE CHILE

UNIVERSIDAD AUSTRAL DE CHILE DECANO FACULTAD DE CIENCIAS FORESTALES Y RECURSOS NATURALES

UNIVERSIDAD AUSTRAL DE CHILE DIRECCIÓN JURÍDICA ABOGADO VALDIVIA

UNIVERSIDAD AUSTRAL DE CHILE VALDIVIA

Executive Summary

Indique en un máximo de tres páginas el plan que sintetice los próximos 5 años de ejecución del Centro. Para ello trabaje en torno a los grandes objetivos que el equipo de investigadores pretende poner en práctica durante ese período. Los grandes objetivos del Centro deben aunar a todas aquellas actividades propias del Centro y aquellas que deberían proyectarse para su óptimo funcionamiento y no exclusivamente a aquellas del ámbito de investigación. Este resumen junto al de su informe final deberán ser en conjunto autosuficientes para la descripción de todo el proceso de los 5 años previos y su proyección a futuro sin la necesidad de requerir información adicional.

In its second phase, CR2 maintains its fundamental objectives: to deepen our understanding of the climate system, processes, and impacts throughout Chile, in a holistic manner that confronts the complexities of socio-ecological systems; to strengthen the emerging community of natural and social scientists in Earth System Science in Chile; and, in collaboration with stakeholders, to contribute to the definition of climate change adaptation and mitigation measures for building societal resilience. Over the next five years, we will continue to work toward these overarching objectives while incorporating a long-term goal of becoming and remaining a major player in developing climate and resilience science and contributing to our country's goals of achieving low-carbon, sustainable development consistent with the Paris Agreement and the Sustainable Development Goals (SDGs). In light of the challenges and difficulties identified during the Center's first phase (Cf. 4.5 year report), we introduce significant organizational changes; continue to increase our research capabilities, particularly in terms of research personnel; and establish a more efficient apparatus for facilitating interaction with stakeholders, society at large, and the international community.

In its second phase, CR2 is organized around five **complex problems framed within climate variability and change and societal resilience**. These problems are: water availability and extremes, coastal zones, land use change, cities in a changing climate, and governance and science-policy interface. Three of these problems were present as integrative questions during the Center's first phase. For phase two, we explicitly incorporate coastal zones and governance and the science-policy interface.

All of these issues are approached and addressed through a combination of natural and social science with corresponding interdisciplinary research teams. These complex problems are explored by means of mono-, multi-, and inter- disciplinary approaches, with an emphasis on fundamental understanding and discovery, and a medium-to-long term perspective focused on research outputs and strategies. Associated and adjoint researchers focusing on each issue converge to address **short-term integrative questions** developed within interdisciplinary frameworks that incorporate stakeholders to deliver societally relevant knowledge. To this end, an area of services communication and in/outreach is formally established (See Figure 1). In this way, we seek to promote both curiosity-driven and solution-oriented research, the balancing of which often produces tension in science making, both inside and outside of CR2 (Beck and Mahony, 2017; Kirchhoff et al., 2013; Lewis, 2017; Tollefson, 2015; Watts, 2017; Weaver et al., 2014). Additionally, this approach allows for an improved conjugation of short-, medium- and long- term objectives, and for perspective regarding further development of climate and resilience science in Chile.

Key scientific objectives for CR's second phase are:

- Disentangle the role of natural variability and anthropogenic factors (either local or remote) as drivers of change in the distribution of extreme hydro meteorological events (frequency, extent, intensity) and their impact, and translate these results into actionable science that enhances Chile's resilience.

- Identify the mechanisms by which climate variability and change affect coastal processes relevant to the functioning of Chilean ecosystems and society.
- Design resilient landscapes for the sustained provision of ecosystem goods and services to cope with climate variability and change.
- Assess the resilience capacities of Chilean cities to climate disturbances at present and under future conditions supposing different emission scenarios and governance conditions.
- Assess governance modes compatible with a low-carbon economy and coherent with the Paris Agreement, SDG priorities, and Chile's socio-economic conditions, emphasizing a sound and strengthened science-policy interaction.
- Provide scientific assessments that support policy-making and resilience to **fire regimes, air pollution, hydro meteorological extremes, and algae blooms** in the context of climate variability and change.

Each of these objectives is associated with deliverables that include integrative, synthesis papers in addition to disciplinary articles, as well as in/outreach material and activities. In the case of integrative questions, in addition to articles, books and book chapters, symposia, data products, and other knowledge products, we expect these investigations to deliver "reports to the nation" or similar material that serves both as state-of-the-science syntheses and as relevant and accessible input for policy-making. To ensure the latter, each integrative question will be developed as a short-term (under 2.5 years) project, with clearly established scientific and in/outreach deliverables to be evaluated by the academic board. Moreover, post-doctoral fellows and dedicated operational costs will be devoted to these products, in addition to support from the services, communications, and in/outreach teams.

Figure 1. CR2 second phase organization scheme.

In order to increase our scientific capabilities, we will create four new, fulltime, four-to-five year research positions open to promising researchers selected from an international application process. Moreover, we contemplate an increase in associate and

adjoint researchers, as well as in post-doctoral fellows. These new research positions will prioritize integrative questions in candidate selection and research project development.

In addition, an executive director will be hired. This person will be responsible for the professional team in charge of facilitating internationalization, management, services, communications, and in/outreach to improve our exchanges with national and international stakeholders, and for decompressing the management burden on the existing team in order to allow the dedication of more hours and resources to academic and research activities. The academic board and research team will maintain key roles in defining CR2 strategies, representing CR2, and building bridges with society and policy makers.

Our communications team will be enhanced by an emphasis on the development of multi-media outreach content (reports, research highlights, videos, info graphics, etc.) while maintaining broad media and press presence and management. Our researchers and students will also be committed to producing "easy-to-read" research summaries, as well as regular talks and written reports on in/outreach experiences. This exercise, in addition to supporting outreach, will facilitate internal outreach records and reviews. We will also continue our support for the in/outreach activities developed by junior researchers and students in the context of the Red Lama initiative.

Although CR2 has gained international presence beyond the connections of individual researchers and specific projects, we will promote an increasingly systematic approach to internationalization, growing the number of mid-to-long term visits by international scholars, and establishing collaboration agreements around mid-to-large scale projects. We will also host conferences, organize two international academies (summer schools), and create an interdisciplinary doctoral program. In this respect, the roles of the academic board and the executive director will be paramount.

To date, we have had one research engineer in charge of databases and computing with occasional additional assistance, as well as a laboratory assistant and two field assistants. The new team will incorporate an engineer with expertise in geographical systems, a systems manager, and a sociologist or similar professional to enable improved dialogue with stakeholders. These professionals will serve the center as a whole, with a focus on in/outreach processes and the production of products relevant to policy and society. Other support personnel funded by the center will be primarily devoted to research objectives and to the production of theses and papers.

All of these proposed organizational changes have emerged from the discussions that followed our organizational assessment. Overall, the evaluation demonstrated appreciation by CR2 fellows of the Center's strategic priorities: knowledge generation, interdisciplinary research, and science-society relationships. These reforms are instrumental to increasing our research capabilities and for providing sustainability to the organization beyond the next five years.

As stated in our first phase synthesis report, we believe that CR2 is prepared for a second phase driven by more ambitious goals and seeking to further contribute to understanding and addressing climate variability and change in order to create a more resilient Chile and to promote to climate science and resilience within the region and worldwide.

KEY GOALS

Enuncie y describa de manera breve y concisa los objetivos principales de los próximos 5 años. Estos deben ser amplios y no circunscribirse sólo al contexto científico sino incluir en términos precisos aquellos objetivos de investigación, formación de recursos humanos, cooperación nacional e internacional, difusión de resultados a la comunidad, educación básica y media, otras áreas profesionales, etc. Recuerde establecer la conexión entre lo presentado en su informe final y lo mencionado en esta sección. (Máximo de 5 páginas)

A continuación de esta sección incluya una carta Gantt con los tiempos esperados para cumplir estos objetivos.

Scientific goals

When proposing this center of excellence in 2012, our goals were to:

- Deepen our understanding of the climate system, processes, and impacts throughout Chile, in a holistic manner that confronts the complexities of socio-ecological systems;
- Strengthen the emerging community of natural and social scientists in Earth System Science in Chile;
- In collaboration with stakeholders, contribute to the definition of climate change adaptation and mitigation measures for building societal resilience.

Over the next five years, we will continue to work toward these overarching objectives while incorporating a long-term goal of becoming and remaining a major player in developing climate and resilience science and contributing to our country's goals of achieving low-carbon, sustainable development consistent with the Paris Agreement and the Sustainable Development Goals (SDGs).

Scientifically, we propose both short and medium-to-long term research objectives.

The following **medium-to-long term general objectives** are proposed for each of the five areas of investigation:

- **Water availability and extremes**: Disentangle the role of natural variability and anthropogenic factors (either local or remote) as drivers of change in the distribution of extreme hydro meteorological events (frequency, extent, intensity) and their impact, and translate these results into actionable science that enhances Chile's resilience.
- **Coastal zones**: Identify the mechanisms by which climate variability and change affect coastal processes relevant to the functioning of Chilean ecosystems and society.
- **Land use change:** Design resilient landscapes for the sustained provision of ecosystem goods and services to cope with climate variability and change.
- **Cities in a changing climate**: Assess the resilience capacities of Chilean cities to climate disturbances at present and under future conditions supposing different emission scenarios and governance conditions.
- **Governance and policy-science interface**: Assess governance modes compatible with a low-carbon economy and coherent with the Paris Agreement, SDG priorities, and Chile's socio-economic conditions, emphasizing a sound and strengthened science-policy interaction.

These issues are addressed using approaches ranging from disciplinary to interdisciplinary studies that explore diverse issues and seek to achieve improved understanding for strategic development of the research lines (issues).

Simultaneously, to avoid disciplinary silos and to provide policy-relevant knowledge, integrative questions focusing on fire regimes, air pollution, hydro meteorological extremes, and harmful algae blooms - all framed within the context of climate variability, change and resilience – will constitute a sixth line of research, with short-to-medium term objectives. To address each of these problems we will promote disciplinary concurrence in the form of medium-term (under 2.5 years) integrative projects, which will be expected to deliver relevant outputs and responses for policy making. We foresee early- to mid- career scientists as leaders or co-leaders of these projects that will, on the one hand, contribute to addressing the Center's overarching focus areas, and on the other hand, provide interfaces with decision-making and policy-making processes as well as societally-relevant deliverables. To facilitate the second of these expected outputs, a transference team will be established to address the following objective:

- Provide scientific assessments that support policy-making and resilience to **fire regimes, air pollution, hydro meteorological extremes, and algae blooms** in the context of climate variability and change.

In this way, we envision CR2 as a Center of Excellence with increasing relevance in terms of scientific ambition and in terms of its role in the public policy domain and discussion.

Other goals

In addition to the scientific objectives described above, we have identified a broader set of goals to address CR2's institutional development; enhanced national and international collaboration; policy relevance as aligned with the Paris Agreement, the Sustainable Development Goals and national counterparts; and in/outreach efforts. Some of these objectives were implicit in our first phase while some emerged along the way. These goals will be instrumental to achieving our strategic objectives, and will additionally facilitate the process of internal and external monitoring of CR2's performance and development.

Institutional Development

Our research addresses complex systems and questions related to timespans and cognitive domains that challenge our ethos and societal and institutional arrangements (Hackmann et al., 2014; Lazarus, 2008; Levin et al., 2012). These complexities often force us into uncharted territory, a process that in and of itself merits documenting and analysis to achieve greater understanding. In response to this challenge, we deem necessary the following:

- Establish protocols for individuals who collaborate as part of CR2, in the role of researcher, student, and support personnel.
- Regularly evaluate the performance of individuals and teams against explicit objectives; additionally, perform independent organizational assessments.
- Improve the search, selection, and monitoring of research personnel, particularly post-doctoral fellows and fulltime associate researchers.

- Assign senior scientists responsibilities for monitoring and assessment to ensure the functionally and strategically consistent development of support, educational and in/outreach activities.
- Search for concurrent funding sources in order to carry out scientific research and applications, and to enhance our impact and improve our performance.
- Carry out at least two plenary meetings each year, with the participation of all researchers, advanced students, and key support personnel.
- Periodically document the Center's evolution in a systematic and transparent manner. This involves consistent records of internal and external monitoring activities and results, meetings, protocols, research outputs, etc.
- Assign responsibility to senior researchers for the monitoring, reporting and guiding of key activities such as: data management, simulation and other services, orientation of the science-policy interface, response to integrative problems, in/outreach activities, research, orientation and advising for early career scientists and students, education and training activities, internationalization, etc.

Networking and internationalization

An important objective of this second phase is to consolidate CR2 as an internationally recognized climate and resilience research center and as a regional hub for climate and resilience research. We aim to expand our platform of climate information by including both observational datasets and climate modeling results for South America. Specifically, we expect to partner with the Environmental Change Unit of the University of Oxford in order to carry out event attribution calculations, and incorporate new tools for understanding extreme events in the context of climate change to our work. Further modeling and data are also expected to result from the recently awarded Prediction of Air Pollution in Latin America (PAPILA) project[1]. One expected output is the compilation of data and proxy data for urbanization and land use studies, as well as demographics and other statistics. We are also committed to sustaining our existing observational sites, such as the buoy system off of the Bio Bio region, the AERONET site in Santiago, the fog monitor in Talinay, the Andean observatory downwind from Santiago (scheduled for launch in late 2017), the flux tower at Alerce Costero National Park, the meteorological and nival station at Nasampulli, as well as the isotopic analysis laboratory at Universidad de Concepción. These efforts will require permanent funding and partnerships, and see to benefit from internationalization.

Additionally, we will host international conferences (e.g., Transformations, Bosques y Agua, etc.), high-level expert meetings (i.e., Global Emission Initiative), and two summer schools. Moreover, we intend to develop an interdisciplinary, inter-institutional doctoral program, and to potentially internationalize our continuing education initiatives.

We are in the process of outlining a plan for establishing partnerships with international centers as part of our effort to prioritize institutional exchanges aligned with our strategic objectives and scientific development.

In/outreach

Our outreach work during the Center's first phase has been recognized as a distinctive feature of CR2. During our second phase, we will strengthen these efforts by enhancing

[1] H2020-MSCA-RISE-2017,777544, 2017-2021. This is led by Prof. Guy Brasseur and co-led by Laura Gallardo.

our outreach team and by taking stock of our research, researchers and students (i.e. RedLama). We also seek to fortify our in/outreach interface, increasing dialogue with stakeholders and society at large. Together with the endeavors outlined by our communications team (See Outreach), we expect to broaden the spectrum of our audience and stakeholders, including the public sector and also private sector actors, communities, and society at large. To this end, we will establish collaboration with sectorial associations and their public sector counterparts, maintaining an independent standpoint and avoiding conflicts of interest while reaching out to sectors with significant needs and facing specific challenges related to climate and resilience knowledge. Moreover, we recognize that these sectors have the potential to contribute additional support and possible funding to the Center, and the role of the executive director will be key in maintaining and orienting these relationships. (For example, the Center's relationship with communities and civil society should be explicitly connected to specific research initiatives driven by our researchers in the framework of our integrative questions.)

Sharing our own learning process through teaching and continuous education initiatives will be central to our in/outreach; several specific actions will support this exchange. We will offer a 1-2 weeklong summer course for PhD students and early career scientists, focused on extremes in a changing world. Both students and lecturers will come from backgrounds in social and biophysical sciences. Two versions of the course are scheduled, for January 2019 and January 2021. In addition, we are coordinating the development of a one-semester course in climate change and impacts for undergraduate students at the University of Chile, in response to the observation that none of the universities affiliated with CR2 currently offer such an integrative course. Once again, the course will be open for students with diverse backgrounds and will be presented by a team of lecturers from multiple disciplines. Finally, we plan to maintain our continuous education program "Climate change and low-carbon development: an interdisciplinary challenge" (Original: "***Cambio Climático y desarrollo bajo en carbono: un desafío interdisciplinario***") that successfully concluded its first round of activities in collaboration with the Center for Solar Energy and the Energy Center at University of Chile.

Policy and societal relevance

In our 4.5-year report we describe several projects and initiatives that demonstrate our strong connection with policy makers. During our second phase, while continuing these interactions we also hope to establish new links with the private sector. The introduction of a line of research focused on governance and the policy-science interface will be instrumental to better understanding these complex and often complicated multi-actor interactions. Finally, an incipient but solid services team, strongly coupled with our integrative questions and our in/outreach team, will work to close the science-policy gap.

Gantt chart

A detailed activity plan is not shown here. However, in Table 1 we present a schematic work plan for our second phase.

Table 1. Schematic work plan for the second phase of CR2 for research-related activities.

Research Lines	Objectives	Activities	Year 1	Year 2	Year 3	Year 4	Year 5
Water availability and extremes	Disentangle the role of natural variability and anthropogenic factors (either local or remote) as drivers of change in the distribution of extreme hydro meteorological events (frequency, extent, intensity) and their impact, and translate these results into actionable science that enhances Chile's resilience.	*Data gathering and analysis*	x	x	x	x	x
		Synthesis paper(s) and public policy oriented assessments					x
		Thesis guidance	x	x	x	x	x
		Public policy oriented assessments					
		Development of in/outreach material	x	x	x	x	x
Coastal zones	Identify the mechanisms by which climate variability and change affect coastal processes relevant to the functioning of Chilean ecosystems and society.	*Data gathering and analysis*	x	x	x	x	x
		Synthesis paper(s) and public policy oriented assessments					x
		Thesis guidance	x	x	x	x	x
		Public policy oriented assessments					
		Development of in/outreach material	x	x	x	x	x
Land use change	Design resilient landscapes for the sustained provision of ecosystem goods and services to cope with climate variability and change.	*Data gathering and analysis*	x	x	x	x	x
		Synthesis paper(s) and public policy oriented assessments					x
		Thesis guidance	x	x	x	x	x
		Public policy oriented assessments					
		Development of in/outreach material	x	x	x	x	x
Cities in a changing climate	Assess the resilience capacities of Chilean cities to climate disturbances at present and under future conditions supposing different emission scenarios and governance conditions.	*Data gathering and analysis*	x	x	x	x	x
		Synthesis paper(s) and public policy oriented assessments					x
		Thesis guidance and education	x	x	x	x	x
		Public policy oriented assessments					
		Development of in/outreach material	x	x	x	x	x

Governance and policy-science interface	Assess governance modes compatible with a low-carbon economy and coherent with the Paris Agreement, SDG priorities, and Chile's socio-economic conditions, emphasizing a sound and strengthened science-policy interaction.	*Data gathering and analysis*	x	x	x	x	x
		Synthesis paper(s) and public policy oriented assessments					x
		Thesis guidance	x	x	x	x	x
		Public policy oriented assessments					
		Development of in/outreach material	x	x	x	x	x
Integrative Questions	Provide scientific assessments that support policy-making and resilience to fire regimes, air pollution, hydro meteorological extremes, and algae blooms in the context of climate variability and change.	Projects 1 & 2					
		Project proposal and evaluation					
		Data gathering and analysis	x	x			
		Publishing of results in peer reviewed journals		x			
		Thesis guidance and education	x	x			
		Public policy oriented assessments		x	x		
		Development of in/outreach material		x	x		
		Closure			x		
		Projects 3 & 4					
		Project proposal and evaluation		x	x		
		Data gathering and analysis			x	x	x
		Synthesizing and publishing in peer reviewed journals				x	x
		Thesis guidance and education			x	x	x
		Public policy oriented assessments				x	x
		Development of in/outreach material				x	x
		Closure					x

INNOVATION AND CHILE'S DEVELOPMENT

Dado que parte de las políticas de gobierno y de los fondos tanto públicos como privados apuntan al financiamiento de la innovación científica y tecnológica y su aplicación al desarrollo del país (entendido en su más amplio concepto: económico, social, educacional), indique qué iniciativas serían las emprendidas por este Centro en esa dirección. (Máximo de 2 páginas).

We consider our research to be inherently relevant for Chile's development; it provides usable knowledge, evaluates future scenarios, and trains the professionals and scientists required to address existing and future challenges in the context of climate change. Moreover, we emphasize the societal relevance of our activities in close partnership with key stakeholders, and the coherence of our activities with national and international agendas, including the Paris Agreement and the SDGs.

Accessible and applicable information and knowledge

Important efforts and resources were dedicated throughout the Center's first phase to building climate model simulation capacities and databases. An outstanding outcome of this process is the success of our "Climate Explorer" that compiles hydro meteorological data in a direct and easily accessible manner. This platform will now be complemented by homogenized watershed and precipitation data products developed under the leadership of early career scientists working at CR2. Moreover, both the dynamic and static platforms being developed in partnership with the Chilean Ministry of the Environment will provide high-resolution (~10km) climate simulation and projection data key to improving climate change assessments and further research. Each of these platforms is developed with consideration to ensuring accessibility and usability for a range of users, from school children and teachers to experts. The data contained by each platform allows for new technological developments such as mobile apps, as well as training and education opportunities.

In addition to these databases, we have implemented multiple state-of-the-science models for simulating atmospheric and oceanographic processes. These efforts have been accompanied by training opportunities and software development.

During CR2's second phase, our goal will be to expand these databases to include social data and permit an assessment and exploration of Chile's societal resilience, and to implement and/or extend current models for addressing the Center's integrative questions.

Monitoring and assessment methodologies for Chile's National Determined Contribution (NDC)

The Paris Agreement constitutes a powerful political statement, and possibly a turning point in human history. Needless to say, it faces enormous challenges for implementation that must be confronted over coming decades. The Agreement also provides an opportunity to change direction and choose new paths for development. Within this framework, the development of *ex ante* (e)valuation tools will be central to appropriate monitoring and for the design of mitigation and adaptation measures. Our economists, in combination with other researchers (both natural and social scientists), will have a unique opportunity to carry out high profile, high-utility investigations. This is also the case for the lawyers and social scientists that will be able to analyze options for improved, democratic and sustainable governance in Chile and elsewhere. The participation of Dr. Pilar Moraga as part of the international team of jurists called by Laurent Fabius to propose a legal framework for the Paris Agreement speaks to the caliber of CR2's team of professionals and no doubt represents an opportunity to promote useful, usable, and relevant research.

MAIN CHANGES SINCE FIRST PROPOSAL

Explique en forma sucinta qué cambios de fondo han existido a su parecer desde la generación de la primera propuesta de este Centro y que inciden en este plan para el siguiente período. (Máximo de 2 páginas)

As stated in our 4.5-year report, we performed an organizational study to support the development of this proposal, and to ensure that the full CR2 team was onboard with the proposal. In response to the results of this study, a number of changes have been introduced and refer to CR2's managerial and scientific organization, allocation of resources, and objectives.

Our first proposal was developed as a five-year project with multiple objectives, some of these defined as such and others presented as overarching themes. For this second phase, we propose an additional five years, this time with the expectation and intention of evolving as a Center into a long-lasting institution, which will be complementary to our host institutions and will fill a key space between curiosity-driven and problem-oriented research.

The original project was organized around five lines of research that were neither disciplinary- nor problem- oriented but rather an amalgam of individual interests and strategic objectives. While we maintain strategic objectives, a major change for the Center's second phase is to define all research lines around complex problems, covering broad, short- to long- term objectives and paving the way towards the constitution of a permanent research organization, complementary and closely related to our host institutions. These new research lines assimilate previous "pseudo-disciplines", combining researchers of diverse disciplinary backgrounds under the umbrella of complex issues to be addressed in the context of climate and resilience research, all of which require interdisciplinary approaches.

Additionally, we present a new line of research devoted to integrative questions to allow for cross-pollination and interdisciplinary exchange between research lines, and to provide a platform for delivering high-quality, societally-relevant science and usable knowledge, and hopefully opening the door for trans disciplinary exploration. This shift is further promoted by the creation of a transversal apparatus instrumental to more efficient science-policy exchanges and aimed at increasing our impact and guiding sustainable institutional development.

Another important change from the first proposal is the prioritization of research personnel via the allocation of greater resources for the hiring of fulltime researchers. In 2012, we opened with seven fulltime equivalent positions; in 2017, we can count 21 such positions. By 2022, we expect to have nearly 30 fulltime positions, including four new fulltime positions for early-to-mid career scientists, and post-doctoral fellows funded by FONDAP and other actors. This new financial direction reduces available funding for operational costs, capital goods and support personnel. However, we assume that those costs can be covered by other grants (FONDECYT, FONDEF, PIA, etc.) and that we will be able to establish partnerships with stakeholders to access additional resources. One of the responsibilities of the executive director, in collaboration with our researchers, will be that of identifying potential partnerships. We will prioritize partnerships that promote our role as a hub for science and science makers and with institutions whose guiding principles demonstrate coherence and consistence with our strategic goals.

RESEARCH LINES

Analice de manera breve y concisa las líneas de investigación que conduce el Centro que usted dirige, incluyendo la viabilidad de éstas y su vigencia. A su vez, analice si en el transcurso del desarrollo del Centro han surgido nuevas líneas de investigación que deban ser incorporadas en la etapa de continuidad de éste o de nuevas líneas de investigación que deban remplazar a las ya existentes.

Below, we outline each of the complex, long-term lines of research, as well as the short- to medium- term integrative questions to be addressed during our second phase.

Long-term themes

Governance and science-policy interface

Rationale

Since the enactment of the 1994 Environmental Law ("*Ley de Bases del Medio Ambiente*"), inspired by the Rio Declaration on Environment and Development, Chile has created a legal framework with the intent of "seeking a balance between development and protection of the environment" and founded on the implementation of environmental management instruments (such as plans, education standards, and an environmental impact assessment system). Additionally, the 1994 Law defined the country's environmental institutional structure, which has evolved over time from the previous National Commission for the Environment to the currently operating Ministry of the Environment. It is within this framework that the legal definition of climate change was introduced and the Ministry of the Environment was designated responsible for devising public policies in this area. However, (OECD/ECLAC, 2016)) argue that "most responsibilities relevant to implementing climate policy lie outside of the environmental ministry's remit. Implementation relies heavily upon voluntary engagement by, and sufficient capacity within, other ministries, resulting in delays in the delivery of information and variable implementation of climate change actions" and identify a need to "strengthen institutional arrangements for embedding climate change policy in government operations". In this sense, (Gupta, 2007) argues that: "climate change is a 'glocal' problem that operates simultaneously at several levels, and that attention must be paid to the global, supranational and national level". This is relevant if we consider that Chile is highly-vulnerable to the effects of climate change, presenting seven of the nine characteristics of vulnerability defined by the United Nations Framework Convention on Climate Change (UNFCCC)((Magrin et al., 2014; MMA, 2016). In spite of several sectorial adaptation plans developed by the Ministry of the Environment and by other authorities, the country's capacities have been heavily challenged by recurrent floods, an extended and long-lasting drought, fires and firestorms, algae blooms, and other extreme events (Barrera, 2017; Buschmann et al., 2016; CR2, 2015; Martinez-Harms et al., 2017). Additionally, Chile is a highly urbanized country and our cities face multiple hazards, inequity, segregation, increasing demands on goods and services, and pervasive problems such as air pollution; attention is therefore increasingly placed on urban vulnerability to climate variability and change and the need to integrate action to improve city planning, increase mobility and connectivity, and address air pollution (OECD, 2013; OECD/ECLAC, 2016). Overall, attention has been called for by scientists and policy makers in regard to the need for institutional change and more solution-oriented research (CREDEN, 2016). Researchers at CR2 have played a significant role in these discussions and in providing scientific evidence to support the above observations. We foresee an enhanced contribution going into the future as we emphasize problem-

and solution-oriented research, strengthen understanding of the policy-science interface, and increase capacities to carry out this research more efficiently.

All in all, these circumstances create a new context that requires a more sophisticated response, based on enhanced scientific knowledge for decision-making and addresses the "scientific and political aspects" of climate change and the outstanding question of what options exist to deal with the problem (Gupta, 2014). This new era requires us to promote the development of science that is relevant, compatible, receptive and accessible (Jones et al., 1999) within a 'constitutional moment' in world politics and global governance, similar to the transformative shift observed in global governance after 1945 (Kotzé, 2014a; Kotzé, 2014b). At the same time, the "legally disruptive nature of climate change" calls for new legal regimes and at the same time triggers multiple legal disputes (Fisher et al., 2017). Recent events such as the spread of a fire storm in the summer of 2017 and widespread water cuts in the country's capital after summer and winter rainfall events reveal the limitations of current private and public institutions to respond to such risks and highlight the urgent need to connect scientific knowledge more closely with those public and private actors whose actions directly affect people. In this sense, there is a need to strengthen and improve our understanding of the science-policy interface, which should favor the adoption of better decisions based on better information.

At the same time, Chile, as part of the UNFCCC and having adopted the Paris Agreement and the UN Sustainable Development Goals, has acquired commitments that require much stronger environmental governance. In particular, in the context of the Paris Agreement, Chile delivered its Nationally Determined Contribution (NDC), pledging mitigation and adaptation measures that are multi- and inter- sectorial. Fulfilling these commitments will require a high level of coordination between different state institutions at all levels and multiple actor groups, including the private sector. Political decisions made by a national government aspiring to a low-carbon economy through commitment to an ambitions NDC, signing of the Paris Agreement, and the definition of the new 2050 energy policy, raise questions concerning the role of science in achieving these goals.

Citizen and community participation represents another key aspect requiring improvement. Although Chilean environmental legislation and institutions have been pioneer in introducing open and transparent procedures –at least when considering other legal and institutional bodies in the country–, as well as open discussions and participatory mechanisms, these procedure and mechanisms require review and strengthening (Chilvers and Longhurst, 2016). Moreover, in collaboration with key-stakeholders, an observation of public opinion using social psychology tools will be instrumental for improving processes and procedures for citizen involvement, a necessary improvement for increasing the efficiency of adaptation and mitigation measures (Lorenzoni et al., 2007).

An integrative model for evaluating public policies for climate variability and change will be enhanced during the Center's second phase. Additionally, we will continue to explore probabilistic approaches for determining economically sound pathways to achieve a low-carbon and sustainable economy in accordance with SDGs and the Paris Agreement.

The inclusion of senior natural scientists in the governance and policy-science interface team, as well as the expected interaction of this line with other research lines, is intended to close the gaps between science and policy needs at an early stage, facilitating the Center's impact in the public arena both nationally and internationally.

In sum, we envision a line of research that fosters a community of scientists researching crosscutting problems such as: governance, the evolution of international negotiations, economics, improving and understanding ways to address the science-policy interface. Documenting this research as well as the processes in which the center participates will represent another central element of this line of research.

Goal: Assess governance modes compatible with a low-carbon economy and coherent with the Paris Agreement, SDG priorities, and Chile's socio-economic conditions, emphasizing a sound and strengthened science-policy interaction.

Water extremes in a changing climate

Rationale

Climate/water-related (environmental) extreme events have disproportionate effects on natural-human systems, and there is generalized perception of an increase in their occurrence and impacts across our country. Recent events include Central Chile's mega-drought (2010-2016) (Boisier et al., 2016; Garreaud et al., 2017), the worst-ever recorded harmful algal bloom in Patagonia (Buschmann et al., 2016), the unprecedented fire season of 2017, and major flooding and landslides in north-central Chile (2015, 2017) (Bozkurt et al., 2016).

These high-impact events have occurred in a time of emerging climate anomalies (i.e., discernible trends in temperature and precipitation). In parallel, (local) human activities have directly altered the environmental base state, although such effects are poorly documented in our country. Furthermore, there are indications of the population's increased exposure and vulnerability (e.g., occupation of flood-prone areas), while at the same time the widespread use of communication-enabling technologies and specific response practices reinforces adaptive capacity and result in increased resilience.

Examples of climate/water extremes include heat waves (and their implications in terms of forest fires and human health), intense and/or extended droughts (and their implications for water availability) and flooding (and their implications for human security and urban infrastructure). Quantifying, understanding and projecting the occurrence of climate extremes is extremely relevant, especially given the disproportionate effects of extreme events on natural versus altered systems. Increases in population and expansion in territorial use can only augment our exposure to extreme events, and there is an urgent need to study and support communities in moving from vulnerability towards resilience.

To advance this line of research, it is imperative to quantify the role of natural variability (ENSO, PDO, others) and secular variations in selected extreme events, based on historical data and paleo-reconstruction. In parallel, we seek to attribute the apparent increase in the occurrence of selected extreme events over past decades to anthropogenic climate forcing, using state-of-the-art techniques. Lastly, we aim to estimate potential changes in frequency, intensity and duration of selected extreme events through the 21st century. The social scientist in our group will work to understand the ways in which society -from local communities to national authorities- is adapting to changes in extreme events, through investigation focused on current practices, their usefulness, barriers to implementation, and opportunities for improvement.

Goal: Disentangle the role of natural variability and anthropogenic factors (either local or remote) as drivers of change in the distribution of extreme hydro meteorological events (frequency, extent, intensity) and their impact,

and translate these results into actionable science that enhances Chile's resilience.

Coastal zones

Rationale

The coastal zone is the meeting point between land and ocean. Despite representing only 10% of the ocean's surface area, this zone supports high primary production, contains 90% of all marine species, and presents physical dynamics capable of modulating regional climate and generating global effects (Hutchins and Fu, 2017). In Chile, a country with more than 8,000km of Pacific Ocean coastline, research on coastal processes is highly relevant. Furthermore, Chile's coastal zone is diverse and highly variable, supporting major urban settlements that are increasingly exposed to climate change impacts (von Glasow et al., 2013). Coastal zones refer to the collective influence of climate variability and anthropogenic forcing on the coastal ocean and seafloor, as well as on contained socio-ecological systems. Coastal processes were initially identified during CR2's first phase as a common area of interaction among disciplines. Second phase development of this line of research will build upon the knowledge gained over the past five years and place greater emphasis on an interdisciplinary focus. Coastal upwelling supports important pelagic and benthic fisheries in south-central Chilean coastal zones (Thiel et al., 2007) and the past few decades have seen an explosive growth in aquiculture, predominantly in the Patagonian fjords and channels (Iriarte et al., 2010). This economic activity poses a threat to coastal environments, especially in the context of climate change. Assessing these risks and impacts will require enhanced observation (monitoring) and modeling, as well as the design and implementation of appropriate adaptation and mitigation actions in order to develop and maintain sustainable and resilient communities.

Changes in regional wind regimes to favor coastal upwelling have been projected. Changes in precipitation systems are also anticipated and are expected to affect freshwater availability (Boisier et al, 2017) These trends have already been observed (Aguirre et al., 2017) and in coastal zones, they may affect mixing processes and/or stratification, and therefore modify important air-sea fluxes and affect heat flow, aerosols, and the behavior and concentration of gases, among other impacts. For this reason, our research efforts will focus on ongoing climatic forcing in order to understand synergistic and antagonistic processes that may have climatic implications, such as modifications in advection or estuarine circulation.

Understanding the potential impacts of climate variability and change on the Chilean coast requires better understanding of key coastal processes such as coastal upwelling and their effects on local socio-ecological systems. Harmful algal blooms (HABS) (Buschmann et al., 2016), eutrophication (Dokulil and Teubner, 2010), as well as the increased occurrence of storm surges and extreme waves (Winkler et al., 2016) pose new challenges to governance processes in coastal zones. In fact, the need for improved management and policy frameworks for coastal zones is shared across Latin America (CEPAL/ONU, 2011). At least 25 government agencies participated in the Environmental Impact Assessment of projects located in coastal areas of Chile. Given Chile's geographic and political distribution and organization of Chile, each agency possesses national authorities and competences but is in turn decentralized by the sub-national division of the country into 15 regions, where administrative practices vary. The regulation that assigns jurisdiction to government agencies is diverse and complex; 107 legal

documents (acts, decrees, circulars, and other documents) refer to the designation or denial of environmental licenses by these agencies. This large volume of legal regulations generates institutional problems that need addressing.

In response to these challenges, over the next five years, we seek to contribute to the creation of a robust scientific basis addressing both physical processes and governance in coastal zones, and particularly focused on key upwelling zones in central and northern Chile.

Goal: Identify the mechanisms by which climate variability and change affect coastal processes relevant to the functioning of Chilean ecosystems and society.

Land use change

Rationale

Changes in land use, such as the conversion of undisturbed ecosystems to extractive land use (e.g. crop production, grazing) and the resulting disruption of natural fire regimes have contributed considerably to global change (Fearnside, 2000; Vitousek, 1994). These changes have produced important impacts on biodiversity, ecosystem structure and function, ecosystem services and their availability, as well as the proliferation of alien animal and plant species, resulting in the homogenization of the biosphere (Foley et al., 2005; McKinney and Lockwood, 1999).

South-Central Chile (35º - 41º S) has experienced rapid land use change over the past 40 years. The dominant pattern of these changes has been the conversion of native forests, shrub lands, grasslands and other land use categories to *Pinus radiata* and *Eucalyptus spp* exotic forest plantations, creating large, homogeneous plantations that extend over a total of 2.75 million ha (Heilmayr et al., 2016; Miranda et al., 2015). This process has made possible the exponential expansion of the forest industry, but it has had negative impacts on biodiversity, fire regimes and ecosystem services, as well as negative social impacts related to the non-equitable distribution of industry profits (Lara et al., 2016). Other important land-use changes include the reduction of agricultural land as a result of urban expansion and the conversion of native forests and shrub lands on hill slopes to avocado orchards and vineyards (Lara et al., 2010).

South-Central Chile constitutes a valuable case study for research on the drivers and impacts of land use change, their interactions, and modeling and prediction. The region has experienced particularly rapid change, while also possessing native forests and other natural vegetation that rank among those with the highest conservation priority worldwide (Brooks et al., 2006; Olson and Dinerstein, 1998).

The ecological, social and economic impacts of land use change should be evaluated. The main drivers of land use change (economic and political factors and climate change) as well as their interactions, coupling and feedbacks, should be addressed in order to predict land use change under different scenarios. Diversified landscapes designed to replace existing, highly homogeneous landscapes dominated by forest plantations would include multiple land use categories considered from a watershed perspective in order to ensure combined production of goods (e.g. timber, agriculture) and ecosystem services (e.g. water provision, maintenance of soil fertility). Investigation should also include costs assessments in order to orient decision-making regarding the feasibility and prioritization of restoration projects based on the conversion of forest plantations back to native forests. All of this knowledge would be crucial for orienting decision and policy makers and to ensuring progress towards more resistant and resilient landscapes

(i.e., capable of both absorbing and recovering after disturbances such as fire). This line of research also requires collaboration, integration and interdisciplinary work by multiple CR2 teams working on land-use change, governance and cities, as well as the application of modeling capacities. The specific challenge of understanding fires, their forcing, regimes, and impacts, and the relevance of this topic for decision-making, provides a unique opportunity to produce results that may be applicable to other problems and within other regions.

Goal: Design resilient landscapes for the sustained provision of ecosystem goods and services to cope with climate variability and change.

Cities in a changing climate

Rationale

According to the United Nations, although cities covered less than 2 % of the earth's surface in 2011, they consumed nearly 80% of the world's energy and produced more than 60% of all carbon dioxide (CO_2) (UN-HABITAT, 2011). This fraction of global energy-related CO_2 emissions is expected to grow in the context of global urbanization trends (Hutyra et al., 2014). City scale action aiming to reduce greenhouse gases in general and CO2 in particular can therefore contribute to the fulfillment of Chile's commitments within the context of the Paris Agreement and to attaining the SDGs, scientific, public and political priorities (Acuto, 2016; Rogelj et al., 2016; Rosenzweig et al., 2010; Weiss, 2015). Depending on their development pathways, cities also offer opportunities for technological and societal transformations towards energy efficiency and decarbonization (Bai et al., 2016; Jorgenson et al., 2014). This is true in Chile where nearly 90% of the population is considered urban, and approximately 50% of the population is concentrated in only three metropolitan areas: Santiago, Valparaíso and Concepción (OECD, 2013).

Several cities in central and southern Chile experience deteriorated air quality during winter months, associated primarily with residential combustion and transportation (MMA, 2014). This explains in part the decision of the Chilean government to include in its Nationally Determined Contribution (NDC) to the Paris Agreement, among other measures, plans to address air quality, emphasizing short-lived climate pollutants (SLCPs), as well as the introduction of a green tax that penalizes the use of diesel fuel (Winkler et al., 2016). Furthermore, Chilean cities are considered highly vulnerable to the effects of climate change, particularly floods, landslides, droughts and temperature increases (heat waves), and health impacts (such as the spread of enteric diseases) (MMA, 2016). Such threats and vulnerabilities are further exacerbated by social inequity and urban segregation, where these impacts are concentrated in poorer areas (OECD, 2013; Romero et al., 2010; Romero et al., 2012).

The Chilean government has recently submitted for public review an Adaptation Plan for urban areas to strengthen their capacities to adapt to climatic events and reduce negative consequences for the population. Strategies for facing climate change in cities must integrate mitigation and adaptation measures. For instance, increasingly extreme temperatures may increase energy consumption through increased demand for air conditioning, whereas lower temperatures might lead to more intensive heating. At the same time, the co-benefits of adaptation and mitigation measures can favor improved quality of life in cities (e.g. more green areas reduce the effect of heat waves, in turn reducing energy consumption; reduced air pollution reduces respiratory infections; and

so on). It is therefore important to address climate change in the urban environment comprehensively, favoring the implementation of measures that improve urban resilience and quality of life (Jabareen, 2013).

During our first phase we developed and implemented tools (models, emission inventories, etc.) (Mazzeo et al., 2017), performed diagnostic analyses (Barraza et al., 2017; Molina et al., 2015) and comprehensive analyses of urban issues (Gallardo et al.). However, there is a need for improved understanding of the intertwined dynamics of urban energy and land use, emissions, demographics, governance, and societal and biophysical processes in Chile, throughout the region and worldwide (Marcotullio et al., 2014; Romero-Lankao et al., 2014). Facing the challenges of a changing climate will require more thorough understanding of urban processes, vulnerability and resilience (CREDEN, 2016; OECD, 2013), in addition to better prepared cities (with programs for infrastructure investment , enhanced services, and appropriate governance conditions, including fortified citizen engagement (Barton, 2013; Barton et al., 2015; Heinrichs et al., 2009). During the Center's second phase, we seek to contribute, along with other centers of excellence in Chile and elsewhere, to better understanding of complex urban processes and governance. Urban impacts will be examined over varying timescales; from paleo climatic records of first settlements to projections of potential urban conditions in future climate scenarios.

Goal: Assess the resilience capacities of Chilean cities to climate disturbances at present and under future conditions supposing different emission scenarios and governance conditions.

Short-to-medium term integrative questions

The following descriptions refer to short-to-medium term integrative questions, whose overall objective is to provide scientific assessments that support policy-making and resilience to **fire regimes, air pollution, hydro meteorological extremes, and algae blooms** in the context of climate variability and change.

Fire regimes in a changing climate

Forest fires constitute important agents that shape the distribution of major world regions, including tropical, temperate, and boreal biomes (Bond and van Wilgen, 1996; Koutsias et al., 2013). Wildfire activity has increased worldwide during recent decades, partially related to extended droughts, and is expected to continue to increase as the result of climate change, and there is growing interest in understanding the drivers of fire activity worldwide (Bowman et al., 2009; Jones et al., 2007; Krawchuk and Moritz, 2011; Liu et al., 2014).

Variability of meteorological conditions over both short and long time-scales (weather and climate, respectively) is a major driver of fire activity and behavior. These time-scales range from hourly and daily scales to monthly, inter-annual, and decadal scales. Climate variability observed inter-annually or on longer time-scales arises primarily from changes in atmospheric circulation in connection with planetary modes such as El Niño Southern Oscillation (ENSO) and the Antarctic Oscillation (Holz and Veblen, 2012; Kitzberger and Veblen, 1997; Swetnam and Betancourt, 1990). Droughts, especially when they are prolonged and intense, represent another major driver of fire occurrence (CR2, 2015; Garreaud et al., 2017).

The study of fire drivers is key to understanding the relationships between different natural and social processes and their interactions. Social drivers include human ignition, fire suppression policy and capacity, land use change and landscape configuration that determines flammability, and fuel load and continuity (crucial factors for fire occurrence and propagation) (Carmona et al., 2012; Cochrane, 2003; Cochrane and Laurance, 2008). Fire has important impacts on landscape and ecosystem structure and functioning, on hydrological and biogeochemical cycles, as well producing CO_2, particulate matter, black carbon and other emissions that may reach and affect remote areas {Li, 2017 #2230}(Bowman et al., 2009). Humans evolved with fire over the last 11,000 years cal BP in Southern South America, and fires continues to have significant economic, social and cultural impacts (Heusser, 1994; Markgraf and Huber, 2010; Whitlock et al., 2007).

The increase in fire occurrence in central and southern Chile is demonstrated by the 600.000 ha (300.000 ha of forest plantations, and a single fire that burned >100.000 in four days), affected by forest fires during the summer of 2016-2017. These fires affected nine times the mean annual area affected by fire over the 1985-20015 period of 54.000 ha/year. The new record is followed only by 120.000 ha and 105.000 ha affected in 2014-2015 and 2013-2014, respectively, which both also greatly surpass the historic mean (Castellnou et al., 2017).

Fire regimes occupy the crossroads of numerous natural and social processes relating to drivers and impacts. Considering the complex interactions and feedbacks between fire drivers and impacts, a comprehensive, interdisciplinary and collaborative approach is required to tackle this problem. The convergence of CR2's diverse teams is necessary to succeed in this area of investigation. Teams focused on land use change (landscape configuration and fuel loads, options to develop landscapes that are more resistant and more resilient to fire), cities (pollutant and greenhouse gas emissions), water extremes, coastal systems (impacts on hydrologic cycles, and coasts) and governance must coordinate and collaborate to apply and combine their knowledge and diverse capacities (including modeling of land use change, forest ecology, climate dynamics, atmospheric transport and chemistry, emissions, biogeochemistry, modeling, social sciences, economy, adaptation) to address this complex challenge.

The study of the 2016-2017 mega fires in Chile in the context of the variability of fire regimes over past decades is of global scientific relevance. The Chilean case study can be taken as a research model where key drivers are set to their extremes (i.e. prolonged drought, extremely high temperatures and water deficits, homogeneous, flammable landscape dominated by plantations, fuel load and continuity, fire ignition by humans). Several international research teams visited the areas affected by the summer 2016-2017 fires, providing the opportunity to improve CR2's capacities and contribution to international investigations through improved networking. Understanding fire is also relevant to informing and interacting with policy and decision makers from the public and private sectors responsible for fire prevention and firefighting, and for guiding decisions regarding forest management in order to promote less homogeneous landscapes that are more resistant and resilient.

CR2 will seek to promote the training of graduate students in this area, and to strengthen our outreach with a growing group of citizens and students that are interested in understanding why fires and their environmental, social and economic impacts have increased, as well as how to best adapt to these new conditions. Considering this context, the main questions posed for this integrative research area are: What are the main

drivers, impacts and responses to altered fire regimes under climate change and variability? What are their feedbacks and interactions? How may we best model and predict fire occurrence under different scenarios?

Air pollution and climate change

At present, in addition to the capital of Santiago, several cities in Chile experience deteriorated air quality (AQ) in terms of PM_{10} and/or $PM_{2.5}$. Photochemical pollution is also apparent, and may become an important problem in the near future (Gallardo et al.). Approximately 60% of the Chilean population is exposed to an annual average $PM_{2.5}$ concentration greater than that permitted by Chilean environmental regulation (MMA, 2014). In the southern central region, atmospheric pollution is largely due to wintertime wood burning for residential heating. Particulate matter, more specifically $PM_{2.5}$, are known to produce adverse health impacts (Keuken et al., 2011). Studies have linked $PM_{2.5}$ to respiratory problems (Hua et al., 2014), cerebrovascular diseases (Leiva et al., 2013) and an increase in mortality (Cakmak et al., 2014). It is estimated that approximately 4,000 premature deaths in Chile can be attributed to air pollution annually (MMA, 2014). In addition to health impacts, particulate matter such as black carbon (BC) can perturb hydrological cycles by affecting the behavior of snow cover (Bond et al., 2013; Molina et al., 2015). Furthermore, ozone (O_3) is known to significantly reduce agricultural yields for crops such as maize, wheat and soy (Avnery et al., 2011; Feng et al., 2015), and such effects are expected to increase in the future (Tai et al., 2014). During our second phase, we will work to estimate the impact of urban pollution on health, downwind ecosystems, agricultural productivity, and on the Andean cryosphere. Furthermore, we will explore how this impact is expected to evolve under different emission trajectories, considering not only technological evolution but also different governance conditions. Finally, we will consider air quality evolution in the context of a changing climate.

Air pollution and climate change are inextricably linked, and should therefore be addressed in a coordinated manner. By taking into account the links between these issues, comprehensive, sustainable policies can be developed that maximize the benefits for AQ and climate change mitigation (Melamed et al., 2016; Zhu et al., 2013). In response to this context, our research will not only address the physical links between AQ and climate change in Chile, but will also seek to assess Chilean governance structures and processes in order to jointly address air pollution and climate change and explore measures to increase resilience in the face of these challenges. Special attention will be assigned to links between mobility and air quality, science-policy interfaces, as well as to citizen participation for increasing urban resilience.

Over the last six years, the central and southern regions of Chile (30ºS-40ºS) have experienced an intense drought with a precipitation deficit of approximately 30%, unparalleled over the past thousand years. Studies suggest that the frequency and intensity of widespread and protracted drought episodes will increase during the twenty-first century (CR2, 2015). Water scarcity and hydro meteorological extremes in general have been a transversal focus during CR2's first five years and will continue to be a priority for the Center's second phase.

Water management under drought conditions can affect urban development. Inversely, urbanization and increasing urban emissions may increase water demand and potentially accelerate the retreat of glaciers through the deposition of particulate matter and resulting disturbance of melting rates, consequently influencing the water cycle required to meet the needs of highly populated areas (Molina et al., 2015).

Additionally, the area affected by fire during the intense drought episode increased by 70%, and the fire season extended to the entire year (CR2, 2015). Fires have a major impact on atmospheric chemistry from the local to regional scales as a result of their production of emissions of gaseous pollutants and aerosols (Giglio et al., 2013; Turquety et al., 2014). These emissions can severely impact AQ in downwind cities and result in important consequences for health, visibility and ecosystems (Reddington et al., 2015). From the urban perspective, the impact of fires on health, climate and air quality will be explored, with particular attention placed on the impact of increased fire emissions as a result of projected dryer conditions.

Knowledge of the way air pollution conditions may evolve in future scenarios would enable decision makers and policy makers to develop strategies to reduce impacts on society. Furthermore, the integration of interdisciplinary knowledge with community involvement supports urban resilience; city governance requires efforts of this type to build capacities. Together with the work conducted surrounding "governance and science-policy interface", we hope to produce strategies to support decision makers in considering scientific knowledge when addressing urban issues in the context of climate change. At the same time, we will work to develop trans disciplinary strategies to better prepare citizens for climate related natural disasters. Finally, we will support the development of policies to address air quality and climate change in a coordinated and comprehensive manner in order to simultaneously reduce air pollution and maximize the impact of climate change mitigation efforts.

Rainstorms in the driest place on earth (northern Chile)

The Atacama Desert in Northern Chile (18-25S) is the driest place on Earth, and arid conditions extend all the way to central Chile (35S). This includes Santiago and other major cities, important agricultural lands, and mining centers. Despite the climate, extreme precipitation events occur throughout this region. In March of 2015, moist air from the tropical Pacific delivered more than 100 mm in just three days to northern Chile (Bozkurt et al., 2016). Although the return period for this event was estimated at 50 years, only two years later another, similar storm took place.

These events and others have triggered floods and resulted in casualties and significant damage. Not only are these events intense; they affect a socio-environmental system that is wholly unprepared for them. Many "dry" rivers lack fluvial defense, the landscape is dotted by mining waste tailings, and homes lack roofs capable of resisting even moderate rainfall. Furthermore, the hydro meteorological characterization of these events has been difficult, especially given the lack of rain gauges in the area, a situation that calls for the creative use of remote sensing techniques.

From a social point of view, increasing societal and economic resilience is imperative in the context of increasingly intense and frequent extreme events. CR2's second phase will address this issue as an integrative question, beginning with an assessment of the role of natural variability (ENSO, PDO, others) and their secular variations for selected extreme events using historical data and paleo-reconstruction. In parallel, we will work to attribute the apparent increase in frequency of major rainstorms in past decades to anthropogenic climate forcing, using novel ad-hoc techniques. Finally, we will seek to estimate potential changes in frequency, intensity and duration of selected extreme events through the 21st century. The social scientists in our group will work to understand the ways in which society -from local communities to national authorities- is adapting to changes in extreme events, reviewing current practices, their usefulness, barriers to implementation, and opportunities for improvement.

Coastal blooms

Chile's coastal waters are subject to both endemic bloom and harmful algal bloom (HAB) events, a phenomena mainly concentrated in Patagonia (Mardones et al., 2012), which results in ecological, social and economic impacts at local and regional levels. The "red tide" event in summer-fall 2016, however, was the worst ever recorded in terms of intensity, duration and extension, expanding into areas where HABs had never previously occurred. The Chilean government was forced to take urgent (and apparently poorly informed) relief measures in order to avoid a major social and economic crisis in southern Chile.

The 2016 HAB coincided with an intense drought and other climate anomalies (CR2, 2015) and over the past decade, several studies have suggested possible relationships between climate and the magnitude, frequency, and duration of microalgae blooms (Edwards et al., 2006; Glibert et al., 2005). Given that phytoplankton growth is largely determined by temperature, light and the availability of nutrients (levels which in turn depend on mixing events and stratification in aquatic systems), it is not surprising that climate-ocean interactions result in changes to the phytoplankton community and can influence the occurrence of phytoplankton blooms and HABs. Since rainfall in southern Chile has been decreasing and further drying is projected, the unavoidable inference is that major HAB events may become more frequent in connection with climate change, resulting in increased socio-economic and environmental impacts. However, to date few studies have used comprehensive datasets together with rigorous statistical analyses to confirm the linkages between climate (including large-scale and low frequency patterns of climate variability, such as the El Niño/Southern Oscillation, as well as anthropogenic climate change) and HABs (Moore et al., 2008), and no studies demonstrating a climate-HAB connection in southern Chile exist.

CR2 researchers were called to participate in the "National Commission on the Red Tide" ("*Comisión Nacional de Marea Roja*"), appointed by the Chilean Government to prepare a report (Buschmann et al., 2016) synthesizing our current understanding and identifying knowledge gaps surrounding this event. The evidence presented by the report points out bloom events coinciding with particular climatic patterns such as drought, increased solar radiation and winds favorable to upwelling, among others, including in southern latitudes.

The vast and rapid damages experienced in Chile over past years, and especially during 2016, greatly increased interest in phytoplankton blooms and demonstrated the need to make an effort to identify and address the factors behind these blooms' appearance, development and decay. Chile confronts many social conflicts within the coastal zone, some of these related to HAB events. This situation, along with complex issues and challenges surrounding costal governance, represents yet another interdisciplinary challenge.

The last algal bloom in Chiloe (2015) caused a particularly complex social problem because of the ecological and economic consequences and the association of this event with intensive aquiculture activity. From a preventive perspective, this event demonstrated that aquiculture regulation (land planning, environmental assessment, and the concession system) has been insufficient (Bustos-Gallardo, 2013) and, from a reparations perspective, that public support for victims has been insufficient. At the same time, we can observe the difficulties in assigning responsibility for this algae bloom, further emphasizing the need for new approaches to governance (Bai et al., 2017; MINECO, 2016).

CR2's second phase will aim to identify climatic attributes to HAB events and to improve our prognostic abilities regarding short-to-mid temporal scales (seasonal and inter-annual variability), as well as the intensity and frequency of phytoplankton blooms, and to better understand the main drivers of these events. The complexity and intertwined nature of HABs call for an interdisciplinary approach and for close collaboration with stakeholders. Algae blooms represent an additional, integrative research question whose investigation will allow for improved understanding as well as policy-relevant science.

PERSONNEL

Analice brevemente las sinergias e interacciones entre los miembros del Centro y qué lugar les cabe en el presente Plan de Continuidad.

Our personnel consist of researchers, graduate students, and support personnel. All personnel will be subject to performance evaluations, receive feedback, and will operate under established protocols for affiliation and disaffiliation.

Researchers

At the moment of writing this proposal, CR2 is made up of principal investigators (6), associate researchers (19), adjoint researchers (14), and post-doctoral fellows (7[2]). We list these individuals in Tables 1, 2 and 3 respectively.

As stated elsewhere, every associate researcher (Table 2) is affiliated with a research line that corresponds to a complex problem, and he/she is expected to contribute to the research developed therein. Any researcher can, nevertheless, collaborate across research lines, particularly via integrative questions. Still, principal investigators for each line are responsible for providing annual performance evaluations for all associates within his/her research line, as agreed by the academic board, and for managing the corresponding feedback. Additionally, each principal investigator, in collaboration with his/her co-leader, is responsible for the overall management of the research line, including administration and management, again in tandem with the academic board. The academic board will in turn be informed by the executive director.

Table 2 contains the names of current researchers as well as new researchers to be submitted formally for the approval of the CONICYT research council during the second semester of 2017, pending the approval of this proposal. The proposed associates are:

- **Rodrigo Arriagada** has a PhD in economics and works at the Catholic University. He has already collaborated with CR2 as an adjoint researcher. His research deals with the economics of ecosystem services, evaluation of environmental policies, forestry and land use change.
- **Gustavo Blanco** has a PhD in sociology and works at Universidad Austral. He has already collaborated with CR2 as an adjoint researcher. His research centers on governance, the sociology of climate change, and public policy. He also participates in IDEAL, another FONDAP addressing socio-ecological changes in the Austral Zone of Chile and Antarctica.
- **Martín Jacques** holds a PhD in climatology and has been recently hired at Universidad de Concepción. He works on climate variability and change at various scales, and is interested in renewable energy.
- **Anahí Urquiza** has a PhD in sociology and works at Universidad de Chile. She has already contributed to CR2 as an adjoint researcher. Her research addresses climate vulnerability, complex systems, energy poverty and governance.

In addition to these associates, we expect to hire four fulltime researchers in associate positions, starting with one in 2018 and with three more thereafter. All of these positions will be filled via international calls for applications, with selection according to merit and relevance.

[2] Only 3 funded by the FONDAP grant in 2018

*Table 2. CR2 associate and principal investigators as proposed for 2018 onwards. In addition to names, we identify their research lines, institutional affiliation, dedication in hours per week, and a broad labeling of their area of expertise. The names of new associates or researchers previously considered in other categories, all pending approval by CONICYT, are indicated in italics. Principal investigators are in bold. Corresponding co-leaders are indicated by an *.*

Paternal Last Name	Given Name	Research Line	Affiliation	Dedication	Area of expertise
Aldunce*	Paulina	WATER EXTREMES	UCH[3]	12	Sociology
*Arriagada**	*Rodrigo*	*LAND USE CHANGE*	*PUC[4]*	*12*	*Economics*
Blanco	*Gustavo*	*GOVERNANCE*	*UACH[5]*	*12*	*Sociology*
Christie	Duncan	WATER EXTREMES	UACH	12	Forestry/Paleo climate
De Pol	Ricardo	LAND USE CHANGE	UMAG[6]	12	Paleo climate
Farías	**Laura**	**COASTAL ZONES**	**UDEC[7]**	**26**	**Oceanography**
Gallardo	**Laura**	**INTEGRATIVE QUESTIONS**	**UCH**	**44**	**Atmospheric Chemistry**
Galleguillos	Mauricio	LAND USE CHANGE	UCH	12	Remote Sensing
Garreaud	**René**	**WATER EXTREMES**	**UCH**	**26**	**Climate dynamics**
Gayó	Eugenia	CITIES	UDEC	12	Paleo climate
Gómez	Susana	LAND USE CHANGE	UACH	12	Ecology
González	Mauro	LAND USE CHANGE	UACH	12	Forestry/Fire dynamics
Huneeus	**Nicolás**	**CITIES**	**UCH**	**26**	**Atmospheric Chemistry**
Jacques	*Martín*	*COASTAL ZONES*	*UDEC*	*12*	*Climate dynamics*
Lambert	Fabrice	CITIES	PUC	12	Paleo climate
Lara	**Antonio**	**LAND USE CHANGE**	**UACH**	**26**	**Forestry/ Paleo Climate**
Moraga	**Pilar**	**GOVERNANCE**	**UCH**	**26**	**Law**
Moreno	Patiricio	WATER EXTREMES	UCH	12	Ecology/Paleo Climate
O'Ryan	Raúl	GOVERNANCE	AI[8]	12	Economics
Osses	Axel	CITIES	UCH	12	Applied Mathematics
Rojas*	Ma(ríaHelo)isa	GOVERNANCE	UCH	12	Climate dynamics
Rondanelli	Roberto	COASTAL ZONES	UCH	12	Climate dynamics
*Urquiza**	*Anahí*	*CITIES*	*UCH*	*12*	*Sociology*

*Acts as co-leader of the research line

[3] Universidad de Chile, sponsoring institution for CR2
[4] Pontificia Universidad Católica de Chile
[5] Universidad Austral de Chile, associate institution for CR2
[6] Universidad de Magallanes
[7] Universidad de Concepción, associate institution for CR2
[8] Universidad Adolfo Ibáñez

Adjoint researchers (Table 3) are also affiliated with research lines and they should also receive evaluation and feedback from principal investigators. In this category we include a mix of senior and early career scientists. These researchers are selected by every principal investigator and do not require CONICYT's formal approval.

Table 3. Adjoint researchers as proposed for 2018 onwards. In addition to names, we identify their research lines, institutional affiliation, dedication in hours per week, and a broad labeling of their area of expertise. New researchers are indicated in italics.

Paternal Last Name	Given Name	Research Line	Affiliation	Dedication	Area of expertise
Aguirre	(María) Catalina	COASTAL ZONES	UV	6	Oceanography
Cordero	*Luis*	*GOVERNANCE*	*UCH*	*6*	
*Delgado**	*Verónica*	*COASTAL ZONES*	*UDEC*	*6*	*Law*
Díez	Beatriz	COASTAL ZONES	PUC	6	Ecology
Hitschfeld	Nancy	CITIES	UCH	6	Computer Science
Little	Christian	LAND USE CHANGE	UACH	6	Forestry/Hydrology
Masotti	Italo	COASTAL ZONES	UV	6	Oceanography
Munizaga	Marcela	CITIES	UCH	6	Transportation Engineering
Muñoz	Ariel	WATER EXTREMES	PCV[9]	6	Forestry/ Paleo Climate
Osses	Mauricio	CITIES	USM[10]	6	Mechanical Engineering
Sapiains	Rodolfo	GOVERNANCE	UCH	6	Social Psychology
Sepúlveda	Armando	COASTAL ZONES	UMAG	6	Biogeochemistry
Véliz	Karina	CITIES	UDP	6	Economics/Health Impacts
Zambrano	Héctor	WATER EXTREMES	UFRO[11]	6	Hydrology
Zamorano	Carlos	LAND USE CHANGE	UAY	6	Forestry

*Acts as co-leader of the research line

Except for two additions, all listed adjoint researchers have collaborated previously with CR2. The additions correspond to two lawyers with a background in policy and governance:

- **Verónica Delgado** has a PhD in law and works at Universidad de Concepción. Her expertise is in environmental law, water governance, and management in coastal zones. She is also an associate researcher at CHRIAM, a FONDAP center focusing on water management and technology. Dr. Delgado will act as co-leader in her research line.
- **Luis Cordero** has a PhD in law and works at Universidad de Chile. He has vast expertise in administrative law, public policies and governance. He coordinated the reform leading to the creation of the Ministry for the Environment.

We foresee an evolution of adjoint researchers into associate researchers according to performance and resource availability.

[9] Pontificia Universidad Católica de Valparaíso
[10] Universidad Técnica Federico Santa María
[11] Universidad de La Frontera

Current post-doctoral fellows at CR2, who should have secured independent funding for 2018 or who may be funded by CR2 if this proposal is granted, are listed in Table 4. We expect to hire three additional fellows in 2018, and to fund five fellows each year thereafter. New post-doctoral fellows should be incorporated within projects focusing on integrative questions, and they will be selected according to merit and relevance from an international call for applications. Positions funded by CR2 will last for at most two years, and fellows should apply for FONDECYT grants during the first year.

Table 4. Post-doctoral fellows who should have available funding in 2018.

Name	Last Name	Affiliation	Sponsoring Researcher	Funding Source	Research Topic
Camila	Alvarez Garretón	UACH	Antonio Lara	CR2 (2016), Fondecyt 3170428 (2017-2019)	Hydrologic vulnerability to climate change: estimation and interpretation.
Jonathan	Barichivich	UACH	Antonio Lara	CR2	Modeling carbon sequestration and water supply as ecosystem services under climate and land-use change.
Francisco	Barraza	PUC	Fabrice Lambert	Fondecyt 3160639	Origin of the aerosol deposited on Andes Glaciers
Lucy	Belmar	UCH	Laura Farías	CR2	Understanding the biogeochemistry of coastal zones and marine minimum oxygen zones, evaluating the modulation of carbon, nitrogen and sulfur cycles in coastal environments with and without anthropogenic intervention and their effect over ecological niches and finally over human
Cecilia	Ibarra	UCH	Raúl O`Ryan	CR2	Enhancing innovation to manage climate change challenges: what can be learned from Chilean efforts to improve environmental performance?
Camila	Tejo	UACH	Mauro González	Fondecyt 3160707	Ecological relevance of the canopy of the giant alerce (fitzroya cupressoides) and its consequences for management and conservation
Rocío	Urrutia-Jalabert	UACH	Antonio Lara	Fondecyt 3160258	Vulnerability of Fitzroya cupressoides or Alerce to climate change (warmer and drier summers in southern Chile) using ecophysiological tools
Raúl	Valenzuela	UCH	René Garreaud	Fondecyt 3170155	Atmospheric rivers in the southeastern pacific and their impact on extreme orographic precipitation

Students

It is not feasible for CR2 to offer student fellowships; for every funded student we are required to fund four additional students with sources other than FONDAP. Therefore, we offer research assistance positions linked to research lines and integrative questions. These assistantships are intended to result in theses and papers, and they should be preferably guided by researchers with different backgrounds and expertise. Assistantships should last for no more than five, three, and one year for PhD, MSc and

undergraduate students respectively. These assistantships will be similar to CONICYT grants in terms of compensation.

Support personnel

In Table 5 we list support personnel, and outline new positions to be filled after open calls for applications.

Table 5. Support personnel considered in the proposal. We assume the continuity of current personnel.

Name	Last Name	Role	Affiliation	Dedication
Susana	Bustos	Project Manager	UCH	35
Jimena	Cortés	Secretary	UCH	44
Michelle	Ferrer	Journalist	UCH	44
Gerardo	García	Laboratorist	UDEC	22
Marcia	Millas	Secretary/Accountant	UACH	22
Cecilia	Montecino	Accountant	UCH	44
Francisca	Muñoz	Computing and Databases manager	UCH	44
María	Ogaz	Designer	UCH	22
Nicole	Tondreau	Journalist	UCH	44
Mabel	Torres	Secretary/Accountant	UDEC	22
Z	Z	executive director	UCH	44
Z	Z	Sociologist/mediator	UCH	44
Z	Z	GIS Engineer	UCH	44
Z	Z	Field Support	UACH	44
Z	Z	Field Support	UACH	44

ORGANIZATION

Presente un diagrama de la organización del Centro y sus vínculos más cercanos (empresas, otras instituciones, otras unidades dentro de la misma institución, etc.) para este próximo período.

Our administrative and management organization has evolved along with our scientific organization, as well as with the establishment of bolder goals for the Center. Whereas management previously rested upon the director and the deputy director supported by a secretary, an accountant and a managerial assistant, we now create a formal directorial apparatus under the leadership of an executive director. This structure falls under the strategic leadership of the center's director and of the academic board, but the role takes on additional responsibility and acquires a key role in attracting resources, overseeing organizational planning and monitoring, and surveying and helping to shape CR2's societal interface. As previously stated, these changes seek to allow for organizational leaders to assign more hours to research hours, and to improve our exchanges with stakeholders, both nationally and internationally. The executive director does not replace existing leadership roles but rather he/she incorporates complementary skills and enhances the Center's potential for long-term success.

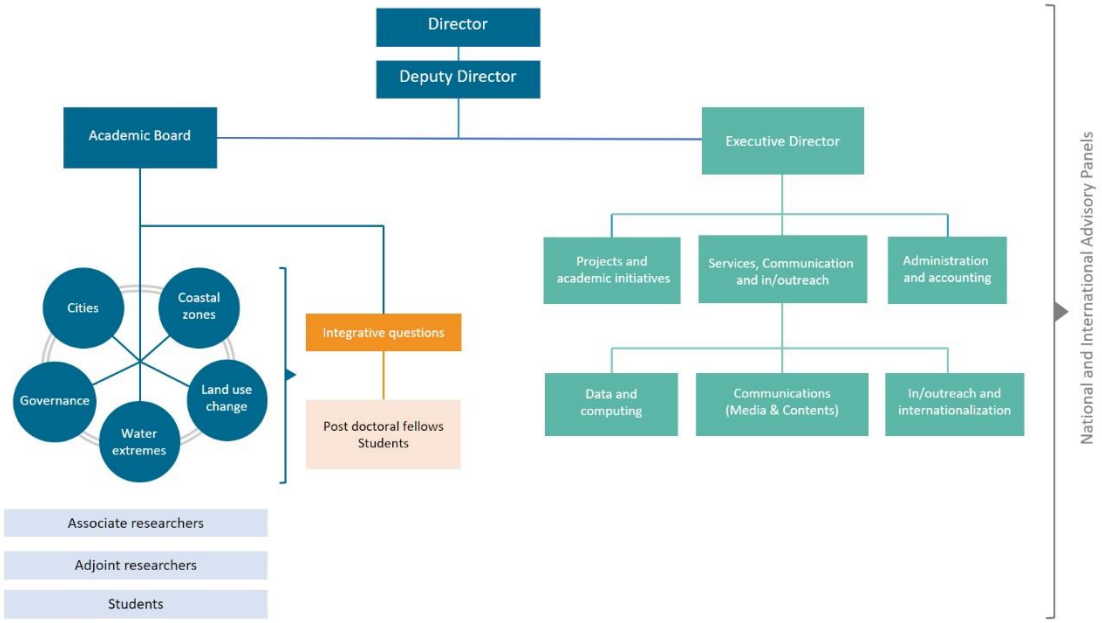

Figure 2. CR2 second phase organization scheme. This scheme shows the dependences among teams.

The left-hand side of Figure 2 depicts the organization of the science making apparatus at CR2. It consists of five lines of research (blue circles), each with mid-to-long term objectives addressing complex issues. Each line is led by a principal investigator and co-led by a senior scientist with a different area of expertise to his/her own (Cf. previous section). Within each line, teams of a few, diverse associate and adjoint researchers and students are included. In this way, we hope to promote within each line an atmosphere that favors interdisciplinary approaches yielding high-quality, relevant science, while preserving space for disciplinary and curiosity-driven science. The achievement of mid-to-long term objectives is emphasized within each line of research. The orange box constitutes a sixth area of research constituted by the integrative questions organized

as short-term projects (<2.5 years each), expected to deliver high quality and policy-relevant science. Leadership on these projects will primarily be held by CR2 researchers not serving as principal investigators. The teams for these projects will be made up of members from multiple research lines, and will be supported by the work of post-doctoral fellows and students. In this way, we can expect cross-pollination and collaboration among different research lines. These projects should be designed to achieve short-term objectives.

The right-hand side of Figure 2 depicts the teams to be led by the executive director. There are three main areas of work: external projects and academic initiatives; services, communication and in/outreach; and administration and accounting. Administration and accounting continues as in the Center's first phase, though technological platforms are being developed to increase efficiency and transparency. The area of services, communication and in/out reach provides a transversal platform to maintain, create and deliver science materials and tools consistent with the spirit of climate service provision, both for internal and external users. Additionally, this area is made up of a team of communicators supported by a half-time designer who will be responsible for media management and content development, and we expect to hire a sociologist or similar professional to facilitate exchanges with stakeholders in Chile and beyond. The project's unit will be functional in managing internal and external projects, and in supporting the development of academic initiatives such as summer schools and continuous education programs.

We are aware of the difficulties in finding a person with the profile to serve as executive director, particularly considering the relatively modest resources available. However, to ensure the prompt and adequate fulfillment of this position if our continuity is granted, we have already begun to define the desired profile, including evaluation metrics, and we have informally approached potential candidates among high-level officials in government and academia in order to gauge their potential interest. We are particularly grateful to the support provided by the leadership of the Faculty for Physical and Mathematical Science in complementing the FONDAP budget with fresh resources to enable the hiring of an executive director. At this point, we are confident that this position will be a positive addition to CR2's institutional development and in/outreach impact.

Regarding our internal governance, we largely maintain the structure and protocols adopted during our first phase, i.e., director, deputy director and principal investigators form the academic board, which is responsible for strategic decisions. The board meets regularly, typically every two to three months. If deemed necessary by the leading team, co-leaders of research lines may attend and have a voice in these meetings. The same applies in the case of other personnel. The executive director will also participate in these meetings. If agreement on a given matter is not reached, board members will vote on the matter. If the votes end in a draw, the director is to settle the tie. The director is responsible for coordinating the overarching scientific and managerial activities at CR2, and he/she receives guidance from the board and from both the National and International Advisory boards. As the center becomes organizationally stable, we will explore the renewal of existing leaderships.

OUTREACH

Presentar un plan de proyección al medio externo (outreach), incluyendo su contribución al desarrollo de políticas públicas y al desarrollo de otros grupos objetivos, indicando metas, objetivos y su implementación.

In its first phase, CR2's outreach work was aimed at disseminating the Center's research and positioning the CR2 "brand", including media management, outreach activities and science communication products for a general audience.

CR2's first phase was marked by the occurrence of important extreme weather events such as droughts, floods and forest fires in Chile, as well as the political milestone of the Paris Agreement. This context was fully exploited, with outreach work focused on positioning the Center and its experts as reliable sources of information to the media, and on outreach activities to address emerging climate change scenarios. This strategy helped to insert the issue of climate change and its impacts within public opinion and build recognition of this issue as a tangible reality in Chile. Similar outreach activities will continue throughout our second phase to ensure a base understanding and recognition of climate change and impacts, but we recognize the need to increase awareness of additional implications in order to address the complex challenges of achieving low-carbon development and building resilience.

Our outreach proposal for the next five years aims to position CR2 as a long-lasting and major player in developing proposals for climate and resilience science. To this end, we will seek to reach non-scientific audiences, particularly decision-makers and stakeholders, and in this way consolidate the work begun in the first phase of the center. We foresee outreach as a relevant, concurrent and complementary process to CR2's research. These activities also play a pivotal role in promoting and supporting the integration and success of our interdisciplinary work through integrative questions. Our approach to outreach is innovative and is characterized by the relevance that we assign to feedback and reciprocal learning. This perspective considers bi-directional exchange, enriching all communicating parties, and is supported by and builds upon our collective experience from the Center's first phase. As "decision-makers and stakeholders", we include not only the central government but also municipalities, the private sector, civil society organizations, and all other relevant actors. The research carried out under CR2's multiple areas of research, and particularly within governance and science-policy interface, provides an unique opportunity to apply this perspective in fulfilling stakeholder needs within the scope of CR2, in terms of knowledge, information and services related to climate change. Our in/outreach approach will be key in enhancing the relevance and overall impact and success of CR2. The general objective of these activities is therefore the following:

- Capture the attention and raise awareness in non-scientific audiences of climate variability and change and resilience building, emphasizing science-based decisions as well as individual and collective engagement.

Specific objectives include:

- Communicate CR2's climate and resilience science to non-scientific audiences and media.
- Support dialogue at the science-policy interface in partnership with CR2 researchers.
- Create awareness in diverse audiences of climate change and mitigation and adaptation measures.

- Promote science communication skills among CR2's students and researchers.
- Support RedLama and other science dissemination initiatives.

According to the Climate Change Survey conducted by the Ministry of the Environment and CR2 (Ministry of the Environment, 2016), 84% of Chileans believe that climate change is induced by human activities. Additionally, 65% of Chileans believe that climate change is outside of their personal control. Although Chileans are aware of climate change's anthropic origin, our society needs to embrace and assume personal and collective responsibility for meeting the challenge of achieving low-carbon and sustainable development. Our in/outreach approach will therefore incorporate the generation of "easy-to-read/hear/see" content, dissemination activities and positioning within the media, and will be fortified by research on the science-policy interface.

Within this framework, we foresee the following activities:

- Upgrading of the Center's Internet platforms (web site, Facebook, YouTube, etc.), re-organization of CR2's digital library to improve user access to databases, climate services, documents, videos, briefs, and other materials.
- Coverage of meetings and seminars to allow complete registration of these events.
- Production and distribution of CR2's internal monthly newsletter and the introduction of new recipients to our mailing list, including companies, parliamentarians, and other stakeholders.
- Ongoing strengthening of our relationship with media outlets and journalists to provide press releases, opinion pieces and other science communication products, responding to information requests.
- Development of additional communication products (web platforms, policy briefs, videos, info graphics, podcasts, etc.) for stakeholders and the general public.
- Creation of communication products for children and family audiences to be presented at science fairs by the outreach team or RedLama.
- Implementation of science communication workshops for students and researchers, in collaboration with other research centers.
- Standardized production of "downloadable paper briefs" of all papers and theses developed within CR2.
- Organization and broadcasting of "tertulias" (gatherings) to present the diverse perspectives of natural and social scientists on critical issues such as drought and fires, as well as seminars and colloquia to present ongoing research.
- Edition and production of "reports to the nation" and other materials to inform policymaking.

Our in/outreach will be led by CR2's communications officers in partnership with CR2 researchers and students, the latter primarily via RedLama, and other science communication initiatives of the Center that we seek to encourage with our training workshops. We intend to incorporate trainees from journalism schools in Chile and elsewhere within our outreach team.

PERFORMANCE INDICATORS

Completar las tablas adjuntas con indicadores académicos y de transferencia para la ejecución de la segunda etapa del Centro FONDAP.

We have adopted the indicators suggested by CONICYT, and performed our calculations based on the average value for the last four years. For indexed publications (ISI), we used the baseline suggested by CONICYT, taking into account the number of hours dedicated per week by each researcher, i.e., 44 by the director and post-doctoral fellows, 26 by each principal investigator, 12 by associates and 6 per adjoint researchers. In most cases, indicators begin increasing starting in the third year, when four fulltime, mid-career researchers will be incorporated.

In the case of in/outreach, indicators do not show significant increases because they had already reached a satisfactory level. In/outreach indicators also depend to a certain extent on the occurrence of extreme weather events. As the Center evolves along with its enhanced in/outreach unit, we may be able to better define other indicators for these activities and their impact. Nevertheless, we have introduced complementary indicators to monitor progress in the development and usage of scientific data, documents and multimedia, for example: coverage of available dataset, website visits, database downloads, number of documents available on the webpage, and number of video visualizations.

Regarding indicators of policy-science interface or societal impact, we have incorporated several, including a measure of response to public consultations in the framework of public policies, and the participation of our researchers in media columns and public debates on relevant issues. Again, understanding and characterizing the policy-science interface is in and of itself an important line of research, and one that we are only beginning to tackle in a more systematic manner.

BUDGET SUMMARY

Provea información presupuestaria detallada de los fondos que requerirá al Programa FONDAP en el formulario adjunto, siendo el subsidio máximo anual para el Centro de hasta 950 millones de pesos. En esta sección se deben respetar las restricciones establecidas en las bases del Cuarto Concurso Nacional de Centros de Investigación de Excelencia FONDAP 2011.

Provea información presupuestaria de los fondos comprometidos tanto por la Institución Patrocinante como Instituciones Asociadas, si existiesen, en el formulario adjunto. Se deben incluir las nuevas cartas compromiso de todas las instituciones indicando claramente los aportes pecuniarios y no pecuniarios por año. En esta sección se deben respetar las restricciones establecidas en las bases del Cuarto Concurso Nacional de Centros de Investigación de Excelencia FONDAP 2011.

Our proposed budget was calculated considering the maximum annual grant permitted by CONICYT, i.e., 950 MCLP or 1469650 USD. This budget is shown in Table 6.

Table 6. Proposed annual budget for the period 2018-2022 for CR2 in its second phase according to CONICYT maximum grant. Values are in US dollars using a conversion rate of 1USD=646 CLP.

Item	Years of execution (USD)						
	Year 6	Year 7	Year 8	Year 9	Year 10	Total	%
Personnel	**$ 720,122**	**$ 817,569**	**$ 847,156**	**$ 847,156**	**$ 863,399**	**$ 4,095,402**	**55.7%**
Researchers	$ 319,783	$ 412,603	$ 412,603	$ 412,603	$ 412,603	$ 1,970,197	26.8%
New Hires							
Post-doctoral fellows	$ 92,047	$ 101,522	$ 121,826	$ 121,826	$ 138,070	$ 575,291	7.8%
PhD Students							
MSc Students							
Under-graduates							
Support Personnel	$ 308,292	$ 303,444	$ 312,726	$ 312,726	$ 312,726	$ 1,549,915	21.1%
Travel	**$ 95,781**	**$ 73,224**	**$ 80,244**	**$ 79,916**	**$ 82,662**	**$ 411,828**	**5.6%**
Per-diem	**$ 25,702**	**$ 16,759**	**$ 18,364**	**$ 18,036**	**$ 19,854**	**$ 98,716**	**1.3%**
National	$ 8,762	$ 5,466	$ 6,530	$ 6,202	$ 7,246	$ 34,206	0.5%
International	$ 16,940	$ 11,293	$ 11,835	$ 11,835	$ 12,608	$ 64,510	0.9%
Tickets	**$ 70,079**	**$ 56,466**	**$ 61,880**	**$ 61,880**	**$ 62,808**	**$ 313,113**	**4.3%**
National	$ 37,747	$ 32,796	$ 34,653	$ 34,653	$ 34,653	$ 174,502	2.4%
International	$ 32,332	$ 23,669	$ 27,227	$ 27,227	$ 28,155	$ 138,611	1.9%
Internationalization	**$ 34,034**	**$ 69,422**	**$ 72,322**	**$ 78,510**	**$ 56,852**	**$ 311,140**	**4.2%**
Operational Costs	**$ 288,748**	**$ 236,720**	**$ 227,635**	**$ 224,815**	**$ 235,590**	**$ 1,213,507**	**16.5%**
Capital goods	**$ 72,684**	**$ 35,760**	**$ 21,544**	**$ 20,538**	**$ 8,227**	**$ 158,753**	**2.2%**
Infrastructure	**$ 32,178**	**$ 15,470**	**$ 0**	**$ 0**	**$ 0**	**$ 47,648**	**0.6%**
General costs	**$ 44,090**	**$ 44,090**	**$ 44,090**	**$ 44,090**	**$ 44,090**	**$ 220,448**	**3.0%**
Administrative staff	**$ 98,519**	**$ 98,519**	**$ 98,519**	**$ 98,519**	**$ 98,519**	**$ 492,596**	**6.7%**
Costs of acquiring legal entity							
Subscriptions to publications	**$ 8,465**	**$ 3,846**	**$ 3,111**	**$ 1,077**	**$ 5,281**	**$ 21,780**	**0.3%**
Bank bonds	**$ 1,547**	**$ 1,547**	**$ 1,547**	**$ 1,547**	**$ 1,547**	**$ 7,735**	**0.1%**
Consulting services	**$ 0**	**$ 0**	**$ 0**	**$ 0**	**$ 0**	**$ 0**	
Overhead	**$ 73,483**	**$ 73,483**	**$ 73,483**	**$ 73,483**	**$ 73,483**	**$ 367,413**	**5.0%**
Unforeseen costs							
Total M$	**1,469,650**	**1,469,650**	**1,469,650**	**1,469,650**	**1,469,650**	**7,348,250**	**100%**

The largest fraction of the budget (~56%) is allocated to personnel, i.e., incentives for associate and adjoint researchers[12], three new positions for fulltime associate researchers[13] (another position is to be funded by the Faculty for Physical and Mathematical Science of the University of Chile), post-doctoral fellows[14], and support personnel including journalists, engineers, students[15], and others.

Only 16.5% of the budget is assigned to operational costs, a small figure considering the fieldwork we carry out, both in terms of biophysical and social science. We expect to cover additional costs with concurrent, smaller scale projects, services, and other funds. In this sense, the role of the executive director and the generosity of associated researchers and institutions will be essential to the ongoing success of the Center.

A small fraction of the budget is dedicated to infrastructure, with the goal of better receiving new researchers, and continuing with the installation of an Andean Observatory downwind from Santiago, a project that represents to part of a larger institutional initiative and on which we will collaborate with other centers of excellence.

It is worth noting that only a small fraction of the budget is assigned to administrative personnel, which we believe represents an important measure of efficient management practices.

Other funds will partially cover travel costs and will be largely devoted to two annual plenary meetings and key CR2 internationalization activities. Internationalization refers to the invitation of foreign scholars to Chile, including members of our international panel, at least once per year.

Regarding contributions from our sponsoring institution the University of Chile (UCH) via the Faculty for Physical and Mathematical Science (FCFM) and the Department of Geophysics (DGF)), and our associated institutions (Universidad Austral de Chile (UACH) and Universidad de Concepción (UDEC)), their cash contributions will be as follows:

- UCH provides 76 million CLP annually to cover one researcher position, part of the executive director's wage[16], and operational and infrastructure costs.
- UACH and UDEC each provide 8.5 million CLP annually to fund support personnel; these funds are allocated between the Land Use and Coastal Zones lines of research, respectively.

Together, these contributions provide a total five-year budget of around USD 10 million. Overhead and general costs are shared among the institutions in proportion to their cash contributions.

[12] Incentives are modest if compared with allowed values. In the case of fulltime researchers we will offer roughly 4000 USD per month.

[13] New hires correspond to individuals with permanent institutional positions.

[14] Part of this cost is allocated under internationalization to address issues related to immigration paperwork, in the case of foreigners.

[15] Students are hired as support personnel; if paid as fellowships, we would need four external fellowships for each student.

[16] We have made an effort to provide an attractive position for an executive director with a profile that is not merely administrative or managerial but rather a professional with a background in the national and international climate change arena, such as a climate negotiator or high-level public officer. We are aware of the difficulties in finding such a person but we have identified several potential profiles. The position will be filled via an open call for applications.

REFERENCES

Acuto M. 2016. Give cities a seat at the top table. *Nature*. doi:doi:10.1038/537611a.

Aguirre C, García-Loyola S, Testa G, Silva D, Farías L. 2017. Insight into anthropogenic forcing on coastal upwelling off central-south Chile.

Avnery S, Mauzerall DL, Liu J, Horowitz LW. 2011. Global crop yield reductions due to surface ozone exposure: 1. Year 2000 crop production losses and economic damage. *Atmos Environ* **45**(13): 2284-2296.

Bai X, van der Leeuw S, O'Brien K, Berkhout F, Biermann F, et al. 2016. Plausible and desirable futures in the Anthropocene: A new research agenda. *Global Environmental Change* **39**: 351-362. doi:http://dx.doi.org/10.1016/j.gloenvcha.2015.09.017.

Bai Y-T, Zhang B-H, Wang X-Y, Jin X-B, Xu J-P, et al. 2017. Expert Decision Support Technique for Algal Bloom Governance in Urban Lakes Based on Text Analysis. *Water* **9**(5): 308.

Barraza F, Lambert F, Jorquera H, Villalobos AM, Gallardo L. 2017. Temporal evolution of main ambient PM_{2.5} sources in Santiago, Chile, from 1998 to 2012. *Atmospheric Chemistry and Physics Discussions* **2017**: 1-21. doi:10.5194/acp-2017-18.

Barrera D. 2017. Emergencia incendios forestales 2017. Ministry for Agriculture. Available at http://www.odepa.gob.cl/wp-content/files_mf/1491251485incendios2017.pdf.

Barton JR. 2013. Climate change adaptive capacity in Santiago de Chile: creating a governance regime for sustainability planning. *International Journal of Urban and Regional Research* **37**(6): 1916-1933.

Barton JR, Krellenberg K, Harris JM. 2015. Collaborative governance and the challenges of participatory climate change adaptation planning in Santiago de Chile. *Climate and Development* **7**(2): 175-184. doi:10.1080/17565529.2014.934773.

Beck S, Mahony M. 2017. The IPCC and the politics of anticipation. *Nature Clim Change* **7**(5): 311-313. doi:10.1038/nclimate3264.

Boisier JP, Rondanelli R, Garreaud RD, Muñoz F. 2016. Anthropogenic and natural contributions to the Southeast Pacific precipitation decline and recent megadrought in central Chile. *Geophysical Research Letters* **43**(1): 413-421.

Bond TC, Doherty SJ, Fahey DW, Forster PM, Berntsen T, et al. 2013. Bounding the role of black carbon in the climate system: A scientific assessment. *Journal of Geophysical Research: Atmospheres* **118**(11): 5380-5552. doi:10.1002/jgrd.50171.

Bond WJ, van Wilgen BW. 1996. Why and how do ecosystems burn? *Fire and plants*. Springer: 16-33.

Bowman DM, Balch JK, Artaxo P, Bond WJ, Carlson JM, et al. 2009. Fire in the Earth system. *science* **324**(5926): 481-484.

Bozkurt D, Rondanelli R, Garreaud R, Arriagada A. 2016. Impact of warmer eastern tropical Pacific SST on the March 2015 Atacama floods. *Monthly Weather Review* **144**(11): 4441-4460. doi:10.1175/MWR-D-16-0041.1.

Brooks TM, Mittermeier RA, da Fonseca GA, Gerlach J, Hoffmann M, et al. 2006. Global biodiversity conservation priorities. *science* **313**(5783): 58-61.

Buschmann A, Farias L, Tapia F, Varela D, Vásquez M. 2016. Informe Final de la Comisión Marea Roja. Academia de Ciencias y Ministerio de Economía. Available at http://www.economia.gob.cl/wp-

content/uploads/2016/11/InfoFinal_ComisionMareaRoja_24Nov2016-1.compressed.pdf.

Bustos-Gallardo B. 2013. The ISA crisis in Los Lagos Chile: A failure of neoliberal environmental governance? *Geoforum* **48**: 196-206.

Cakmak S, Kauri L, Shutt R, Liu L, Green MS, et al. 2014. The association between ambient air quality and cardiac rate and rhythm in ambulatory subjects. *Environment international* **73**: 365-371.

Carmona A, González ME, Nahuelhual L, Silva J. 2012. Spatio-temporal effects of human drivers on fire danger in Mediterranean Chile. *Bosque* **33**(3): 321-328.

Castellnou M, R. Á, Almodóvar J, Martins FM, Mayoral PC, et al. 2017. Situación de incendios forestales en Chile entre enero-febrero 2017. European Union Civil Protection Mechanism: 11. Available at http://www.redhum.org/documento_detail/onu-informe-de-situacion-n2-por-incendios-forestales.

CEPAL/ONU. 2011. Efectos del cambio climático en la costa de América Latina y el Caribe: dinámicas, tendencias y variabilidad climática. CEPAL: 263.

Chilvers J, Longhurst N. 2016. Participation in transition (s): reconceiving public engagements in energy transitions as co-produced, emergent and diverse. *Journal of Environmental Policy & Planning* **18**(5): 585-607.

Cochrane MA. 2003. Fire science for rainforests. *Nature* **421**(6926): 913.

Cochrane MA, Laurance WF. 2008. Synergisms among fire, land use, and climate change in the Amazon. *AMBIO: A Journal of the Human Environment* **37**(7): 522-527.

CR2. 2015. Informe a la Nación La megasequía 2010-2015: Una lección para el futuro. Santiago, Chile: Center for Climate and Resilience Research (CR2): 28. Available at http://www.cr2.cl/wp-content/uploads/2015/11/informe-megasequia-cr21.pdf.

CREDEN. 2016. HACIA UN CHILE RESILIENTE FRENTE A DESASTRES: UNA OPORTUNIDAD Available at http://www.cnid.cl/wp-content/uploads/2016/12/CREDEN-27122016-2.pdf.

Dokulil MT, Teubner K. 2010. Eutrophication and climate change: present situation and future scenarios. *Eutrophication: causes, consequences and control*. Springer: 1-16.

Edwards M, Johns D, Leterme S, Svendsen E, Richardson A. 2006. Regional climate change and harmful algal blooms in the northeast Atlantic. *Limnology and oceanography* **51**(2): 820-829.

Fearnside PM. 2000. Global warming and tropical land-use change: greenhouse gas emissions from biomass burning, decomposition and soils in forest conversion, shifting cultivation and secondary vegetation. *Climatic change* **46**(1-2): 115-158.

Feng Z, Hu E, Wang X, Jiang L, Liu X. 2015. Ground-level O 3 pollution and its impacts on food crops in China: a review. *Environmental Pollution* **199**: 42-48.

Fisher E, Scotford E, Barritt E. 2017. The Legally Disruptive Nature of Climate Change. *The Modern Law Review* **80**(2): 173-201.

Foley JA, DeFries R, Asner GP, Barford C, Bonan G, et al. 2005. Global consequences of land use. *science* **309**(5734): 570-574.

Gallardo L, Barraza F, Ceballos A, Galleguillos M, Huneeus N, et al. Evolution of Santiago's air quality: the role of mobility and lessons from the science-policy interface.

Garreaud R, Alvarez-Garreton C, Barichivich J, Boisier JP, Christie D, et al. 2017. The 2010-2015 mega drought in Central Chile: Impacts on regional hydroclimate and vegetation. *Hydrol Earth Syst Sci Discuss*. doi:0.5194/hess-2017-191, 2017.

Giglio L, Randerson JT, Werf GR. 2013. Analysis of daily, monthly, and annual burned area using the fourth-generation global fire emissions database (GFED4). *Journal of Geophysical Research: Biogeosciences* **118**(1): 317-328.

Glibert PM, Anderson DM, Gentien P, Granéli E, Sellner KG. 2005. The global, complex phenomena of harmful algal blooms. *Oceanography* **18** (2): 136-147.

Gupta J. 2007. The multi-level governance challenge of climate change. Taylor & Francis.

Hackmann H, Moser SC, St Clair AL. 2014. The social heart of global environmental change. *Nature Climate Change* **4**(8): 653.

Heilmayr R, Echeverría C, Fuentes R, Lambin EF. 2016. A plantation-dominated forest transition in Chile. *Applied Geography* **75**: 71-82.

Heinrichs D, Nuissl H, RODRÍGUEZ SEEGER C. 2009. Dispersión urbana y nuevos desafíos para la gobernanza (metropolitana) en América Latina: el caso de Santiago de Chile. *EURE (Santiago)* **35**(104): 29-46.

Heusser C. 1994. Paleoindians and fire during the late Quaternary in southern South America. *Revista Chilena de Historia Natural* **67**(4): 435-443.

Holz A, Veblen TT. 2012. Wildfire activity in rainforests in western Patagonia linked to the Southern Annular Mode. *International Journal of Wildland Fire* **21**(2): 114-126.

Hua J, Yin Y, Peng L, Du L, Geng F, et al. 2014. Acute effects of black carbon and PM 2.5 on children asthma admissions: A time-series study in a Chinese city. *Science of the Total Environment* **481**: 433-438.

Hutchins DA, Fu F. 2017. Microorganisms and ocean global change. *Nature microbiology* **2**: 17058.

Hutyra LR, Duren R, Gurney KR, Grimm N, Kort EA, et al. 2014. Urbanization and the carbon cycle: Current capabilities and research outlook from the natural sciences perspective. *Earth's Future* **2**(10): 473-495.

Iriarte JL, González HE, Nahuelhual L. 2010. Patagonian fjord ecosystems in southern Chile as a highly vulnerable region: problems and needs. *AMBIO: A Journal of the Human Environment* **39**(7): 463-466.

Jones P, Trenberth K, Ambenje P, Bojariu R, Easterling D, et al. 2007. Observations: surface and atmospheric climate change. *Climate change*: 235-336.

Jones SA, Fischhoff B, Lach D. 1999. Evaluating the science-policy interface for climate change research. *Climatic Change* **43**(3): 581-599.

Jorgenson AK, Auerbach D, Clark B. 2014. The (De-) carbonization of urbanization, 1960–2010. *Climatic Change* **127**(3-4): 561-575.

Keuken M, Zandveld P, van den Elshout S, Janssen NA, Hoek G. 2011. Air quality and health impact of PM 10 and EC in the city of Rotterdam, the Netherlands in 1985–2008. *Atmos Environ* **45**(30): 5294-5301.

Kirchhoff CJ, Lemos MC, Dessai S. 2013. Actionable knowledge for environmental decision making: broadening the usability of climate science. *Annual review of environment and resources* **38**.

Kitzberger T, Veblen TT. 1997. Influences of humans and ENSO on fire history of Austrocedrus chilensis woodlands in northern Patagonia, Argentina. *Ecoscience* **4**(4): 508-520.

Kotzé LJ. 2014a. The Anthropocene's global environmental constitutional moment. *Yearbook of International Environmental Law* **25**(1): 24-60.

Kotzé LJ. 2014b. Rethinking global environmental law and governance in the Anthropocene. *Journal of Energy & Natural Resources Law* **32**(2): 121-156.

Koutsias N, Xanthopoulos G, Founda D, Xystrakis F, Nioti F, et al. 2013. On the relationships between forest fires and weather conditions in Greece from long-term national observations (1894–2010). *International Journal of Wildland Fire* **22**(4): 493-507.

Krawchuk MA, Moritz MA. 2011. Constraints on global fire activity vary across a resource gradient. *Ecology* **92**(1): 121-132.

Lara A, Reyes R, Urrutia R. 2010. Bosques Nativos. *Informe País, Estado del Medio Ambiente en Chile 2008*. Santiago, Chile: Instituto de Asuntos Públicos. Centro de Análisis de Políticas Públicas. Universidad de Chile: 126-171.

Lara A, Zamorano C, Miranda A, González M, Reyes R. 2016. Bosques Nativos, in Gligo N ed., *Informe País Estado del Medio Ambiente en Chile Comparación 1999 - 2015*. Santiago, Chile: Centro de Estudios públicos. Centro de Análisis de Políticas Públicas. Universidad de Chile.

Lazarus RJ. 2008. Super wicked problems and climate change: Restraining the present to liberate the future. *Cornell L Rev* **94**: 1153.

Leiva GM, Santibanez DA, Ibarra ES, Matus CP, Seguel R. 2013. A five-year study of particulate matter (PM2.5) and cerebrovascular diseases. *Environ Pollut* **181**: 1-6. doi:10.1016/j.envpol.2013.05.057.

Levin K, Cashore B, Bernstein S, Auld G. 2012. Overcoming the tragedy of super wicked problems: constraining our future selves to ameliorate global climate change. *Policy sciences* **45**(2): 123-152.

Lewis SC. 2017. Blue Skies and Other Shades. *A Changing Climate for Science*. Springer: 117-135.

Liu Y, Goodrick S, Heilman W. 2014. Wildland fire emissions, carbon, and climate: Wildfire–climate interactions. *Forest Ecology and Management* **317**: 80-96.

Lorenzoni I, Nicholson-Cole S, Whitmarsh L. 2007. Barriers perceived to engaging with climate change among the UK public and their policy implications. *Global environmental change* **17**(3): 445-459.

Magrin G, Marengo J, Boulanger J, Buckeridge E, Castellanos E, et al. 2014. Central and South America. *Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press Cambridge, UK.

Marcotullio PJ, Hughes S, Sarzynski A, Pincetl S, Sanchez Peña L, et al. 2014. Urbanization and the carbon cycle: Contributions from social science. *Earth's Future* **2**(10): 496-514.

Mardones J, Clement A, Rojas X. 2012. Monitoring potentially ichthyotoxic phytoflagellates in southern fjords of Chile. *Harmful Algae News*.

Markgraf V, Huber UM. 2010. Late and postglacial vegetation and fire history in Southern Patagonia and Tierra del Fuego. *Palaeogeography, Palaeoclimatology, Palaeoecology* **297**(2): 351-366.

Martinez-Harms MJ, Caceres H, Biggs D, Possingham HP. 2017. After Chile's fires, reforest private land. *Science* **356**(6334): 147-148.

Mazzeo A, N. H, C. O, A. O-C, L. M, et al. 2017. Impact of residential and transport emissions on atmospheric pollution in Santiago.

McKinney ML, Lockwood JL. 1999. Biotic homogenization: a few winners replacing many losers in the next mass extinction. *Trends in ecology & evolution* **14**(11): 450-453.

Melamed ML, Schmale J, von Schneidemesser E. 2016. Sustainable policy—key considerations for air quality and climate change. *Current Opinion in Environmental Sustainability* **23**: 85-91. doi:http://dx.doi.org/10.1016/j.cosust.2016.12.003.

MINECO. 2016. Plan estratégico demonitoreo integral y diversificación productiva en la región de Los Lagos. Available at http://www.subpesca.cl/sitioprensa/614/articles-95904_documento.pdf.

Miranda A, Altamirano A, Cayuela L, Pincheira F, Lara A. 2015. Different times, same story: Native forest loss and landscape homogenization in three physiographical areas of south-central of Chile. *Applied Geography* **60**: 20-28. doi:10.1016/j.apgeog.2015.02.016.

MMA. 2014. Planes de Descontaminación Atmosférica. Estrategia 2014-2018. . Santiago, Chile. Available at http://www.mma.gob.cl/1304/articles-56174_PlanesDescontaminacionAtmosEstrategia_2014_2018.pdf.

MMA. 2016. *Tercera Comunicación Nacional de Chile ante la Convención Marco de las Naciones Unidas sobre Cambio Climático*.

Molina LT, Gallardo L, Andrade M, Baumgardner D, Borbor-Córdova M, et al. 2015. Pollution and its Impacts on the South American Cryosphere. *Earth's Future* **3**(12): 345-369. doi:10.1002/2015ef000311.

Moore SK, Trainer VL, Mantua NJ, Parker MS, Laws EA, et al. 2008. Impacts of climate variability and future climate change on harmful algal blooms and human health. *Environmental Health* **7**(2): S4.

OECD. 2013. *OECD Urban Policy Reviews, Chile 2013*. OECD Publishing.

OECD/ECLAC. 2016. OECD Environmental Performance Reviews: Chile 2016. Paris. Available at http://www.oecd-ilibrary.org/environment/oecd-environmental-performance-reviews-chile-2016_9789264252615-en.

Olson DM, Dinerstein E. 1998. The Global 200: a representation approach to conserving the Earth's most biologically valuable ecoregions. *Conservation Biology* **12**(3): 502-515.

Reddington C, Butt E, Ridley D, Artaxo P, Morgan W, et al. 2015. Air quality and human health improvements from reductions in deforestation-related fire in Brazil. *Nat Geosci* **8**(10): 768.

Rogelj J, den Elzen M, Höhne N, Fransen T, Fekete H, et al. 2016. Paris Agreement climate proposals need a boost to keep warming well below 2 °C. *Nature* **534**(7609): 631-639. doi:10.1038/nature18307 http://www.nature.com/nature/journal/v534/n7609/abs/nature18307.html#supplementary-information.

Romero-Lankao P, Gurney KR, Seto KC, Chester M, Duren RM, et al. 2014. A critical knowledge pathway to low-carbon, sustainable futures: Integrated understanding of urbanization, urban areas, and carbon. *Earth's Future* **2**(10): 515-532. doi:10.1002/2014EF000258.

Romero H, Salgado M, Smith P. 2010. Cambios climáticos y climas urbanos: Relaciones entre zonas termales y condiciones socioeconómicas de la población de Santiago de Chile. *Revista invi* **25**(70): 151-179.

Romero H, Vásquez A, Fuentes C, Salgado M, Schmidt A, et al. 2012. Assessing urban environmental segregation (UES). The case of Santiago de Chile. *Ecological Indicators* **23**: 76-87. doi:http://dx.doi.org/10.1016/j.ecolind.2012.03.012.

Rosenzweig C, Solecki W, Hammer SA, Mehrotra S. 2010. Cities lead the way in climate-change action. *Nature* **467**(7318): 909-911.

Swetnam TW, Betancourt JL. 1990. Fire-southern oscillation relations in the southwestern United States. *Science(Washington)* **249**(4972): 1017-1020.

Tai AP, Martin MV, Heald CL. 2014. Threat to future global food security from climate change and ozone air pollution. *Nature Climate Change* **4**(9): 817-821.

Thiel M, Macaya EC, Acuna E, Arntz WE, Bastias H, et al. 2007. The Humboldt Current System of northern and central Chile: oceanographic processes, ecological interactions and socioeconomic feedback. *Oceanography and marine biology* **45**: 195-344.

Tollefson J. 2015. Climate-panel chief Hoesung Lee wants focus on solutions. *Nature*. doi: http://doi.org/b4r8.

Turquety S, Menut L, Anav A, Viovy N, Maignan F, et al. 2014. APIFLAME v1. 0: high-resolution fire emission model and application to the Euro-Mediterranean region. *Geoscientific Model Development* **7**: 587-612.

UN-HABITAT. 2011. Cities and climate change. London, Washington DC: United Nations Human Settlements Programme: 300. Available at http://unhabitat.org/books/cities-and-climate-change-global-report-on-human-settlements-2011/.

Vitousek PM. 1994. Beyond global warming: ecology and global change. *Ecology* **75**(7): 1861-1876.

von Glasow R, Jickells TD, Baklanov A, Carmichael GR, Church TM, et al. 2013. Megacities and large urban agglomerations in the coastal zone: interactions between atmosphere, land, and marine ecosystems. *Ambio* **42**(1): 13-28. doi:10.1007/s13280-012-0343-9.

Watts DJ. 2017. Should social science be more solution-oriented? **1**: 0015. doi:10.1038/s41562-016-0015.

Weaver CP, Mooney S, Allen D, Beller-Simms N, Fish T, et al. 2014. From global change science to action with social sciences. *Nature Climate Change* **4**(8): 656.

Weiss K. 2015. Cities bask in spotlight at Paris climate talks. Nature News.

Whitlock C, Moreno PI, Bartlein P. 2007. Climatic controls of Holocene fire patterns in southern South America. *Quaternary Research* **68**(1): 28-36.

Winkler H, Delgado R, Palma-Behnke R, Pereira A, Vásquez Baos T, et al. 2016. Information for a developmental approach to mitigation: linking sectoral and economy-wide models for Brazil, Chile, Colombia, Peru and South Africa. *Climate and Development*: 1-12. doi:10.1080/17565529.2016.1174660.

Zhu T, Melamed M, Parrish D, Gauss M, Gallardo Klenner L, et al. 2013. WMO/IGAC Impacts of Megacities on Air Pollution and Climate. Geneva, Switzerland: GAW Report 205. 205. Available at http://www.wmo.int/pages/prog/arep/gaw/documents/Final_GAW_205_web_31_January.pdf.

CONTENTS