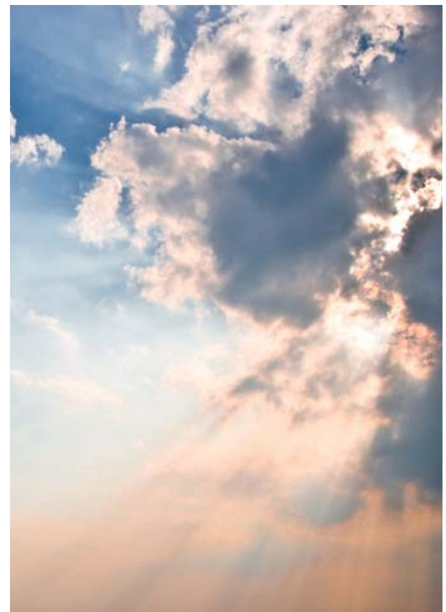




Report to the Nation

The 2010-2015 mega-drought: A lesson for the future

Center for Climate and Resilience Research (CR)2

November 2015



Center for Climate and Resilience Research
www.CR2.cl


DRINKING WATER

A lesson for the future

The current drought has been widespread, protracted and warm, and it has had detrimental impacts throughout central Chile. It does, however, offer revealing lessons on how to prepare for a warmer and drier climate future, and on ways to increase our resilience in the face of natural and anthropogenic climate fluctuations.

Throughout history, central Chile has repeatedly witnessed droughts lasting one or two years, caused by natural climate variations. On occasions, the water shortage has exceeded 50% (as was the case in 1925, 1968 and 1989), leading to the building of reservoirs, the establishment of agricultural subsidies and other palliative measures to help the country cope with these extreme events.

Starting in 2010, the Chilean territory between the Coquimbo and Araucanía Regions has experienced a precipitation deficit of approximately 30%. Not only have these conditions lasted continuously since then, but they have coincided with the warmest decade of the last 100 years, exacerbating the water deficit by increasing the evaporation rate from lakes, reservoirs, and agricultural crops. The duration and spatial extent of the current drought – which we will refer to as a "mega-drought" - are extraordinary in Chile's historical record. This phenomenon is also unparalleled in one thousand years of reconstructed precipitation based on tree-ring growth records.

Faced with the multiple impacts of the mega-drought, Chilean society has responded in a variety of ways. However, all the measures taken have been based on the assumption that the current drought is an extraordinary but transitory event. We have overlooked the fact that at least 25% of the precipitation deficit during the mega-drought is attributable to anthropogenic factors. Studies indicate that during the twenty-first century these trends will continue, causing the gradual aridification of Central and Southern Chile, and increasing the frequency and intensity of widespread and protracted droughts such as the current one.

Considering the fact that this type of drought is almost unique in historical records and that it is expected to be more frequent in the future, the Center for Climate and Resilience Research (CR2) presents this report to the nation, as a contribution to our understanding of the root causes and consequences of the phenomenon, along with a critical analysis of the ways in which civil society and the government are responding.

The first part of the report consists of the hydro-climatic characterization and contextualization of the current event through as well as an analysis of natural and anthropogenic climate phenomena that contribute to the precipitation deficit. Next, the report describes the event's impacts on water availability, natural vegetation, occurrence of forest fires, and primary productivity along Chile's coastal areas. The third part of the report describes society's perception of these climate trends and the response of the State in the face of the mega-drought. Finally, recommendations are presented relating to management and regulation of water resources, prevention of climate risks, coordination of various stakeholders and actors, as well as the use of instruments to evaluate our vulnerability and best practices for the construction of resilience.

CHARACTERIZATION

A long-lasting, widespread drought

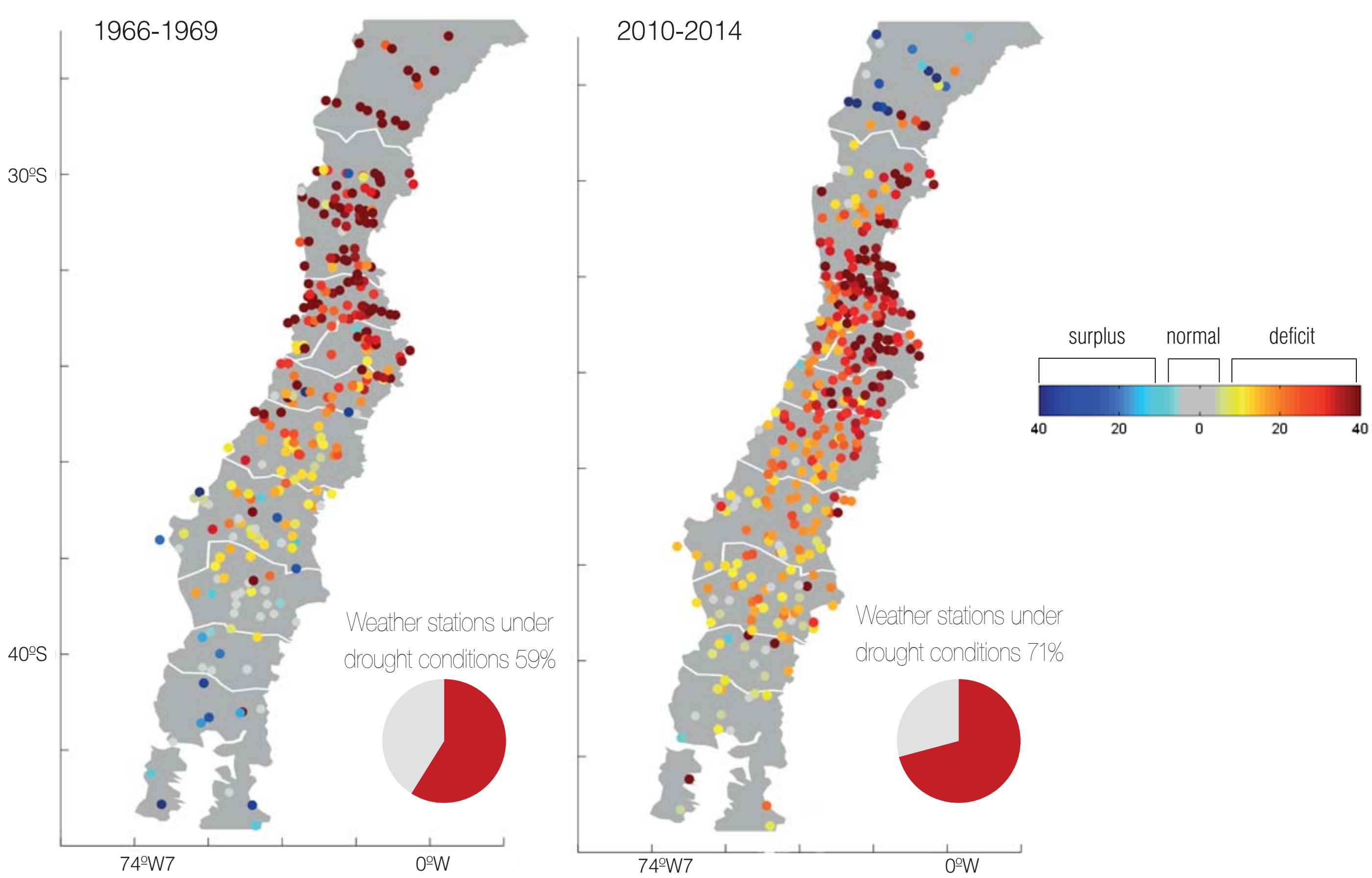
Although droughts lasting one or two years have been relatively frequent historical phenomena in the climate of Central Chile, the last six years are longest and most spatially extensive dry spell since the early twentieth century

The rainfall records for the area comprised between the southern part of Coquimbo Region and the north of Biobío Region indicate that approximately a quarter of the years from 1940 to 2010 have seen precipitation deficits exceeding 30%, i.e, droughts. Most of these dry years are isolated events, but there have also been four multi-year events: the first covered the period from 1945 to 1947; the second lasted from 1967 to 1969; the third from 1988 to 1990; and finally, the current period (2010 – 2015). This last event continues to this day, and now constitutes the longest-lasting and most geographically widespread water shortage phenomenon on record, deserving the name of "mega-drought".

The intensity of each multi-year event has varied from place to place in Central Chile. For example, the drought that occurred in the late 60's was especially severe in Chile's Near North (Norte Chico) and includes the year 1968, in which many weather stations recorded precipitation deficits exceeding 60%. However, rainfall conditions south of the Maule River were near normal.

During the current mega-drought, the highest rainfall deficits have also been recorded in the Near North, but the rainfall shortages also exceed 30% as far south as Araucanía Region. This pattern – except for slight variations – has continued unaltered from 2010 to 2015. In the Near North, conditions similar to the present have occurred about once every 15 years, while at most weather stations located in central and southern Chile the current mega-drought is unparalleled in the last 70 years of climate records. Similarly, the return period for the driest year of the current mega-drought varies from 10 years in the Near North to more than 30 years in central and southern Chile.

Average rainfall deficit or surplus for the periods 1966-1969 and 2010-2014. The deficit (as a percentage) is calculated at each weather station as the total yearly average of the dry period divided by the long-term average (1970-2000). Also shown is the percentage of weather stations reporting average deficits exceeding 30% from Coquimbo to Los Ríos Regions. Source: General Water Authority (DGA) and Chilean Meteorological Office.



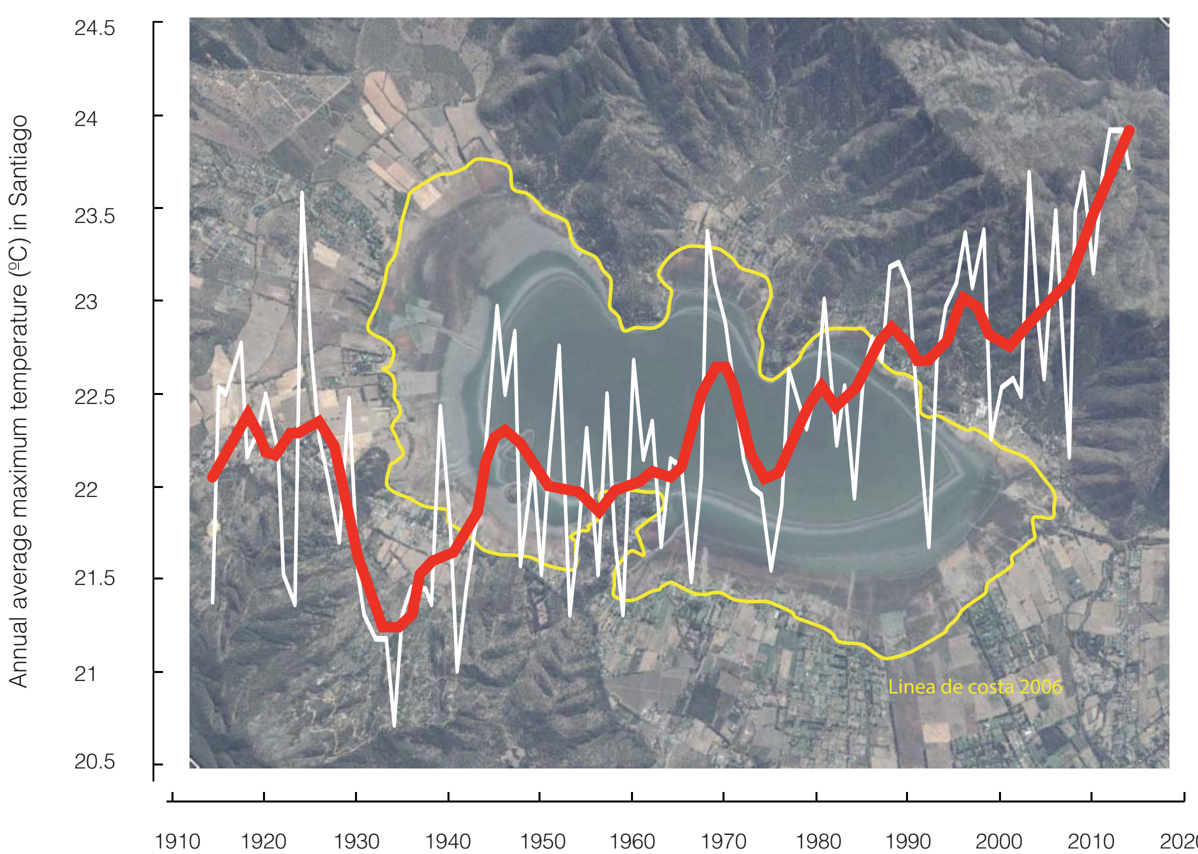
Drought and heat

The mega-drought is coinciding with the warmest decade recorded in Central Chile, thereby increasing water loss due to evaporation and worsening the water deficit.

Northern and central Chile has experienced a gradual warming since the mid 1970's (with the exception of the coast, where temperatures have remained constant or even diminished. Maximum temperatures have risen sharply over the last 10 years, and this increase is especially pronounced at elevations above 1,000 masl. This is consistent with climate change caused by emissions of greenhouse gases into the atmosphere.

Thus, the mega-drought is taking place during the warmest decade ever recorded throughout Central Chile. During the period 2010-2014, most weather stations in Chile's Central Valley and the Andean foothills recorded average and maximum temperatures that are from 0.5 to 1.5°C above the normal values corresponding to the period entre 1970 - 2000.

Higher temperatures lead to greater water loss from snow-covered areas (sublimation), crops and natural vegetation (evapotranspiration), and lakes and reservoirs (evaporation), making the water deficit worse. For example, annual evaporation from Aculeo Lagoon in the Metropolitan Region has historically been about 1,200 mm, based on average figures for 1970-1997. This value increases approximately 10% due to the 0.8°C temperature increase experienced during the mega-drought. This results in a total water loss of more than one million cubic meters from this lagoon.



Time evolution of average annual maximum temperatures at Quinta Normal weather station (Santiago) between 1914 and 2014 (white line). The red curve is a 3-year moving average. The background image (Google EarthTM) shows the current condition of Aculeo Lagoon (April 2015) and the Lagoon's coast line in April 2006, evidencing the reduction of the water surface area. Source: Chilean Meteorological Office.

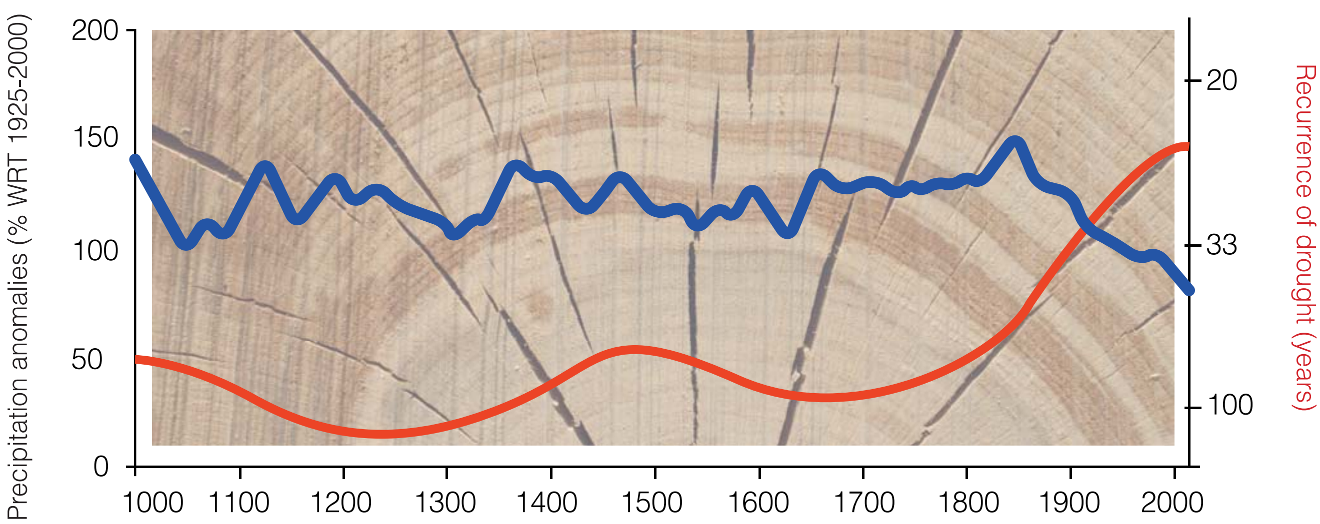
A look into the past

Annual tree-ring growth is an indicator of past precipitation in Central Chile, and shows that the current mega-drought is an exceptional event in the last 1,000 years.

Water availability directly affects annual tree-ring growth in certain tree species such as the conifer Austrocedrus chilensis (Chilean Cedar). Measurements taken on hundreds of Austrocedrus specimens growing in Valparaíso and O'Higgins Regions have made it possible to estimate annual rainfall in Central Chile over the last millennium.

This paleoclimate reconstruction reveals that conditions were wetter than the present during certain periods in the XII, XIV and XV centuries, as well as one particularly long wet period between 1650 and 1900. There were also dry spells during the initial and final periods of the millennium-long record, and also between the years 1300 and 1650.

The recurrence period of multi-annual droughts (such as the current one) is aproximately 100-year during most of these last 1,000 years, but their frequency increases sharply over the latter part of the historical period. The current mega-drought stands out as an extreme case within a general trend toward drier conditions, especially since the beginning of the twentieth century.



Multi-decade variations (blue curve) of precipitation in Central Chile (dendroclimatological reconstruction, 1000-2005 AD), expressed as precipitation anomalies compared to the 1925-2000 average (scale on the left). The red curve is an estimation of the return period (in years, scale on the right) of three-year droughts with rainfall deficits equal to or greater than 20%, compared to the 100 year-moving average. The reconstruction was carried out by Duncan Christie and Carlos Lequesne at Universidad Austral of Chile.

CAUSES

La Niña and the mega-drought

Although the La Niña climate phenomenon tends to produce a rainfall deficit in Central Chile, its effect on the current event has been less pronounced. The 2015 “El Niño” climate phenomenon has not been capable of reversing the situation.

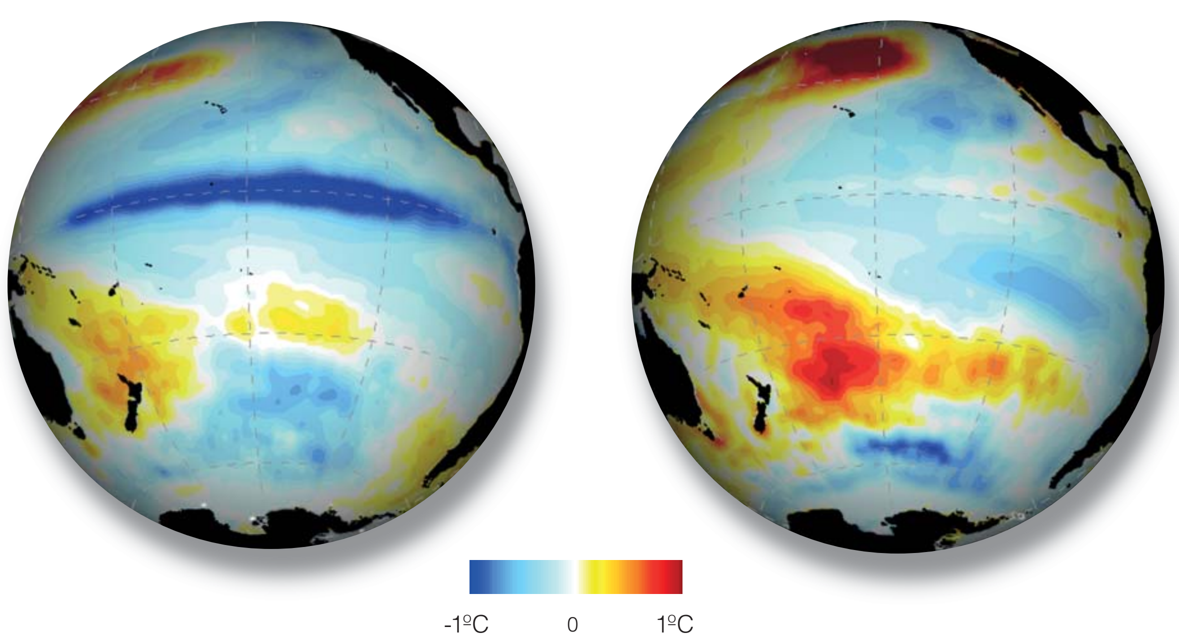
An important share of the year-to-year precipitation variability in Central Chile is modulated by the El Niño Southern Oscillation (ENSO) phenomenon. This is a natural phenomenon characterized by 1- to 2-year-long periods of temperatures colder than the long term average in the tropical Pacific Ocean (La Niña), which alternate with periods of warmer temperature (El Niño) every 3-7 years.

The alterations of the atmospheric circulation patterns during La Niña include a weakening of Westerly winds over South America and a more intense South Pacific Anticyclone, which lead to drier than average conditions in Central Chile. On the contrary, during El Niño rainfall increases over this region of the world.

The years that conform the mega-drought are characterized by neutral conditions over the Equatorial Pacific Ocean, without any significant cooling of the tropical Pacific, except for the year 2010 which is characterized as a La Niña year. Although 2015 has seen the development of an intense El Niño event with significant storms in the northern Chile, the precipitation deficit has continued in Central Chile.

Historically, the occurrence of neutral conditions may bring either rainfall deficits or surpluses in Central Chile. The random probability of seeing a sequence of five dry years, such as the present one, is extremely low, which suggests that other climate factors are contributing to the great duration and intensity of the mega-drought.

La Niña average **Mega-drought average**



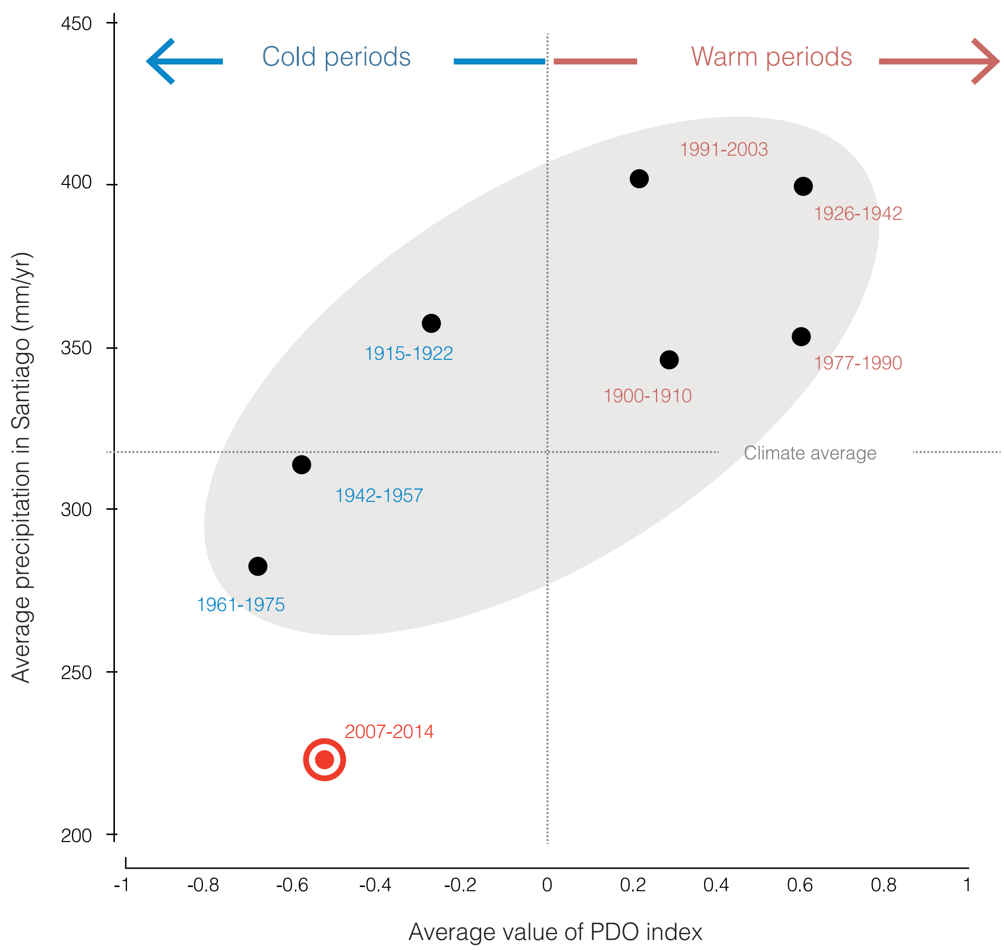
Anomalies (variations from average conditions) of the sea surface temperatures during a number of winters (May-September) under La Niña conditions (average of 1974, 1975, 1985, 1988, 1998, 1999, 2000) and during the mega-drought period (average of 2010-2014). Source: Earth System Research Laboratory, NOAA, USA (OISST product).

Decadal variability and mega-drought

The current cold phase of the Pacific Decadal Oscillation –another naturally-occurring global phenomenon- has helped to prolong the precipitation deficit, but it only accounts for about half of the intensity of the mega-drought.

A second factor that modulates precipitation in Central Chile is the Pacific Decadal Oscillation (PDO). The PDO is an ENSO-like natural mode, but its cold and warm phases tend to last for decades. Similar to what occurs during a La Niña year, the PDO's cold phases are characterized by intensification of the South Pacific anticyclone and a weakening of westerly winds, which together tend to produce relatively dry conditions in Central Chile.

In view of the average value (-0.5) of the PDO index from 2007 to 2014, one might expect a rainfall deficit of about 15% in Central Chile, which is considerably lower than the actual value (close to 30%). This discrepancy suggests that anthropogenic factors are contributing substantially to climate change, and are helping produce the marked and persistent water deficit observed in the current mega-drought.



The circles indicate average precipitation in Santiago (vertical axis) and the average value of the PDO index (horizontal axis) for each of the eight warm and cold periods of this oscillation identified since the beginning of the twentieth century. For example, from 1977 to 1990 the PDO experienced a warm phase, with an average index value of +0.6, and precipitation in Central Chile was about 15% over the average climatological value (calculated for the period 1970 - 2000). Source: Chilean Meteorological Office (precipitation) and Earth System Research Laboratory, NOAA, USA (PDO index).

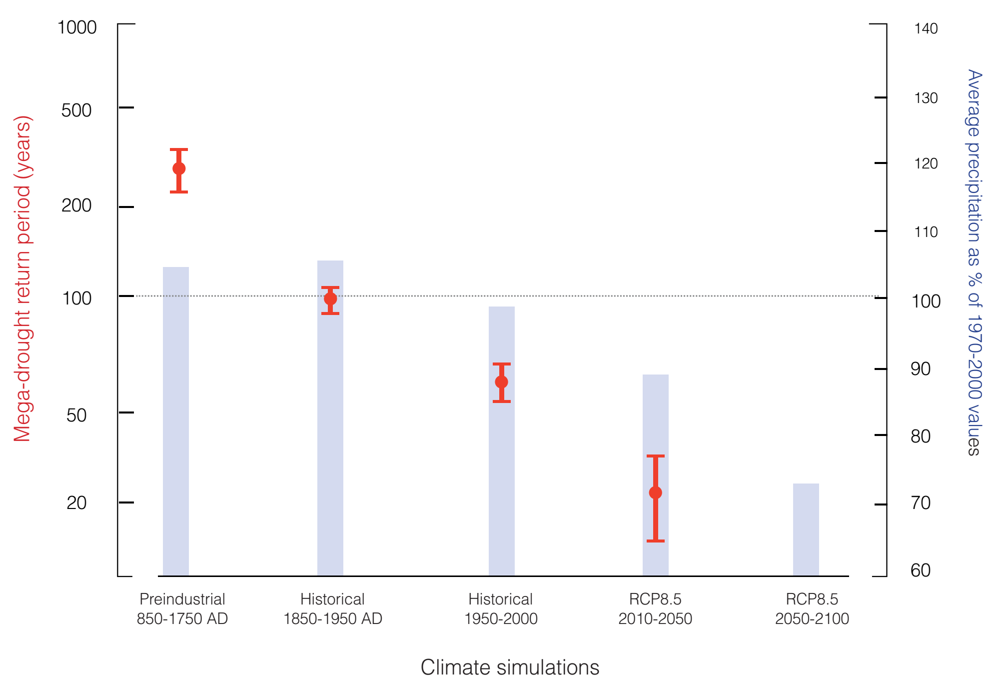
Effects of anthropogenic climate change

Approximately 25% of the precipitation deficit during the mega-drought can be attributed to anthropogenic climate change. This factor will continue in the future, favoring the occurrence of droughts like the current one and increasing the rate of aridification in central and southern Chile.

During the last four decades there has been a gradual displacement, towards the South, of the Westerly jet stream and the subtropical high-pressure belt. Climate models that take anthropogenic factors into account (such as the increase in greenhouse gas emissions (GGE) and decrease of stratospheric ozone) are capable of reproducing these displacements, and also predict that they will continue during the twenty-first century, if GGEs continue to rise. Consistent with this, the models predict a reduction of annual precipitation of up to 30% by the end of this century, compared to the current average for Central Chile.

In pre-industrial simulations (1850-1750 AD), in the absence of anthropogenic factors, mega-droughts occur every 300 years, on average. Historic simulations (1850-2005) take into account the observed increase in GGE. In these simulations, mega-droughts continue to be the exception (once every 100 years) until the mid-twentieth century, but their return period is halved in the second half of the century.

Simulations for the period 2010-2050, based on pessimistic GGE emissions scenarios, indicate the occurrence of mega-droughts every 20 years. As the twenty-first century advances, the definition of drought as a transitory condition becomes invalid, because there will be substantial and permanent decreases in annual precipitation. In other words, average conditions in the future could be similar to those of the current mega-drought.



Return period in years (scale on the left) of three-year or longer droughts (>30% of precipitation deficit in Central Chile), using seven climate models that simulate past, present and future climate conditions. The return period was calculated for each model. The red circles indicate the mean value, and the vertical lines represent standard deviation between models. The light-blue bars indicate the multi-model average precipitation, relative to the average for 1970-2000 (scale to the right). Source: Coupled Model Intercomparison Project (CMIP5-WCRP).

IMPACTS

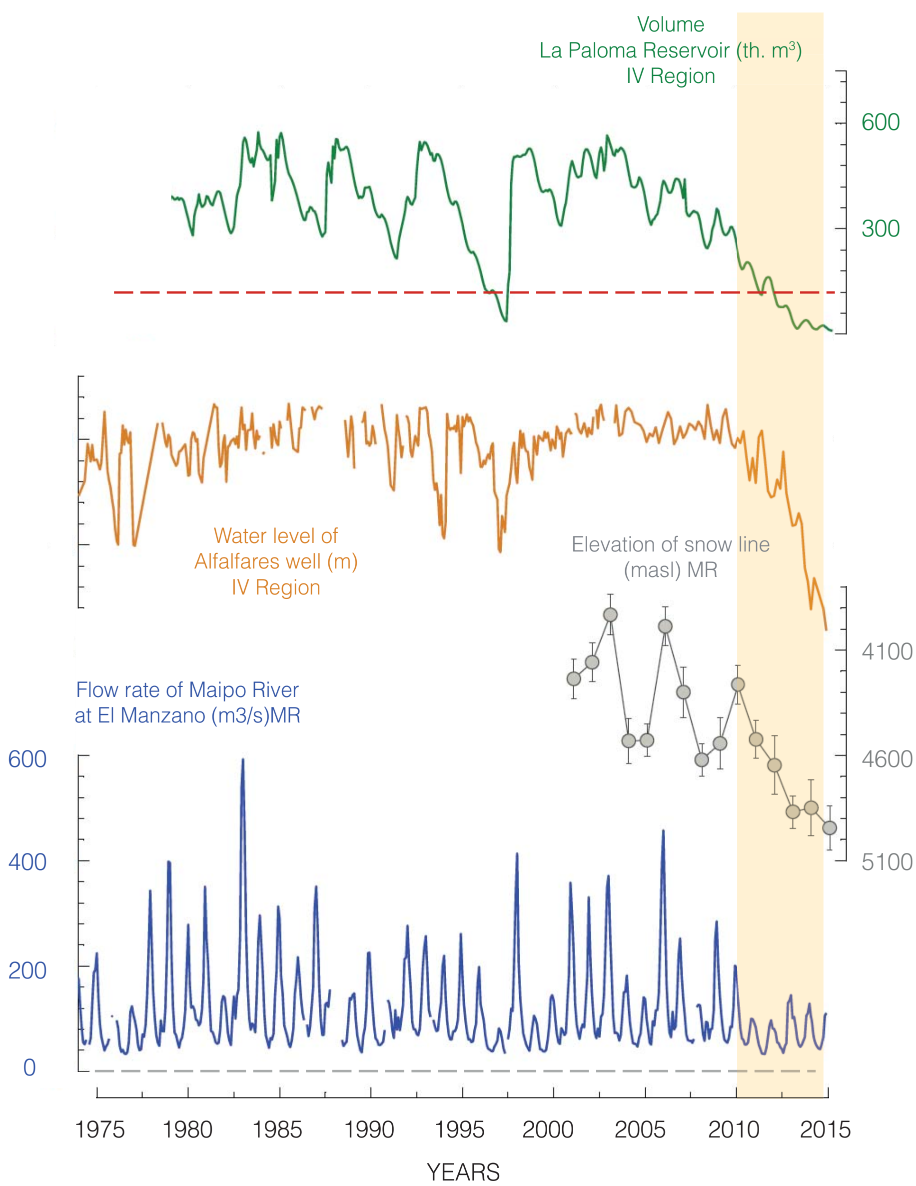
Impact on water resources

The amount of water flowing in the rivers of Central Chile has diminished as a direct result of precipitation deficit during the mega-drought. The effects of the drought are also evident in lakes, reservoirs, snow cover, and groundwater levels.

During the period 2010-2014, the average flow rate deficit in the rivers of Coquimbo and Valparaíso Regions was as high as 70%. Further South, the deficit gradually diminished down to values bordering 25%. The magnitude of this deficit is similar to the precipitation deficit in the Andean foothills, but it was even greater at the mouth of some rivers, as a result of higher consumption of water resources during the mega-drought.

The quantity of water stored in different reservoirs and hydrological systems has also dropped dramatically during the mega-drought. For example, the volume of La Paloma reservoir and the groundwater level of the Alfalfares well (a direct indicator of groundwater volume) have been at their historical lows for over three years. Both of these systems are located in Coquimbo Region and are used mostly for agricultural irrigation.

Similarly, during spring and summer in the Andean foothills of Central Chile the elevation of the snow-line has gradually increased, with an ensuing reduction of snow cover and a marked drop in maximum water flow rates from melting snow and ice.



Evolution in time of water volume stored in La Paloma reservoir (green line); groundwater level in Alfalfares monitoring well (orange line); elevation of snow line during January in Andean foothills near Santiago (gray line); and flow rates at Maipo River monitoring station at El Manzano. Monthly values (except for the snow line). Data on La Paloma reservoir by kind permission of Pablo Álvarez at Universidad de La Serena. Data on Alfalfares monitoring well and on flow rates: General Water Authority. Snow line data: National Snow and Ice Data Center, USA

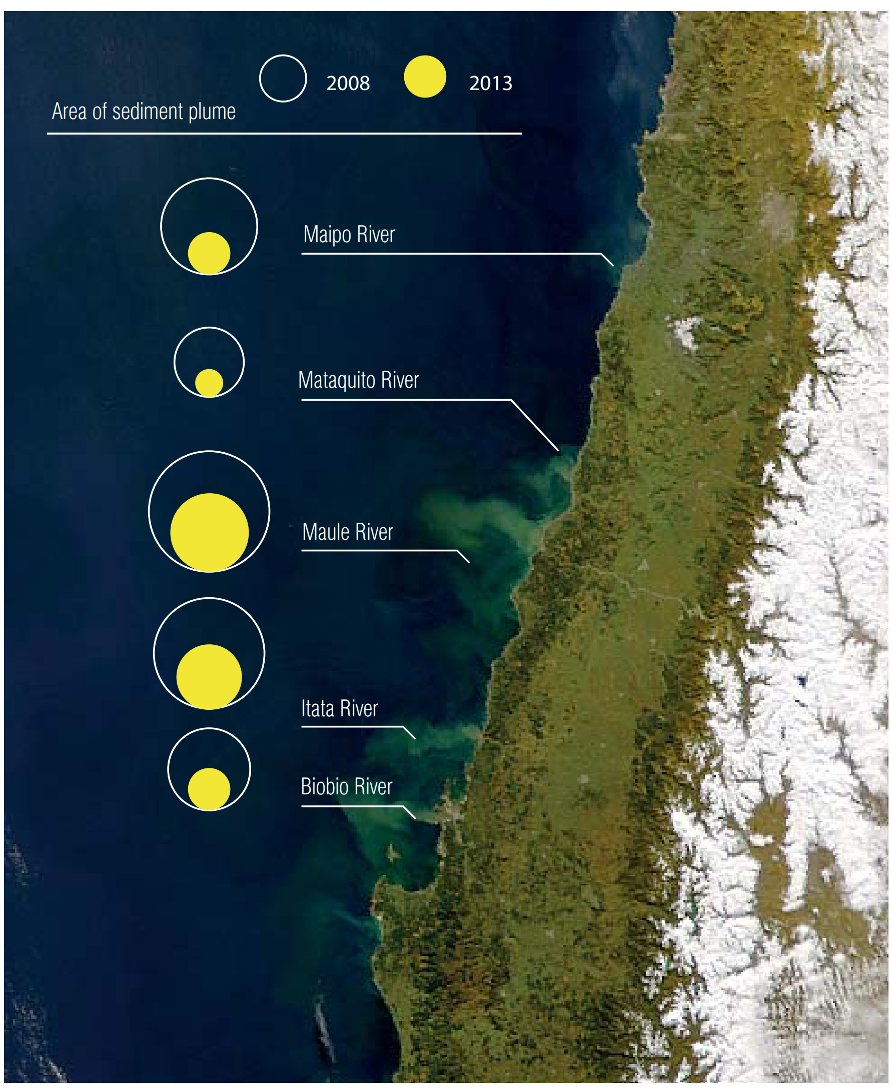
Impact on coastal resources

As a result of the lower flow rates observed in various rivers during the mega-drought, lower quantities of nutrients such as nitrates and phosphates reach the sea, directly affecting the ocean's bio-productivity along the coast.

In addition to lower flow rates of rivers in central and southern Chile (watersheds of the Maipo, Mataquito, Maule, Itata, and Biobio Rivers), we observe a direct consequence of lower water flow: a drop of 25% - 75% in the quantities of nutrients such as nitrates and phosphates discharged into the ocean during autumn and winter.

The discharge of nutrients and suspended solids from rivers into the ocean creates sediment plumes, whose shape, size and concentrations of surface nutrients depend directly on the volume of fresh water discharged into the ocean. The area covered by these river-mouth plumes has shrunk by up to 60% in Central Chile during the mega-drought, in comparison with the period 2000-2009. Additionally, the concentrations of photosynthesis-capable biomass (chlorophyll) have decreased.

The decrease in the chlorophyll levels correlates with lower nutrient concentrations. These nutrients are indispensable for phytoplankton growth (the first key link in the aquatic trophic chain), which in turn is essential during spawning, larval development and feeding of fish and crustaceans. Some of these fish species have great economic importance in Chile, for example anchovetas and sardines.



Satellite image (SeaWIFS, NASA) of ocean color, which is an indicator of sediment plumes created by the rivers of Central Chile. The size of the circles is proportional to the area covered by these plumes during a normal winter (2008) and during a winter of the mega-drought (2013).

Impact on vegetation

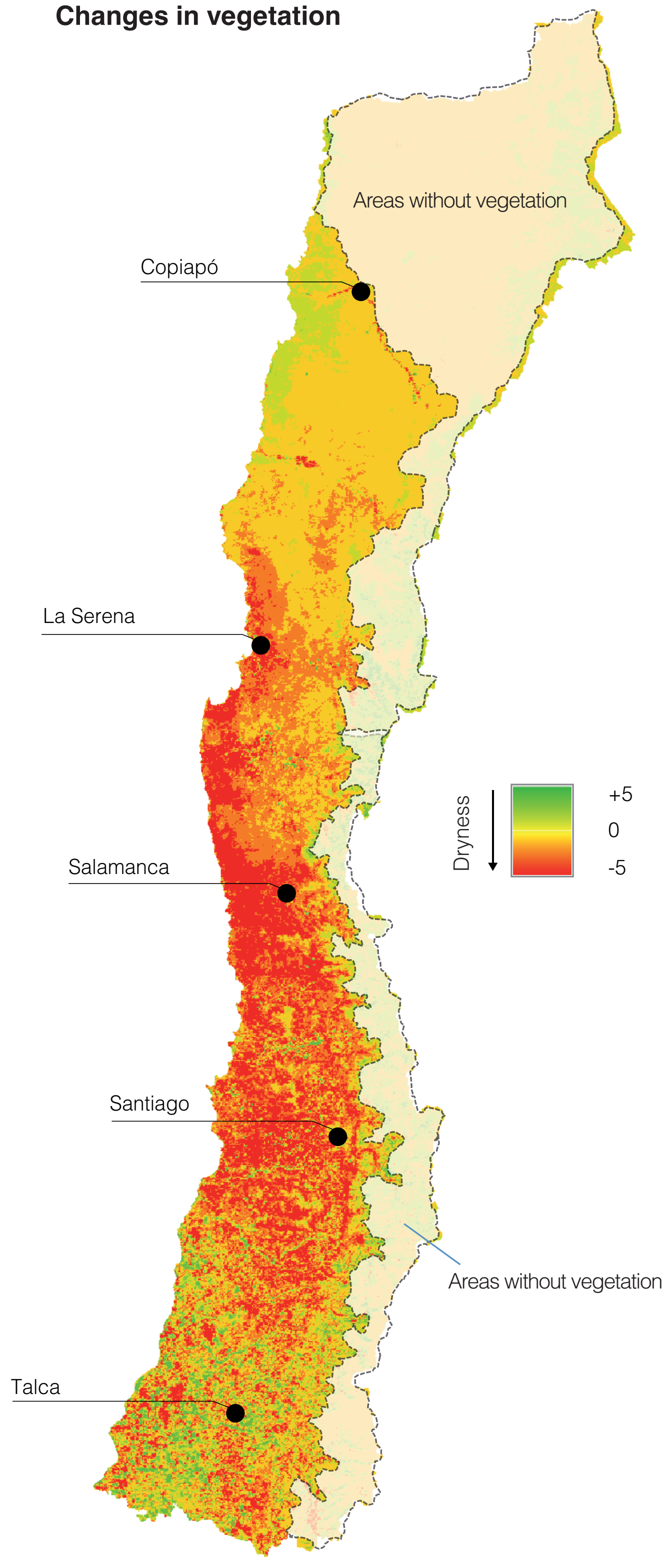
Although native vegetation and certain exotic species have adapted to short-lived, intense droughts, the persistence of the current mega-drought is starting to cause visible deterioration of non-irrigated vegetation in a vast part of Central Chile.

In order to cope with lower moisture levels in the soil during periods of drought, plants reduce evapotranspiration (water loss) by closing the stomata of leaves, but this in turn reduces the rate of photosynthesis and plant growth. If the drought persists, plants go into a state of water stress, interfering with the plant's metabolism and making it more prone to infections.

Satellite imagery shows a widespread and marked reduction in vegetation growth during the mega-drought (red color in the map), in comparison with the period 2000-2009, along coastal areas and interior valleys, all the way from Coquimbo Region to O'Higgins Region. Further south, evidence of the mega-drought is not so obvious because a large part of the territory is under irrigation, and the precipitation deficit has been offset by more intensive irrigation.

In trees, lower growth rates during periods of drought are reflected in the width of tree-rings. For example, the 1998 drought only had minor effects on tree-ring growth in the Nothofagus trees of Monte Oscuro, possibly because this species has adapted and can resist intense dry spells of short duration. In contrast, the effects of the mega-drought are evidenced by the gradual but substantial reduction of radial growth observed since 2008.

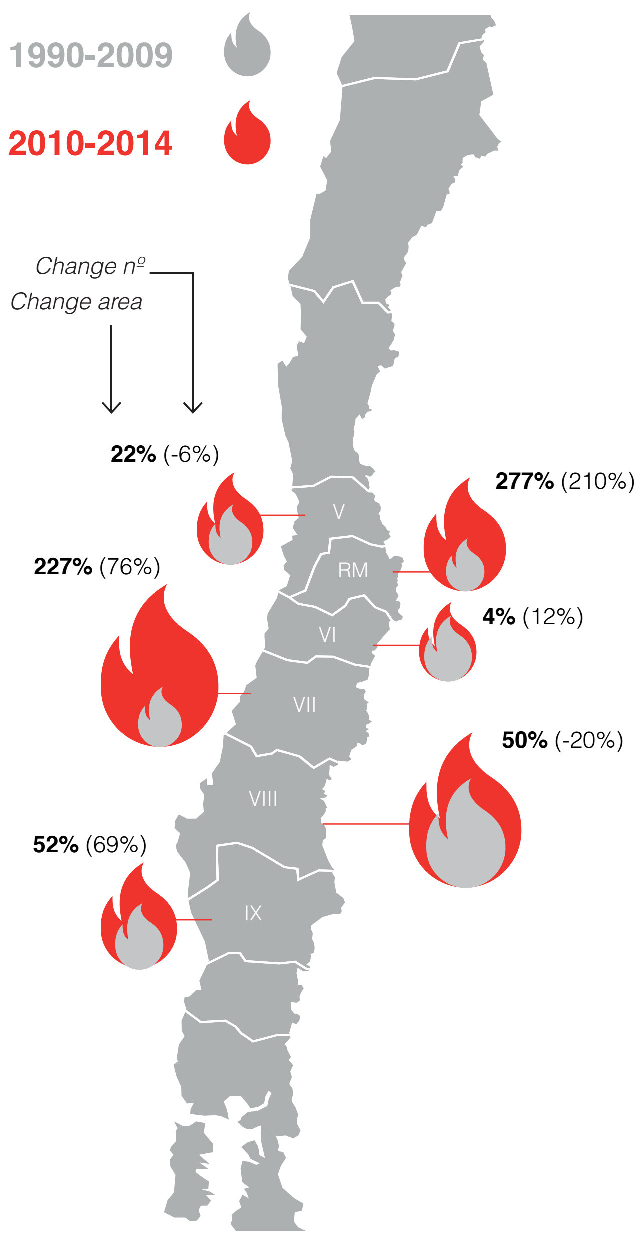
Changes in vegetation



Differences in the Enhanced Vegetation Index (EVI) during early spring (July-September) between the mega-drought period (2010-2014 average) and the previous decade (2000-2009 average). Source: The EVI is obtained by the MODIS sensor on board NASA's TERRA and AQUA satellites, USA. Kindness of David López, CEAZA.

Impact on forest fires

The area of forest destroyed by fire in central and southern Chile has increased 70% during the mega-drought, and the forest-fire season now lasts for the entire year. During each of the last two years, the affected area exceeded 100,000 hectares, which is unprecedented in the last 50 years.



The size of the flame symbols is proportional to the total area burnt annually by large forest fires (over 200 hectares) in each Region during the mega-drought (2010-2014, red symbols) and base period (2000-2009, gray symbols). The numbers indicate the percent increase in burnt area. Shown in parenthesis is the percent increase in number of large fires during 2010-2014 and 2000-2009. Forest fire statistics provided by National Forestry Corporation.

During the current mega-drought, the number of large-scale forest fires (more than 200 hectares) from Valparaíso to La Araucanía Regions has increased 27% compared to the historical average. The area destroyed by fire has increased even more dramatically (69%). This is because some of these fires covered very large areas during the mega-drought, which is consistent with the inverse relationship between rainfall and the size of burnt area.

The increase in forest fires has been especially acute in the Metropolitan and El Maule Regions, and has affected forestry plantations mainly (20,000 hectares per year), which is equivalent to 34% of the total burnt area. Another impact of the mega-drought is the constant lengthening of the forest fire season. Traditionally, the fire season would begin in late September and last until mid-May of the following year. During the last decade, the forest fire season has expanded to cover the entire 12 months of the year (from July 1st to June 30th of the following year). In each year of the current mega-drought (2010-2014), there have been 53 additional days per year during which large forest fires have raged, compared to the period 1985-2009. These fires have accounted for more than 70% of the total area affected during the current drought.

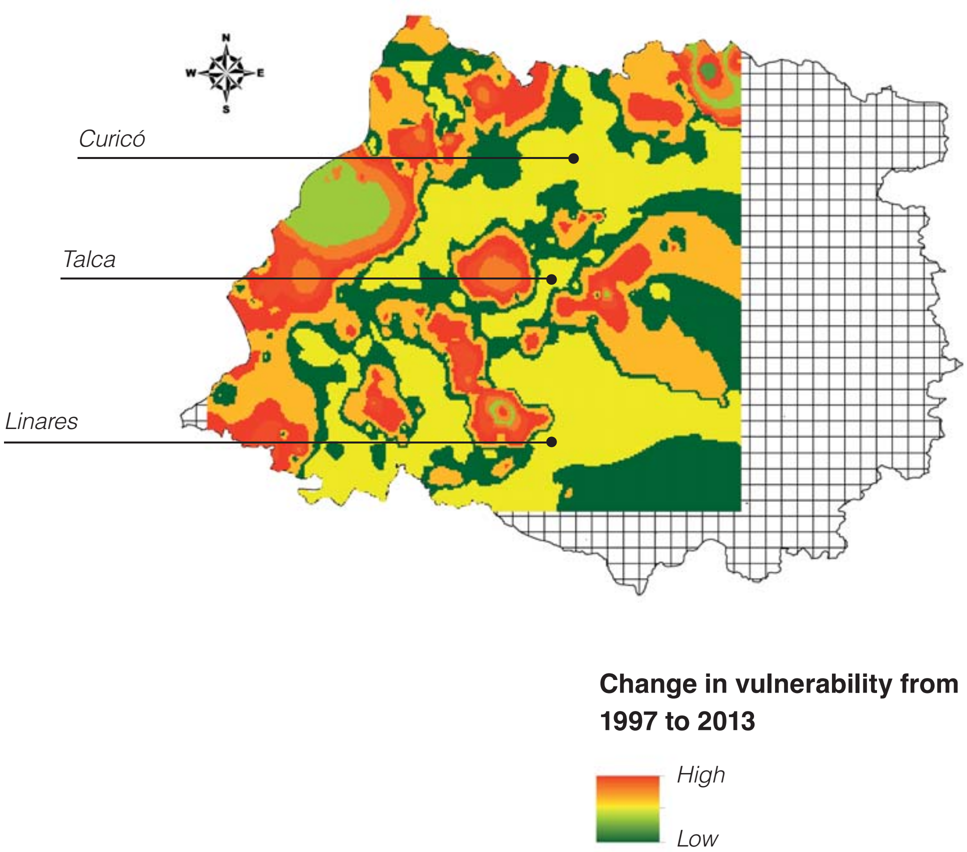
Vulnerability in the face of the drought

In order to implement mitigation and/or repair measures to deal with the negative impacts of the mega-drought or similar events, instruments are needed that will make it possible to adequately focus these measures on the most vulnerable areas and population sectors.

The impact of the mega-drought on the vulnerability of any socio-ecosystem depends on the magnitude of drought conditions (variations in temperatures and precipitation), the system's sensitivity to such exposures (in terms of changes in water flow rates and key eco-systemic services), and the system's capacity to resist and adapt. By evaluating these three components, we have determined the vulnerability of the Maule Region in the face of climate change. This is a highly-exposed, land-locked area, which has seen dramatic changes in land use and a high concentration of small-scale, family agricultural operations (AFC). Shown here is the case of food production such as potato, wheat and maize for the period 1997 - 2013. Degree of exposure is represented as the water deficit (or surplus) compared to average precipitation over the last 30 years. The vulnerability of the food supply (as a basic eco-systemic service) was estimated as the loss of biomass and of crop yields AFC, under rain-fed agricultural conditions.

The socio-ecosystem's capacity to adapt was estimated as the result of the interaction of economic variables (for example, presence and availability of substitutes to the socio-ecosystem in question, and degree of automation), social variables (for example, average educational), and institutional variables (for example, existence of networks such as irrigation monitoring boards).

The preliminary results obtained using this instrument, indicate that in 2013 in the Maule Region, the mega-drought has increased the Region's vulnerability compared to 1997. The analysis period was determined by the availability of socioeconomic data from the past censuses. Adaptive capacity is insufficient to reverse the effects of the exposure levels, or to lessen the vulnerability of the socio-ecosystem. The use of this instrument makes it possible to focus mitigation measures, taking into account the physical and social factors.

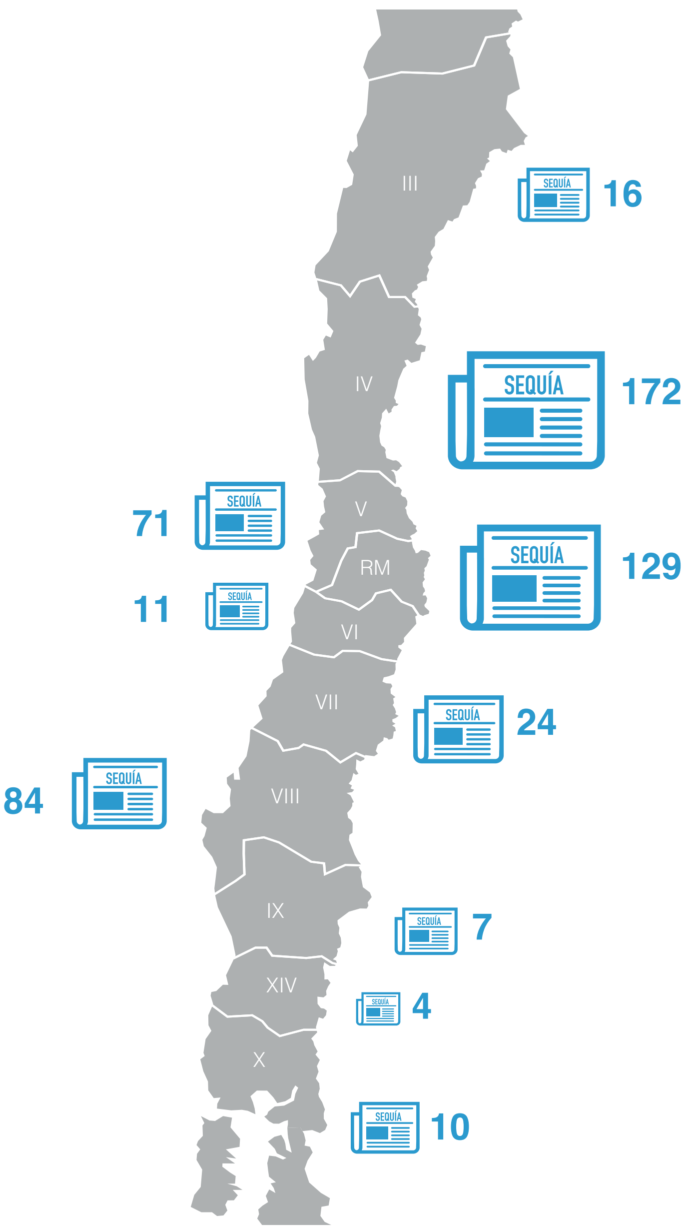


Change in overall vulnerability in the face of drought from 1997 - 2013 in terms of food supply in Maule Region. Values have been standardized with regard to the highest value. No data available for the cross-hatched areas.

RESPONSES

People's perception of the mega-drought

The population perceives the precipitation deficit in Chile's south-central zone as a phenomenon that affects their daily lives. In those regions subject to acute water shortage conditions, the news media repeatedly mention the drought.



According to surveys conducted as part of a pilot study in the districts of Paine and La Pintana in the Metropolitan Region, all of the respondees are aware that Chile is facing a period of drought. As for the main impact of the drought on their daily activities, they mentioned the following: smaller crops, lost crops, lack of surface water for irrigation, disappearance of swimming and fishing areas, and even confrontations over water use.

When asked about the cause of the drought, they offer a broad range of explanations: it's a normal climate event; it's part of natural climate cycles; it is due to anthropogenic factors; greater water demand due to human activities.

Concerns about the drought are reflected in the news media. A nation-wide study of the number of mentions of the concept "drought" in the printed press indicated that 554 news items were published in 2014 dealing directly with the drought or water shortage conditions. Most of these items were published in Coquimbo, Metropolitan and Biobío Regions, which is the geographical area most affected by this climate phenomenon. The highest number of printed media mentioning the drought corresponds to Coquimbo Region, while in O'Higgins and El Maule Regions the number is lower.

The size of the symbols is proportional to the number of mentions of the concept "drought" in print news media in each Region during 2014. These numbers are indicated for each Region. Data provided by Litoral Press.

Response of civil society

Civil society has responded to the mega-drought through different practices, instruments and strategies, either locally or at the national level. In most cases, the drought is interpreted as an extraordinary occurrence.

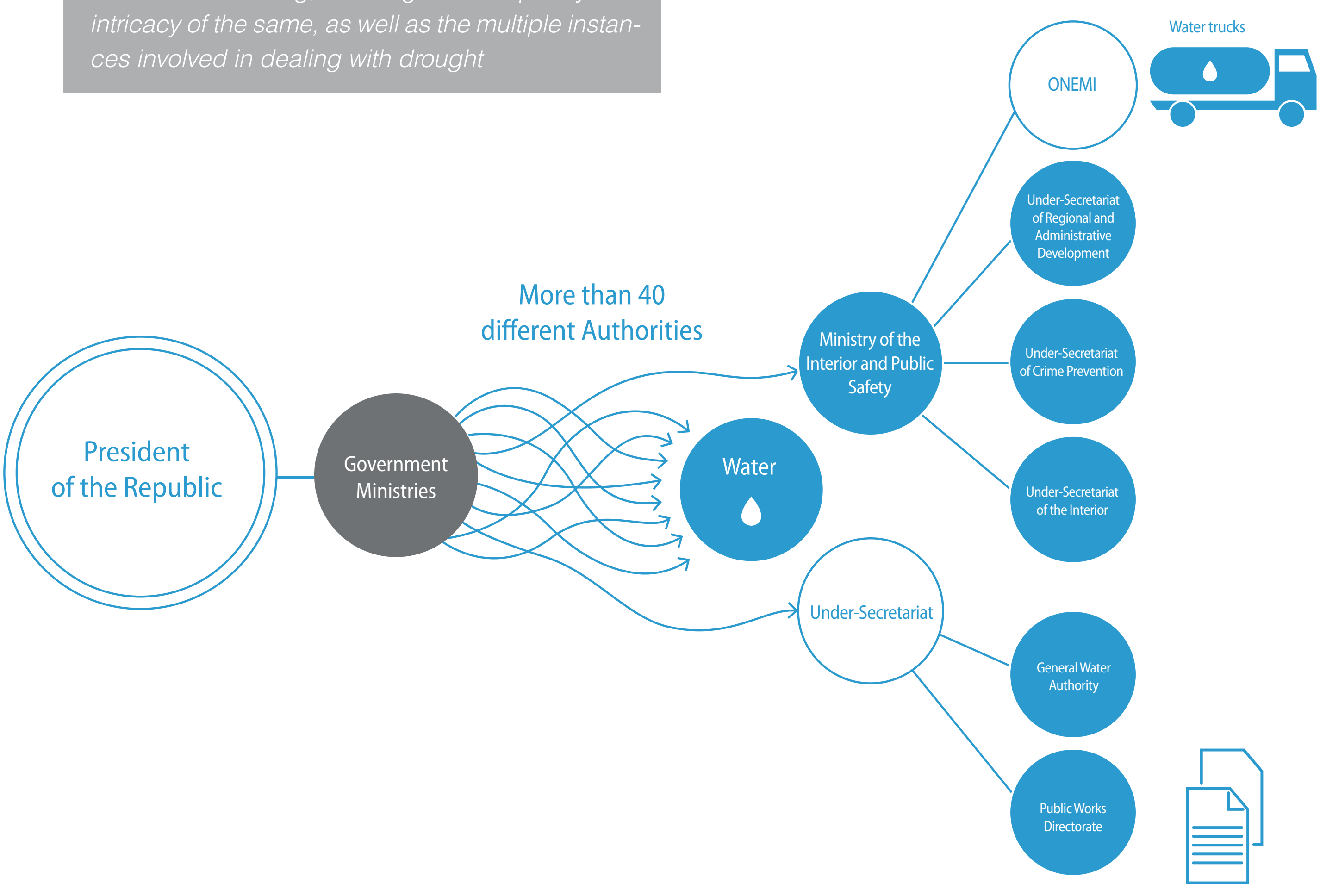
We have identified 148 different practices for dealing with the prolonged water deficit in central and southern Chile. About 50% of these practices were executed by government agencies, 29% by the private or productive sectors, and 21% were applied by civil society. These three groups usually act independently of each other, though in some cases they do coordinate their actions.

Forestry and agriculture account for more than a third of the initiatives taken in order to deal with this mega-drought. In second place - 20% - of the strategies against drought are from the sanitation services sector, which is responsible for ensuring drinking water supplies for the population. A smaller number of practices deal with the building of resilience: for example, only 6% have to do with technology transfer to increase efficiency in water use.

The different measures undertaken cover a broad spectrum of actions or works. Civil engineering works and infrastructure are the most frequent, followed by agricultural subsidies. In the public sector, the Office of the President of the Republic acts by designating a Presidential Delegate for Water Resources, while the General Water Authority issues Water Shortage Declarations at the regional level or for specific watersheds. Municipal governments try to mitigate the effects of the mega-drought by renting water trucks o increasing emergency deliveries of drinking water. The private sector and civil society tend to make plans at the local level, with practices such as deepening water wells, increasing automation, adopting new technologies, building irrigation infrastructure, or organizing seminars on water conservation.

This great diversity of actors and decision-making levels, along with the absence of a framework designed to coordinate the use of water resources, may possibly be affecting the effectiveness of these practices and making them more expensive for all.

Conceptual diagram of governmental measures and decision-taking, showing the complexity and intricacy of the same, as well as the multiple instances involved in dealing with drought



Drought and water legislation

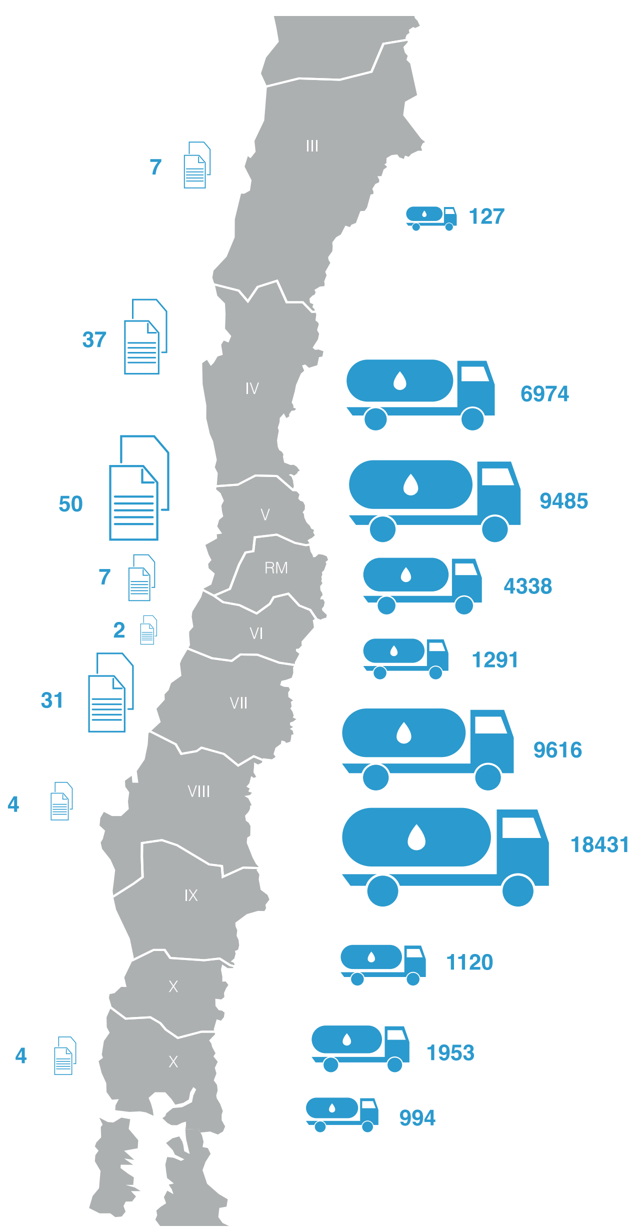
Existing water legislation seeks to ensure water supplies for productive activities and for human consumption, but these laws assume that droughts are extraordinary events.

All of Chile's Water Codes (1951, 1967 and 1981) have conferred special powers to government agencies for dealing with ordinary or extraordinary water shortages (drought). In the case of ordinary water shortages, the laws seek to preserve water resources as well as the corresponding legal certainties. In the case of drought, the aim is to ensure water supplies by means of Decrees dealing with water shortage conditions. For example, the laws empower the General Water Authority (DGA) to redistribute water, to suspend the powers of irrigation monitoring boards, to divide natural water courses, and to authorize extraction of groundwater and/or surface water without granting permanent water rights or taking into account any minimum ecological flows. No thought is given to ensuring efficient use of the water.

The above faculties and procedures have remained unchanged over time, in spite of the changing paradigms that have nuanced the various water codes. In fact, both the 1967 Water Code (which was more favorable to the State) and the 1981 Water Code (more favorable to the private sector) consider drought as an extraordinary occurrence, and deal with it in similar ways. Present-day debate about reforming the legal and the constitutional water regime also fails to consider drought as a recurring or long-lasting condition.

Declarations of Water Shortage (drought) account for 74% of all the legal instruments used by the DGA during the period 2008-2014 to safeguard the water resources. The Coquimbo, Valparaiso, El Maule, and Metropolitan Regions account for 86% of cases of application of such instruments by the DGA.

These same regions also absorb the largest share of expenditures in water distribution by means of water trucks by ONEMI (National Emergencies Office). These expenditures have grown three-fold from 2011 to 2014.



The symbols on the left of the map are proportional to the number of Decrees of Water Shortage issued by the General Water Authority (DGA) between 2010 and 2015. The symbols on the right side are proportional to the expenditures made by National Emergencies Office (ONEMI) on water and on water trucks between 2011 and 2014 (in millions of pesos). Source: DGA and ONEMI, respectively.

CONCLUSIONS AND RECOMMENDATIONS

This report deals with the causes and consequences of the widespread, protracted and warm drought we have been experiencing in many parts of Chile since 2010, as well as some responses and practices adopted to deal with this phenomenon. Based on the above, our conclusions are:

• Due to its great duration and the size of the affected areas, the mega-drought affecting Chile's most populated areas is an extraordinary phenomenon, which is unprecedented in historical and/or instrumentally recorded logs or paleo-climate records covering the last 1000 years.
• More than half of the precipitation deficit experienced during the mega-drought is the result of naturally-occurring climate factors that vary over time. However, anthropogenic climate change is responsible for at least 25% of the current water deficit, and this percentage is expected to rise in the future.
• The impact on water resources and many ecosystems has been substantial, including groundwater recharge rates, river flow rates, coastal area climate conditions, multiplication of forest fires, and decreasing vegetation cover. They are simply a few examples of the multiple mutually-dependent effects of the drought on our watersheds and socio-ecosystems.
• The answers and responses given by the State, the private sector and civil society are all based on the assumption that the mega-drought is a transient event, like the droughts our country has experienced in the past. Additionally, the great number of different government agencies having jurisdiction over water resources makes coordinated action extremely cumbersome and slow, as well as sub-optimal in social and economic terms.

The future will be drier and warmer, with conditions unparalleled in the last millennium. At the same time, society is becoming ever more complex and demanding. Our country will have to seek and try innovative solutions that transcend administrative limits and divisions, or the particular interests of one or another sector. Solutions will need to involve many different actors and stakeholders as well as a variety of scientific, economic and social disciplines. The great engineering projects that once facilitated agricultural development will now have to be designed under different assumptions, in order to address changing climatic and social scenarios in a highly urbanized country.

There are no magic solutions capable of conjuring up new water resources without triggering economic, environmental or social repercussions. We will not be able to continue using and consuming water at the rate and in the manner we have in the past. New structural changes will have to be regularly evaluated by the whole of society, and this will have to be done in a participatory way, particularly at the local level, so that obstacles and deficiencies may be identified. Traditional knowledge will have to be recovered and socialized. Similarly, adapting to a changing climate will require us to comprehensively assess our country's vulnerability, considering the exposure level, the susceptibility and the adaptive capacity of our socio-ecosystems. And this, in turn, will require better scientific and social knowledge as well as the strengthening of social networks.

It will be important to create an administrative entity charged with coordinating the work of the different institutions having jurisdiction over our water resources both at the national scale and at the scale of each watershed. This entity must be capable of deepening Chile's adaptive capacity and creating awareness about the limited nature of our water resources. Similarly, the Water Code will have to be reformed, putting in first place the basic human right to access and consume water, and also ensuring adequate preservation of the environment. Both these factors are essential for sustainable development. Our knowledge and understanding of Chile's principal fresh water reservoirs - glaciers and groundwater – has gradually improved over time, but this understanding urgently needs to be deepened, strengthened, and shared. We need to improve our capacity to acquire and process quantitative data in a timely, participative and transparent manner, so that effective policies may be designed and implemented. These reservoirs are part of complex hydrographic watersheds that are subject to change, alterations and demands that need to be properly quantified. Monitoring of local and global climate conditions must be conducted in a systematic manner, and medium- and long-term climate projections must be regularly reviewed.

An artist's rendering of simulated precipitation trends
during the last three decades in Chile.
(Period: 1981-2020)

Data obtained by means of the
CESM1 and CAM5 predictive models.

Artist: Tully Satre (www.tullysatre.com)

Chile's most populated areas must start adapting immediately to a future of drier and warmer climate conditions. Climate projections consistently indicate that in a few decades, the normal climate will be similar to the conditions we have experienced over the last five years, and that the current imbalance between fresh water supply and demand will also affect other regions further south. Chile must take immediate action to face the future. It's up to us to learn the lessons of the mega-drought in time.

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The results presented in this report were obtained through interdisciplinary work carried out at the Center for Climate and Resilience Research (CR2). The electronic version of this document and other additional material are available from the website www.cr2.cl/megasequia. (CR)2 is a center of excellence funded by CONICYT's FONDAP programme (Project 15110009), which brings together some 60 scientists from Universidad de Chile, Universidad de Concepción, and Universidad Austral de Chile.

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