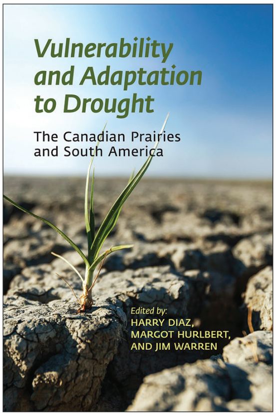

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PART 6

LEARNING FROM OTHER EXPERIENCES

CHAPTER 13

DROUGHT RISKS AND OPPORTUNITIES IN THE CHILEAN GRAPE AND WINE INDUSTRY: A CASE STUDY OF THE MAULE REGION

Monica Hadarits, Paula Santibáñez, and Jeremy Pittman

Introduction

This chapter focuses on the vulnerability of an agricultural system in Chile and offers potential lessons learned that could apply to Canadian agriculture. Although many differences exist between Canada and Chile, there are similarities at a regional scale between the Canadian Prairies and the Maule region in Chile. Water supplies for irrigation in both countries, for example, are mostly derived from snowmelt in the mountains (the Rockies and the Andes, respectively). Similarities also exist in governance structures in that a private-sector marketing system exists in both countries, whereby producers market their own products. In Canada, this open market, for grain in particular, is a result of very recent policy changes. In the past, producers marketed some grains, wheat, and barley collaboratively on the global market; now they have the option of marketing their product independently. This marketing change, along with other projected changes (e.g., climate, social), may create new risks and opportunities for Canadian producers. The viticulture sector in Chile's Maule region may offer some lessons based on the experiences of Chilean producers.

Climate change poses challenges and opportunities for the agriculture sector, including viticulture (Hadarits et al. 2010; Belliveau et al. 2006; White et al. 2006). Viticulture is particularly sensitive to climate change because small fluctuations in temperature and rainfall can significantly influence wine quality and quantity (Gladstones 2011). In addition, wine grapes (*Vitis vinifera*) are perennial plants, representing a long-term investment for producers of at least several decades, over which the climate is projected to change beyond the optimal range of growing conditions in many regions (Hannah et al. 2013; Jones et al. 2005). The wine industry is growing rapidly in Chile—the number of hectares planted in vinifera grapes almost doubled from 1991 to 2011 (ODEPA 2013). During this same time period, wine production increased by 500%. Wine exports are important to Chile's economy, contributing over US$1.4 billion in 2012 (ODEPA 2013; Vinos de Chile 2012). However, a recent study by Hannah et al. (2013) concluded that mean climatic suitability for viticulture in Chile may decrease by up to 25% and available water discharge may decrease 20%–30% by 2050. Future projected decreases in precipitation will also result in an increasing need for irrigation (Hannah et al. 2013). These projected changes have serious economic and cultural implications, especially when coupled with changes in social and economic conditions (e.g., labour laws, consumer preferences, fluctuations in global markets).

This chapter describes drought-related vulnerabilities for the wine industry in Chile using a case study of the Maule region. It begins with a discussion of the conceptual framework and rationale guiding the work, followed by a description of the study site. It then documents the main findings, discusses some potential lessons learned that may be applicable to Canada, and concludes with a summary of the chapter's main points.

Conceptual Framework and Rationale

Climate Change and Viticulture

The wine industry has observed changes in vine development and fruit maturation in recent years; for example, budbreak, flowering, and fruit maturity have occurred earlier in the growing season in Germany, France, and California (Mira de Orduña 2010: 1844). There is growing concern about the viability of the industry in some well-established wine-producing regions, and as a result, there is a growing body of scholarship investigating the implications of climate change on viticulture and viniculture (Jones and Goodrich 2008; Webb et al. 2008; White et al. 2006; Jones et al. 2005). Holland and Smit (2010) suggest this scholarship falls into four broad categories: i) climate change impacts on wine quality; ii) climate change impacts on grapevine phenology and yield; iii) viticultural suitability and terroir in a changing climate; and iv) the adaptive capacity of the wine industry to climate change.

Much attention has been given to the first three categories, where most of the work has focused on modelling future climate change and assessing the impacts of these changes using phenological and physiological models (Stock et al. 2005). Some research has complemented this work by modelling and estimating the economic impacts on the industry (Webb et al. 2008). Although many studies recognize the need to understand the capacity of the wine industry to adapt to climate change, few studies have explicitly addressed the role of human adaptation in this context (Hadarits et al. 2010; Holland and Smit 2010; Belliveau et al. 2006).

Vulnerability Assessments in Agriculture

Vulnerability assessments have been used successfully to understand how an agricultural system experiences and manages climate and non-climatic risks and opportunities. These assessments have provided invaluable insights from the perspective of producers into current risks and opportunities for their operations, the range of adaptive strategies they draw from, the forces affecting their adaptive capacity, and how climate change may affect them in the future (Hadarits et al. 2010; Young et al. 2010; Reid et al. 2007; Belliveau et al. 2006).

This research adopted a community-based vulnerability approach, where vulnerability is conceptualized as a function of a system's exposure-sensitivity and adaptive capacity (Smit and Wandel 2006). For a more detailed description of these concepts, please refer to Chapter 1. The empirical application of this approach requires the actors within the system itself (e.g., grape growers, wine producers) to identify the relevant exposure-sensitivities and adaptive capacity contributing to their vulnerabilities (Smit and Wandel 2006). Actors are typically engaged through participatory methods such as interviews and focus groups. Moreover, the assessment of current exposure-sensitivities and adaptive capacity provides a lens through which future vulnerabilities to climate change can be understood (Ford and Smit 2004). Qualitative information about current vulnerability can be combined with quantitative output from climate and agricultural production models (e.g., Hannah et al. 2013; Lereboullet et al. 2013; Jones et al. 2005) to provide a more holistic view of future vulnerability.

Integrating the modelling work (described above) with adaptation research is a new approach in the climate change and viticulture field to understand climate change impacts and the adaptive capacity of the wine industry to deal with these impacts in a more holistic manner (e.g., Lereboullet et al. 2013). This chapter integrates the modelling approach with a community-based vulnerability assessment.

Description of the Maule Region, Chile

The Maule region is located in central Chile and spans an area of more than 30,000 km^2 (Figure 1). Maule is the largest wine-producing region in the country, containing the most hectares planted of any region in the country. It also accounts for half of the country's wine production, most of which is exported. Most of the region's soils are loam and loamy clay; near the coast the soils are less fertile than the central valley and eastern foothills. As such, most wine grapes are grown in the central valley.

Approximately 1 million people live in Maule, of which 5,000 are involved with growing wine grapes. Grape-growing operations range in scale from large multinational corporations to very small producers. Vineyards exhibit highly varied degrees of capital investment and agronomic expertise, and range in size from 6 ha to over 2,000 ha. Many growers have invested in wineries, either independently or through co-operatives.

With over 55,000 ha of vineyards planted in 35 *Vitis vinifera* varieties, including Chardonnay, Sauvignon Blanc, Cabernet Sauvignon, Merlot, Carmenère, and Syrah, the region produces almost 400 million litres of wine per year (SAG 2012a, 2012b). Tender fruits are also commonly grown in Maule, including cherries, plums, kiwis, apples, table grapes, blueberries, and raspberries. Many wine grape growers also engage in other

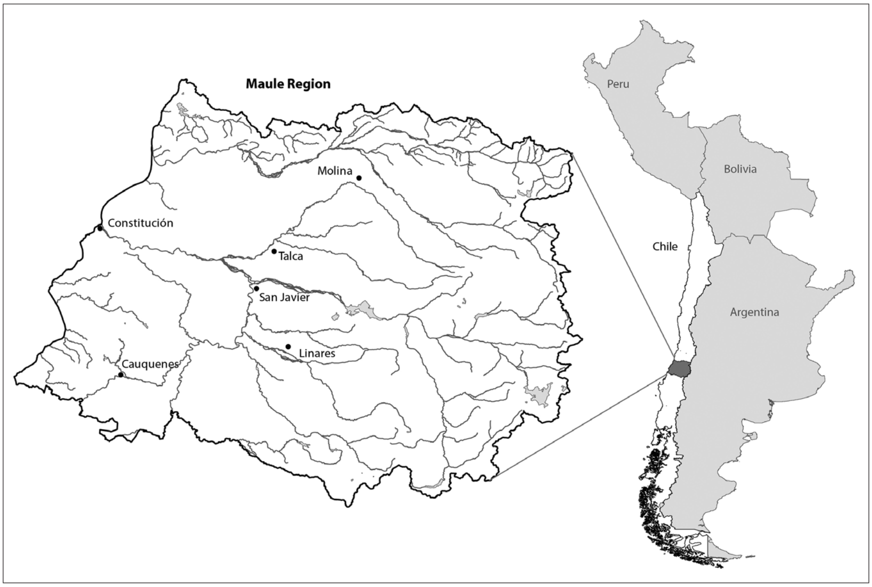

Figure 1. Map of the Maule region, Chile

tender fruit production. Besides viticulture and viniculture, silviculture is also an important economic driver in the region.

The Mediterranean climate in the valley is characterized by heavy winter rains and a long dry period beginning in spring (November) and ending in summer (March), creating ideal growing conditions for wine grapes (Vinos de Chile 2010). The dry period facilitates excellent grape maturation, and since rain during harvest is rare, quality remains relatively consistent from year to year. The sharp contrast between maximum and minimum daily temperatures supports preferred vine development and fruit maturation (Vinos de Chile 2010).

Many of the vineyards in Maule are irrigated by either flood or drip systems. Their primary source of water is derived from snow and glacier melt in the Andes Mountains, which feed the Maule, Lontuè, and Teno Rivers. Water is supplied via canals to agricultural producers (Díaz 2007). In Chile, water rights are held separately from property rights. Under the 1981 Water Code, water rights can be obtained from the government, but once rights are fully allocated, transfers take place through the market (Corkal et al. 2006). Although rights are formally specified according to an allocated volume (e.g., litres per second), in practice rights tend to be expressed as a portion of flow or shares of canals (Bauer 1997). In many regions where water resources are scarce, water rights have a high economic value and can therefore be very expensive to purchase (Gómez-Lobo and Paredes 2001).

Methods

Interviews

A multi-method approach was adopted for this work. Seven semi-structured key informant interviews were conducted in Maule between April and August 2008 to provide context for the research. Key informants were purposefully selected based on their experience and knowledge of the wine industry and included oenologists and governance representatives. Building on the key informant interviews, 46 in-depth semi-structured interviews with grape growers and wine producers were conducted. Interviewees were selected using a purposive, snowball sampling technique. Three key collaborators provided short lists of potential interviewees, all of whom were contacted for interviews, and each person interviewed was asked to provide additional contacts. The interview guide was structured around the vulnerability approach, with exposure-sensitivity and adaptive capacity as the main themes. Interviewees were asked categorical questions describing the characteristics of their operation. They were also asked open-ended questions about recent and current risks and opportunities for their operations, management strategies to reduce risks and capitalize on opportunities (current vulnerability), and about potential future vulnerabilities (see Hadarits et al. 2010). The interviews were complemented by secondary sources to provide additional context and verify the information provided by interviewees. In total, 13 grape growers, 31 grape and wine producers, and 2 wine producers were interviewed. This cross-section of individuals involved in the wine industry helped to provide insights into the vulnerabilities across different production systems. Summary statistics for the sample are listed in Table 1.

Table 1. Summary statistics for interviewees

	Mean	Median	Mode	Range
Vineyard size (ha)	29.3	107.5	150	5–2,000
Winery size (litres)	3,420,037	1,280,000	1,500,000	6,000–18,000,000
Produce other crops?	Yes: 48% No: 52%			

Climate Change Scenarios

To assess future exposure-sensitivity, climate change scenarios were generated using weather station data and regional climate change models. The baseline (1980–2010) was established by compiling meteorological data obtained from the Chilean National Meteorological Institute and various public and private organizations. This information was supplemented with data provided by the *Agroclimatic Atlas of Chile* (Santibáñez and Uribe 1993: 66); however, the reference period was updated for this study. This atlas contains cartographic information with a spatial resolution of 1 km. The digital version of this cartographic set is available at the Center on Agriculture and Environment website (AGRIMED, Universidad de Chile; http://www.agrimed.cl). For the future climate scenarios, the PRECIS (Providing Regional Climates for Impacts Studies) dynamic downscaling model was applied to the 2050 climate period and A2 scenario (http://www.ipcc.ch/ipccreports/sres/emission/index.php?idp=94).

SIMulator of PROCedures (SIMPROC) Modelling

The SIMulator of PROCedures (SIMPROC) model was used in this study to assess the climate change scenarios and their impacts on wine grape behaviour. The SIMPROC model is a climatic crop simulator that helps identify important changes in agricultural production (MMA 2010; CONAMA 2008; Santibáñez 2001). The model considers weather variables as well as key variables associated with the production system in question to simulate potential crop yields. Gross photosynthesis, potential dry matter production (Penning de Vries and Van Laar 1982), and maintenance respiration (Van Keulen and Wolf 1986: 479; Ludwig et al. 1965) are all incorporated into the model. There is also a subroutine to simulate the water balance of the soil-plant system, and the user can fix a criterion for irrigation watering and consider the efficiency of water applied. The water deficit is represented through a production function, the growth phase and the process of senescence, when soil water content falls below a critical threshold.

For this study, red and white varieties were evaluated separately, as their optimum growing conditions differ greatly. For example, optimum temperatures for photosynthesis in red wine grape varieties range from 22°C to 30°C (Schneider 1989). High temperatures during bud development stimulate fruitfulness (Baldwin 1964), and optimum temperature for flower primordial induction ranges from 30°C to 35°C (Bruttrose 1970). Buds are more fruitful at high temperatures and light intensities, whereas the optimum range for pollen germination is from 25°C to 30°C (10°C is the minimum, 35°C the maximum) (Santibáñez et al. 1989). For white varieties, the optimum temperature for photosynthesis is between 20°C to 25°C (Schneider 1989), and temperatures above 29°C are detrimental to fruit development and quality. SIMPROC was run for red and white grapes for both the baseline and 2050 under full irrigation and a 20% deficit.

Phenology also modulates crop sensitivities to rising temperatures, frosts, and heat stress. Crop sensitivity may differ from one phase to another. The model contains algorithms to simulate frost damage and the effect of water shortages on production, as well as the loss of leaf area index due to frost occurrence. Frost and water stress sensitivity and temperature thresholds are simulated by a phenological sub-model that assigns each phase a different sensitivity. The model also incorporates the accumulation of degree-days above a base temperature through the relative phenological age variable, which varies from 0 at crop just emerged to 1 at maturity (harvest); this variable represents phenological development.

Results and Discussion

Current Drought-related Vulnerabilities

Drought is a complex issue for the wine industry in Maule. Dry years are extremely problematic for producers—57% of interviewees noted drought,

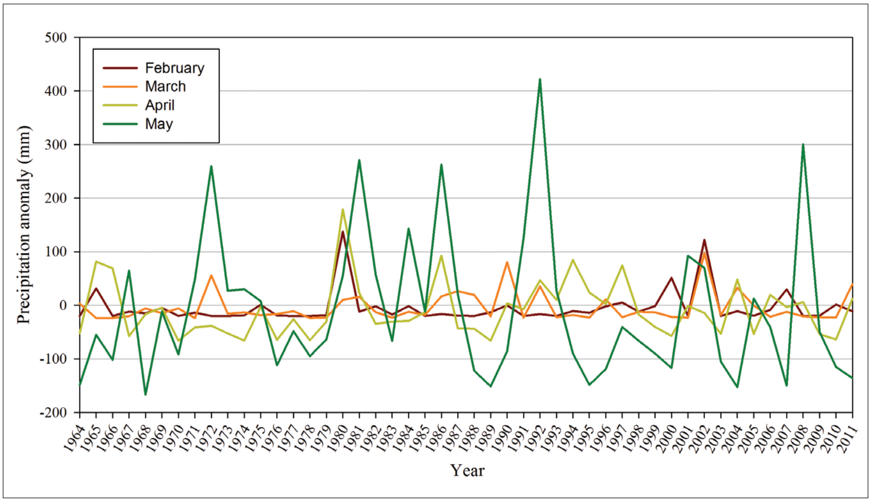

Figure 2. 1964–2010 precipitation anomalies for Parral (1980–2010 baseline)

primarily irrigation water shortages, as contributing to below-average years for their operations. Since most vineyards are irrigated in Maule, adequate winter recharge in the Andes is important to maintain water supplies during the summer (the dry season). In dry years, recharge is often inadequate to satisfy demands (i.e., all water rights allocated on a canal). When water supply declines, producers are unable to irrigate their grapes to their satisfaction and the vines' needs. The vines then experience water stress, which can be advantageous in small amounts but extremely disadvantageous if stress is excessive. Minimal stress is associated with desirable colour and phenolic compound characteristics in wines. Extreme stress, however, is associated with blocked phenolic maturation and reduced production (Lereboullet et al. 2013). Figure 2 shows precipitation anomalies for Parral, located in southern Maule, and highlights the high degree of year-to-year variability growers have to manage.

Many producers reported that production decreases in times of drought because the vines cannot produce the same volume of juices under water stress, and therefore the grapes are smaller (i.e., volume decreases). Since 2001, many grape growers and wine producers experienced up to a 30% decrease in production as a result of drought. Growers have fewer kilograms to market and therefore their economic returns suffer because they are paid by weight. This loss has carry-over effects because less operating money is available for the next growing season (e.g., for inputs, labour). Although affected by decreases in production, producers engaged in high-quality wine production noted that mild drought increases wine quality in some years because the juices become more concentrated. This effect of mild drought on wine quality creates a marketing opportunity for producers. However, excessive drought decreases their production and negatively affects wine quality.

Growers' proximity to the main canal influences their exposure to drought. The canals closer to the main canal receive water before those that are farther away. Growers who receive their water last identified much more severe water shortages than those closer to the main canal. Interviewees attributed this effect to water hoarding, a lack of adherence to rationing rules upstream, and losses to seepage and evaporation, in some cases because people do not maintain their canals.

Grape growers and wine producers have a wide range of adaptive strategies they use in the vineyard to reduce drought risks. Almost all growers monitor conditions very closely—many have installed climate and agronomic monitoring equipment—and assess their vines regularly during the growing season to quickly identify signs of plant stress. In drier parts of the region, they also strategically plant vines in low-lying areas to take advantage of natural drainage, and they harvest before the plants begin to show signs of stress. One wine producer mentioned they harvested 20 days earlier than normal (February instead of March) in one drought year to avoid excessive stress, and this worked well for them. Another producer harvested later than normal to allow grapes to reach the preferred level of maturation, but some of the grapes were dehydrated, and this negatively affected wine quantity and quality.

Access to water and water rights also influences drought vulnerability. Water rights in Maule are scarce and expensive (Gómez-Lobo and Paredes 2001), and some large growers mentioned they purchase additional rights to help them through dry times. This situation has led to an unequal distribution of resources and questions around social equity, as small- and medium-size operations become marginalized because they are unable to afford to participate in the water market (Bauer 2004, 1997). The government has attempted to curtail water-rights hoarding by fining users who do not use their allocation—a small price that large producers are willing to pay for increased water security.

Producers explore alternative sources of water and modify their management strategies in times of drought. A few of the interviewees drilled new groundwater wells or upgraded their existing groundwater pumping capacity. One grower also upgraded their irrigation equipment. Many growers modify their irrigation schedules and ration water; 48% of the interviewees produce other crops and prioritize irrigating their higher-value, more water-sensitive crops in drought years (e.g., they water cherries and kiwis before wine grapes). Wine producers often purchase additional grapes or bulk wine to offset their production losses.

Temperature is commonly identified as the main determinant of vine phenology, or the vine's rate of physiological development from budbreak to flowering, setting, vèraison (change of grape colour), and fruit ripeness (Gladstones 2011: 5). At temperatures above 25°C, net photosynthesis decreases, and at temperatures above 30°C, berry size and weight decrease, and metabolic processes and sugar accumulation may stop (Mira de Orduña 2010: 1845). High summer temperatures, which often accompany drought in Maule, were identified by 20% of interviewees as being problematic. Merlot was identified as particularly sensitive to high temperatures, as exposure results in dehydration, lower yields, and ultimately, reduced financial returns. In addition, when high temperatures are coupled with intense solar radiation, the risk of sunburn increases if growers de-leaf and thin their vines too much; this is more of a concern for white wine grapes because it negatively affects quality, specifically colour and taste.

To reduce the risks associated with high temperatures and intense solar radiation, growers reduce de-leafing and thinning, and remove affected bunches at harvest. They also graft different varieties that are not working well for their vineyard. For example, a couple of growers grafted Pinot Noir and Carménère on Cabernet Sauvignon rootstocks in response to market conditions (i.e., better prices) and to experiment with wine grape suitability in their vineyard. Wine producers try to mix out the undesirable flavours and colour, and they also upgrade their winery equipment to better deal with these challenges. For example, one producer invested in cold fermentation tanks to facilitate better aromas in white wines, and another invested in individual cylinders for each wine batch, which resulted in better-quality wines.

Non-drought Related Risks

Although drought creates significant risks and some opportunities for grape growers and wine producers in Maule, several other forces influence their vulnerability. As is the case in the agriculture sector in general, fluctuations in market conditions create economic uncertainty for growers and producers. Many producers export their wine, and therefore the value of the US dollar greatly affects their bottom line. Much of the industry relies on manual labour to complete their vineyard work (i.e., pruning, thinning, harvesting), and labour is becoming increasingly scarce. Vineyards compete with other agricultural producers in the region for labour; since there is widespread high-value production, people can afford to pay their labourers relatively higher wages than grape growers. This situation results in fewer workers being available to complete vineyard tasks or in delays in work, both of which can be detrimental to production. Education can also influence vulnerability. Maule has one of the lowest literacy rates in Chile, which affects access to information, especially regarding government subsidies, grants, or special programs.

The wine industry is relatively new in Chile when compared to wine-producing regions in Europe. The industry has been growing rapidly since the adoption of neo-liberal economic policies in the 1990s. Foreign investment has increased dramatically since then, as has the replacement of lower-quality País grapes with higher-quality, more climate-sensitive French varieties. Many interviewees highlighted the fact that they are learning through practice and experimentation, and are adapting as they go. Growers are also managing a variety of forces that create risks and opportunities for their operations, although their decision making is largely driven by economics.

Future Drought-related Vulnerabilities

Future climate change scenarios project increases in temperature throughout all of Maule in 2050; the maximum temperature in January (the warmest month) is projected to increase between 1°C and 2.5°C, with the most pronounced increases projected in the Andean region (Figure 3). The minimum temperature in July (the coldest month) is also projected to increase between 1°C and 3ºC. The Andean region experiences the largest increase in minimum temperatures, and this trend decreases from north to south (Figure 4). Conversely, precipitation is projected to decrease

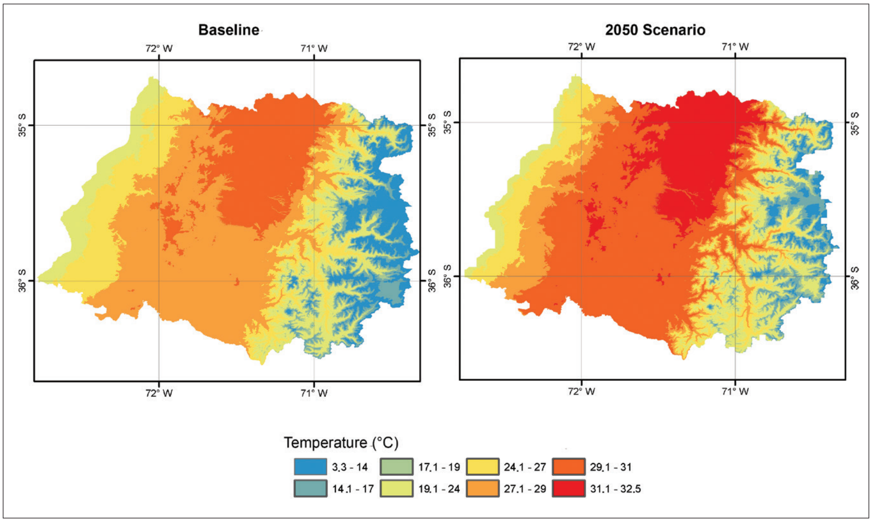

Figure 3. Maximum temperature in January (baseline and 2050) for the Maule region

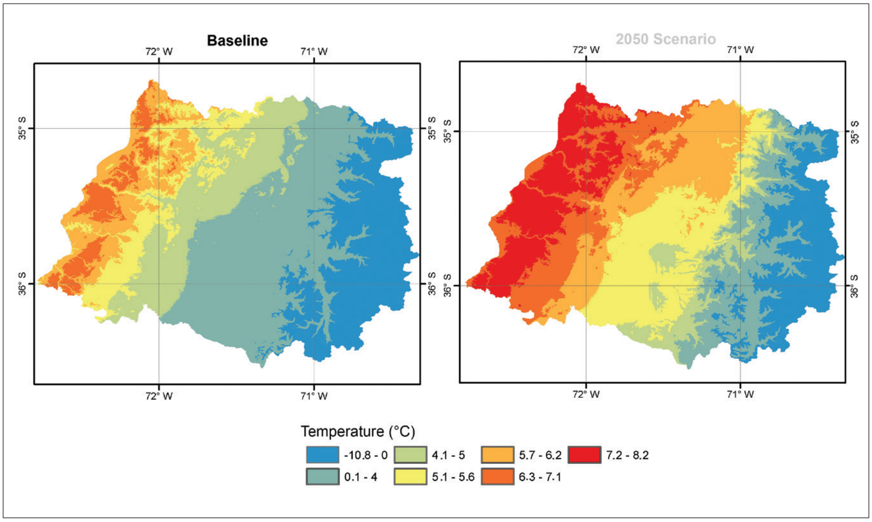

Figure 4. Minimum temperature in July (baseline and 2050) for the Maule region

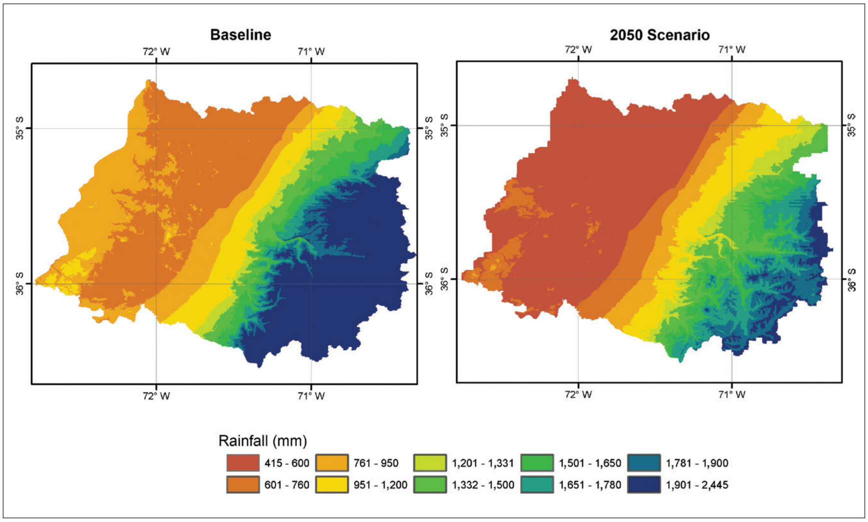

Figure 5. Annual rainfall (baseline and 2050) for the Maule region

(Figure 5). The largest decrease in precipitation is expected on the coast, which could experience up to a 30% water deficit, although the Andean region is also expected to experience a decrease in precipitation (Figure 5). These decreases, coupled with increases in maximum and minimum temperatures, could shift the arid zone in the southern part of the basin by up to 100 km.

The results of the SIMPROC modelling provide insights into grape yields under full irrigation and a 20% water deficit for both the baseline and 2050 for red and white varieties (Figures 6 and 7, respectively). Under full irrigation, red wine grape yields decrease in the northern portion of the central valley, the coast, and the Andean region in 2050 compared with the baseline. Here, optimum growing conditions would shift toward coastal and foothill regions, which are currently too cold for red wine production. However, yields increase by more than one kilogram per hectare per year in the southern portion of the central valley. Under a 20% water deficit, yields decrease on the coast and the northern portion of the central valley in 2050 compared with the baseline, but yields increase in the southern portion of the central valley and in some parts of the Andean region by almost two kilograms per hectare per year. Comparing the

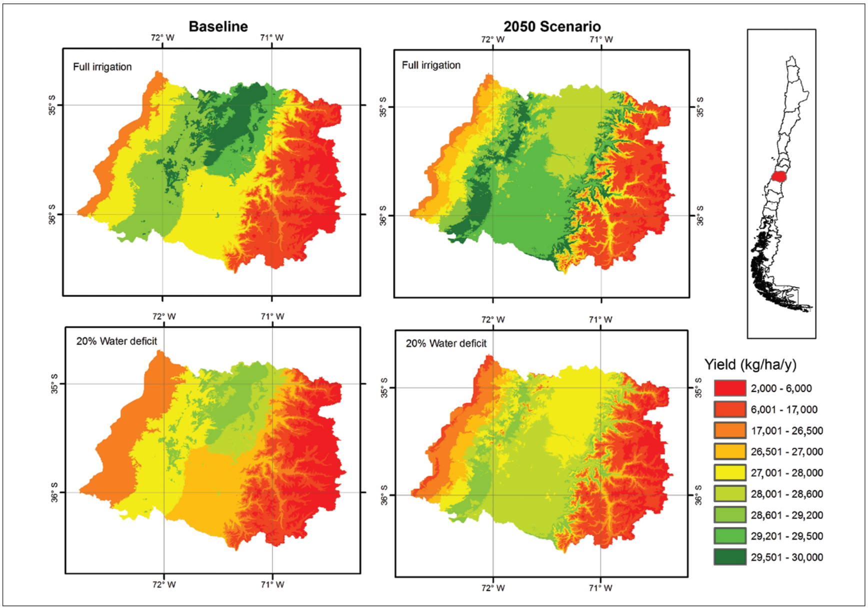

Figure 6. Red wine grape yields under full irrigation and a 20% water deficit (baseline and 2050) for the Maule region

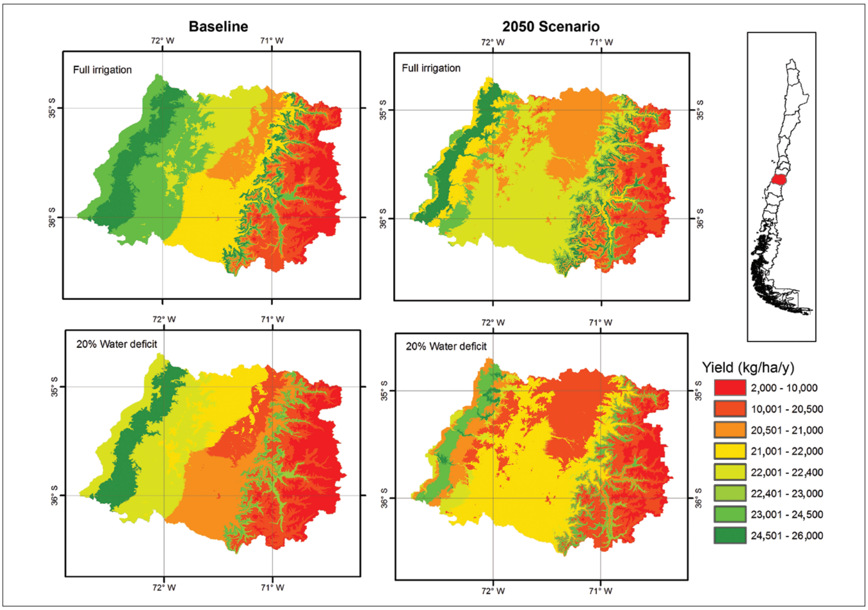

Figure 7. White wine grape yields under full irrigation and a 20% water deficit (baseline and 2050) for the Maule region

full irrigation and 20% water deficit scenarios for 2050, yield decreases throughout the entire region, highlighting the negative impacts of future drought on production.

Under full irrigation for white varieties, yield decreases along the coast and increases in the central valley and the Andean region when 2050 is compared with the baseline, both under full irrigation (Figure 7). For the baseline and 2050 under a 20% water deficit, yield decreases on the coast and the northern portion of the central valley and increases in the southern portion of the central valley and the Andean region. In 2050, yield decreases across most of the region in the 20% water deficit scenario when compared with full irrigation.

To summarize, productivity decreases for red varieties in the north-central valley and parts of the Andean region in the future; this decrease is more pronounced under future water deficits. However, there appear to be opportunities for red varieties in the south-central valley, as future productivity in this area increases in both scenarios. Access to full irrigation is essential for growers, especially in the central valley, to take advantage of the opportunities in 2050 (Figures 6 and 8), as red varieties will require more water (8% for each degree increase in average temperature) due to an increase in evapotranspiration (Figure 8). This underscores the importance of increased efficiency in irrigation water use and reliable water supplies.

For white varieties, productivity decreases along the coast and parts of the north-central valley and increases in the south-central valley, the eastern portion of the north-central valley, and parts of the Andean region (Figure 7). Similar to reds, irrigation requirements will increase for white varieties in the future (Figure 9), and again, access to irrigation water will be essential to maximize opportunities in the future. There is a strip on the coast where irrigation requirements could decrease because the fruit development cycle will be shortened as a result of rising temperatures (Figure 9).

Although there are potential opportunities in the future associated with production increases, growers will need to be able to adapt to the shifts in optimum growing conditions. Vineyards are already planted throughout the region, and growers in the south-central valley may benefit in the future if they have access to water. However, growers in the rest of

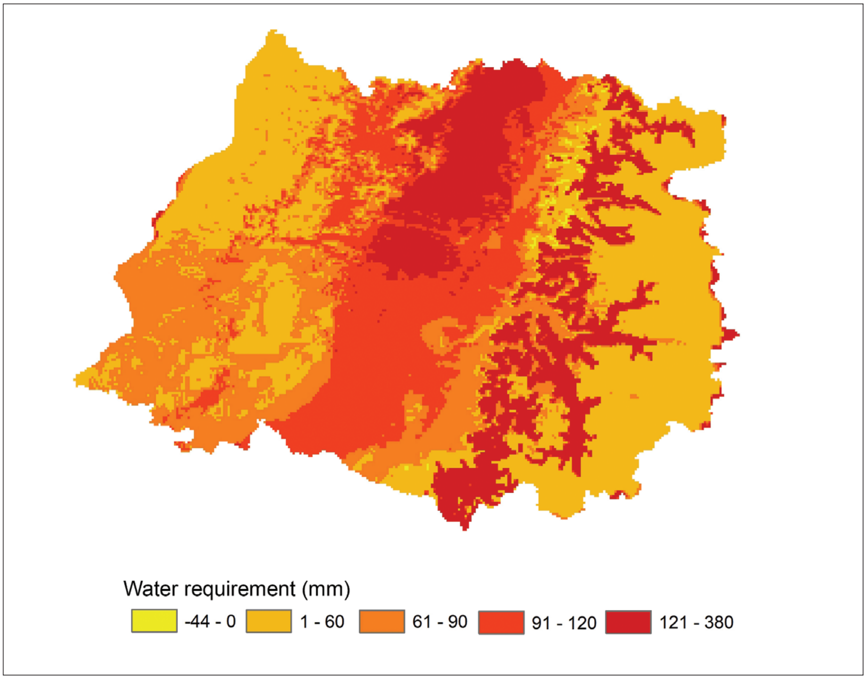

Figure 8. Changes in water requirement for red wine grapes (baseline compared with 2050) for the Maule region

the region may need to make adjustments to accommodate the risks and opportunities projected for them in the future.

Access to capital will influence future adaptive capacity. Large, capital-intensive operations have the ability to invest in water rights, land, and modern equipment; hire well-trained agronomists and winemakers; and take advantage of the projected shifts in optimum growing conditions. Those that both grow grapes and produce wine have more flexibility and are in a better position to adopt a wider range of strategies to reduce drought risks and take advantage of opportunities, as they can make changes not only in their vineyard but also in their winery. Small growers do not have that option if their crop fails or if their quality is reduced.

A few growers were seriously considering acquiring land in new locations to spread their climate risks. Some interviewees mentioned they had purchased or were planning to purchase land in regions located to

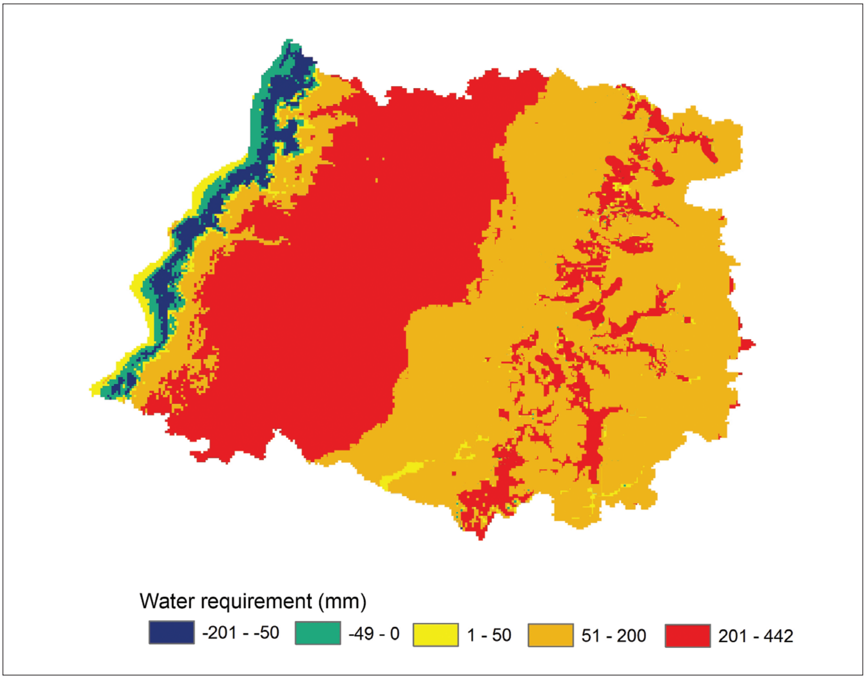

Figure 9. Changes in water requirement for white wine grapes (baseline compared with 2050) for the Maule region

the south of Maule to reduce climate risks as well as explore new terroirs. Many were actively exploring new varieties and experimenting with them to determine the most suitable varieties. They were also adding varieties to their production list to be able to quickly adapt to market demands and maximize their economic returns.

Lessons Learned

Drought has significant impacts on the grape and wine industry in Chile, and climate is an important driver for adaptation; however, economics is always at the forefront of producers' decision making. Profitability is the main concern for producers, resulting partly from the presence of an open market. There are very few government payouts, crop insurance is not widely purchased, and, save for a few small co-operatives, producers market their product independently. Producers spread their economic risk in times of drought and employ adaptation options that help them remain profitable. Many large growers have invested in secondary processing; for example, many growers have established wineries in order to produce bulk wine or fine wine for domestic consumption or export. They also sell grapes, buy grapes, make bulk wine, *and* buy bulk wine in order to remain competitive. Medium and small growers diversify their operations and incorporate high-value crops such as blueberries, cherries, avocados, and olives. Many growers and producers have also worked together to form co-operatives to collectively market their product (grapes and/or wine), but few co-operatives have succeeded in Maule. These are a few examples of how Chilean producers spread their economic risks in times of drought. Some of these adaptations may transfer to the Canadian Prairies and provide guidance from a different context on how producers successfully navigate drought while trying to maintain profitability in a setting where they must market their product independently.

The water market has been used as a tool by agricultural producers to manage drought vulnerability. But despite water being used very efficiently, it is an expensive commodity, which has influenced who is able to participate in the market. For example, there are increasing concerns about hoarding of water rights and conflicts and social equity (Bauer 2004,1997). These types of issues need to be considered when adopting this type of water market system—another important lesson from Chile that may be applicable to Canada in the future.

The SIMPROC modelling work described in this chapter is an innovative approach to understanding the interactions between agro-climatic trends and changes in climate. The model also identifies the subsequent implications of these interactions for crop yields in Chile. This type of modelling could help provide insights into the interactions and implications that exist for the Canadian context and support the agriculture sector with future adaptation planning efforts; for example, it could help identify new crop diversification options and help guide crop science research interests.

Conclusions

Over the past 30 years, Chile has garnered international attention for its production of high-quality wine at very affordable prices. Since then, growers have been capitalizing on the opportunity to engage in high-value agricultural production and have been transitioning their operations to wine grapes and other tender fruit production. They have widely adopted irrigation technology and are continuously learning about the art of viticulture and viniculture as they experiment from year to year. This shift, in turn, has changed their vulnerability to drought, and the broad lessons learned can be transferred to other contexts (e.g., Canada).

Exposure-sensitivity to drought in Maule can be adverse or beneficial for the wine industry, depending on a variety of factors, including the drought's timing, duration, and intensity, as well as the production system characteristics and its adaptive capacity. A small amount of water stress can be beneficial for quality, but it decreases production. As such, moderate water stress provides benefits for some wine producers, but results in income reductions for most grape growers in the region. This situation creates an interesting dynamic in the industry as well as differential vulnerabilities, with wine producers accruing benefits from drought at times and grape growers being negatively affected.

The SIMPROC modelling work suggests there will be changes for both growers and producers in Maule. Productivity (yields) is projected to decrease in the northern and western portions of the central valley and increase in the south, which may create more risks for growers in the north and west, but opportunities for those in the south. However, if production decreases are accompanied by higher-quality production, it may actually create an opportunity for some wine producers. The modelling work also indicates that there will be a decrease in future annual rainfall—potentially affecting irrigation supplies—and that crops will require more water in the future, largely due to increases in temperature. Therefore, droughts may become more frequent, and in order for the industry to succeed, access to sufficient irrigation water will be critical. These future conditions add another level of complexity for growers who have begun to feel confident growing wine grapes and producers who have found their niche.

Over the past few decades, growers and producers have developed a wide range of adaptive strategies they use in times of drought. Capital investments may be necessary to accommodate future changes in optimum growing conditions, as new regions may become more or less suitable for certain varieties of wine grapes. Some growers have even begun purchasing lands in the south in anticipation of future changes. This adaptability and foresight will be beneficial in the future should the projected changes become reality. However, some growers and producers are not prepared for, nor even thinking about, the future. As a result, they may face greater challenges under future droughts, especially when coupled with a variety of external forces (e.g., lack of education and access to capital) that will influence their ability to adapt to drought.

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CHAPTER 14

DROUGHT IN THE OASIS OF CENTRAL WESTERN ARGENTINA

Elma Montaña and José Armando Boninsegna

Introduction

This chapter discusses droughts and episodes of water scarcity in the context of the Mendoza River basin, an area in central-western Argentina where a dynamic agriculture emerges in an arid complex Mediterranean climate. The Mendoza River basin is similar to many dryland territorial configurations on both sides of the central Andes or to the Palliser Triangle in the Canadian Prairies, where "green oases" emerge as a result of human-built irrigation systems. As in many semi-arid and arid regions of the Americas, the sensitivity of the regional economy and population to climate variability and the new threats of global warming lead to questions of how to reduce vulnerability of agricultural producers, integrate climate change into their activities, and foster the best possible adaptive strategies for facing inevitable climate change consequences.

The chapter assumes that climate and water-related issues should be understood in terms of coupled natural and social systems. In these terms, the presence and the impacts of droughts should be discussed from a perspective that integrates both the natural and social scientific views. The first section of this chapter deals with the natural scientific perspective; it discusses the climatological conditions that characterize the basin and their impact on regional water scarcities. Following the conceptual approach discussed in Chapter 1, the second section of this chapter deals with the social dimension, focusing on the vulnerabilities of the basin and paying special attention to the social and economic structures of the basin in setting up variable conditions of vulnerability for different producers. The third section focuses on the adaptive capacity of these rural producers, linking this capacity to the social and economic structures. Finally, policy implications for managing future droughts are discussed.

Several natural and social studies, which are the main inputs to this chapter, have been carried out in the region. The natural studies have focused on hydrological cycles, their relationship to agriculture, and the vulnerability of the region to water scarcities, which are the main constraints to economic growth and expansion. Rainfall, runoff variability, and their relationship with large-scale circulation anomalies and different climate conditions have been discussed in both past (Prieto et al. 2000; Compagnucci and Vargas 1998; Rutllant and Fuenzalida 1991; Cobos and Boninsegna 1983) and more recent studies (Gonzalez and Vera 2010; Viale and Norte 2009; Vargas and Naumann 2008; Masiokas et al. 2006; Boninsegna and Delgado 2002). Past droughts have been analyzed by Villalba et al. (2012), and Christie et al. (2011), and Le Quesne et al. (2009) used tree ring series to reconstruct the Palmer Drought Severity Index back to year 1346, providing an insight into the central Andes drought recurrence. Climate change impacts on the Cordillera have been addressed by Bradley et al. (2006), Nuñez (2006), Urrutia and Vuille (2009), Nuñez and Solman (2006), and Vera et al. (2006). Glacier evolution has been the subject of several studies (Le Quesne et al. 2009; Bottero 2002; Luckman and Villalba 2001; Leiva 1999). An estimation of the future streamflow of the San Juan and Mendoza Rivers was made by Boninsegna and Villalba (2006a, 2006b).

In the region, risk and vulnerability studies have focused mainly on water and water scarcity–related issues, as well as on the potential impacts of climate change. The historical perspective of the relationship between water and society can be found in Marre (2011), Montaña (2011, 2008a, 2007) and Montaña et al. (2005) while studies concerning the possible role of global change in altering risk patterns appear in Scott et al. (2012) and Salas et al. (2012). Vulnerability has been addressed by Masiokas et al. (2013), Montaña (2012a, 2012b) and Diaz et al. (2011). New ways of thinking about conservancy ethics, society, and adaptation applied to the central Andes region are found in Montaña (2012a), Montaña and Diaz (2012) and Diaz et al. (2011). As indicated earlier, the chapter integrates this diversity of studies.

Climate Variability and Droughts in Mendoza

The central western Andes region of Argentina, where the province of Mendoza and the Mendoza River are found, is complex in terms of its orography, climate, and socio-economic development. The topography is characterized by the steep north-south barrier of the Andes, which strongly modulates the climate between the western (Chilean) and eastern (Argentinian) sides of the mountains. In the eastern slope of the Andes, located in central-western Argentina, Mendoza is part of what is called the "dry pampas," where most of the scarce yearly precipitation occurs during the hot summer months. During the cold winters, snow accumulates in the higher mountains and occasionally in the valley, where frost episodes are common. As in the case of the Canadian Prairie provinces, the winter snow melts during the spring due to the rise of temperature, increasing river runoff, which peaks in the summer months of December and January. This runoff provides water for human consumption, agricultural activities, and hydroelectric production. This hydrological cycle, which is conditioned by climate, is crucial to sustain human activities in the region. In this context, the Andes have been defined as a "natural water tower" capable of collecting, storing, and distributing water from rain and melting snow (Viviroli et al. 2007, Vitale 1941).

Most of the irrigated agriculture in the Mendoza region is both intensive and diversified. Famed worldwide for its viticulture, Argentina produces approximately 1.5 billion litres of wine per year. Other agriculture-based industries—such as olive oil, and canned and preserved food production—are also highly developed. Tourism, while a relatively new industry, is becoming an important source of revenue for the region. A more marginal agriculture, which has limited access to irrigation and is highly dependent on summer precipitation, extends throughout the eastern and northern part of the province. Only 3.6% of the provincial territory is irrigated, an area identified as “the oasis,” which provides the conditions for agriculture and urban development. This concentration of activity clearly highlights the region’s potential for producing goods but also its increasing vulnerability to climate variability.

In recent years, there has been increasing concern about the implications of climate change for the region. Recent projections indicate a probable decrease in snow in the mountains and a rise in temperature during the present century, two factors that could seriously increase the water deficit and compromise the survival of the oasis. Reducing (as much as possible) the uncertainties in the long-term forecast of hydrological supply is essential to designing adaptive measures whose implementation will require long-term efforts.

The amount of snowfall and its accumulation, the variation of temperature, and the influence of some climate forcing systems, such as the El Niño–Southern Oscillation (ENSO), regulate the quantity of water available in the mountains. The water regime is highly dependent on the amount of snow that falls during winter and accumulates in the high basins. Temperature regulates the occurrence and rate of the snowmelt and runoff volumes to the extent that the seasonal temperature cycle produces variations in the height of the 0°C isotherm. The position of this line allows for estimating the surface on which the accumulation and/or melting of the snow will occur. The melting of the accumulated snow produces runoff, with the largest volumes produced during the spring and summer months (Figure 1).

The largest inter-annual climate variability driver in the tropical and subtropical regions of South America is the ENSO. Montecinos and Aceituno (2003) noted that during El Niño there is a tendency for the occurrence of above-average rainfall between 30° and 35° S in winter and from 35° to 38° S in late spring. Precipitation anomalies are opposite during La Niña episodes. Increased blockages in the southeastern Pacific during El Niño events produce westerly winds at lower latitudes—a key element that explains winter humidity conditions in central Chile.

At larger scales, the Pacific Decadal Oscillation (PDO) and long-term trends in the Antarctic Oscillation have influenced the climate in the Andes. Wetter conditions are present during the positive phase of the PDO in the subtropical belt of South America. Consistent with these observations,

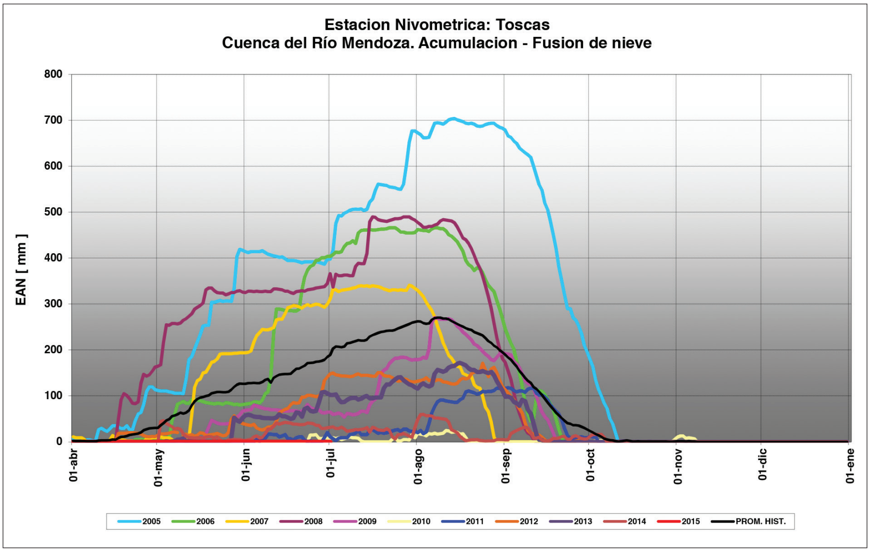

Figure 1. Annual snow accumulation measured at Toscas station (3,100m asl). Note the existence of an accumulation period, from early May until late September when snow starts melting. The snowmelt is quite fast at the measuring station and is completed by mid-November. Snow persists at higher elevations until the end of summer. Also note the large variability in the timing and quantity of the snowfall. (Source: DGI (General Department of Irrigation). 2012)

Masiokas et al. (2010) have reported an association between periods of low and high runoff in Andean rivers (between 30° and 35° S) and in the negative and positive phases of the PDO, respectively, during the twentieth century.

Figure 2 shows periods of snow and runoff shortages between 1910 and 2010. Assessing these periods as drought onsets is not easy, because of the high variability in snowfall and streamflows.

Long-term climate change assessed by different regional circulation models indicates that there will be an increase in temperature (+2.5°C to +3.0°C A2 scenario), less snowfall and runoff (-10% to -15%), and an increase in summer precipitation in the oasis (+30%) between 2090 and 2100. The model of CONAMA (2006), for example, shows a decrease in precipitation on the upper mountain, which could experience up to a 15%–20% snow deficit, but a steady increase in precipitation (rain) concentrated from October to March in the productive oasis (Figure 3) of the

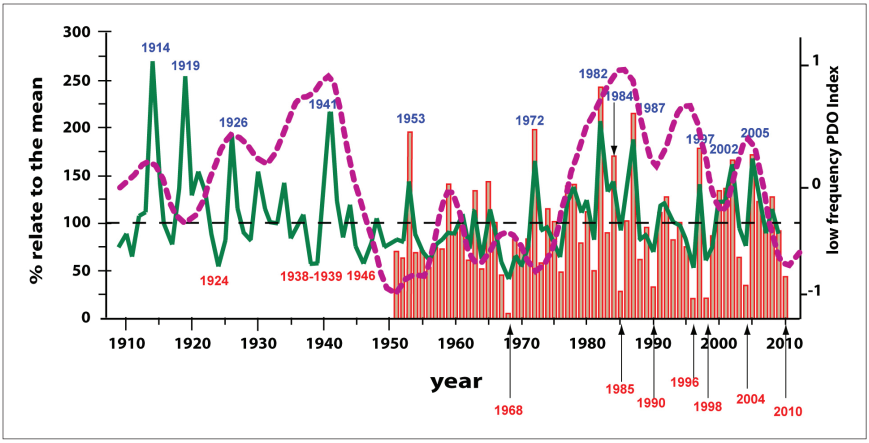

Figure 2. Mendoza River snowfall and streamflow, showing the regional average of snowfall measurements and regional average of streamflow measurements for the period November to February, expressed as percentage of water equivalent, base period 1966–2000. Note the variability in the annual record of snowfall and runoff. Years in blue are El Niño–Southern Oscillation years. The correlation coefficient between the series is $r = 0.945$, $p < 0.001$ (highly significant). Filled bars are mean snow measurements (mean of 10 stations), green line indicates streamflow measurements (mean of 8 stations), and dashed line represents the Pacific Decadal Oscillation (PDO) low-frequency index.
(Modified from Masiokas et al. 2010).

valleys. This summer input of water in the oasis hydrology differentiates Mendoza's oasis from the central Chile situation, where the summers are normally very dry.

It is extremely important to account for all interactions among the variables. For instance, if mountain temperatures rise steadily, snow cover will melt early in the year, provoking a rise in runoff during the early spring months and a drop during the summer, just when agriculture most needs irrigation (Figure 4). The increase in summer precipitation could make the situation even worse, since summer precipitation has been found to be detrimental to vineyard yields due to the increase in hailstorms and fungal diseases (Agosta et al. 2012).

In a viticulture-based agriculture (with the grapes rapidly growing from January to the harvest period in March), this change in the hydrogram produces an agricultural drought situation even with above-average

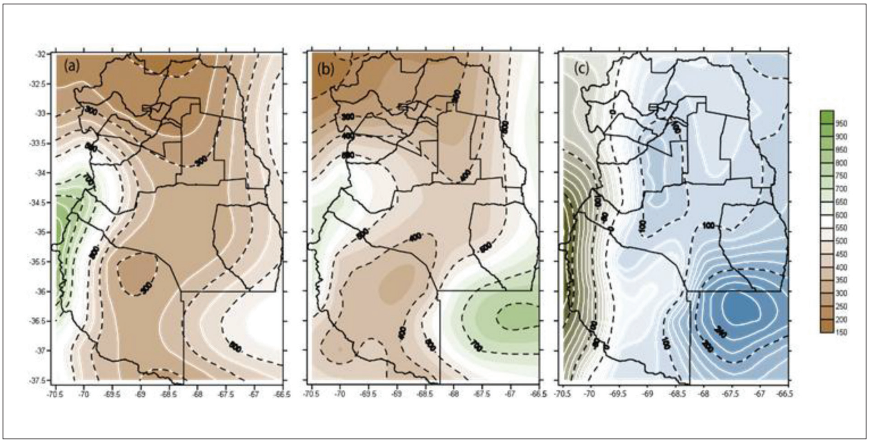

Figure 3. Shown are (a) Mendoza annual precipitation 1961–90, (b) Mendoza annual precipitation 2071–2100 according to PRECIS (Providing Regional Climates for Impacts Studies) circulation model, and (c) difference between future and present estimates. The figure shows a steady increase in precipitation to the east of mountain foothills but a decrease in the higher Cordillera.

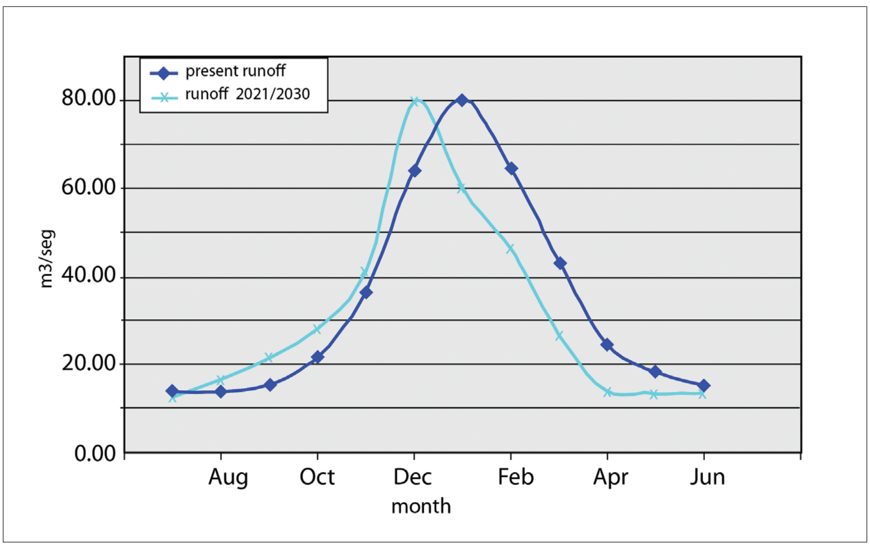

Figure 4. Hydrograph of Rio Vacas (Mendoza River basin) and modelled hydrograph of Rio Vacas (Mendoza River basin) with similar snow cover, but temperature +1.5°C higher than present values

snowfall in the mountains, a situation that calls for adaptive measures such as increasing reservoir capacity.

Drought is a regional natural hazard and should be considered a normal part of climate rather than a departure from normal (Glantz 2003). In these terms, it is difficult to assess whether a drought exists and/or its degree of severity. In the Argentinian and Chilean central Andes, instrumental and paleoclimate records could provide a method to analyze periods of water scarcity, at least from a meteorological point of view. However, it is difficult to define each of those periods as "drought," with all its negative connotations. Periods of drought are not by themselves a disaster; qualifying them as a disaster depends on anthropogenic and environmental impacts. The magnitude of the impacts in turn depends on the timing, duration, and intensity of the phenomenon.

All types of drought originate from a deficit in precipitation (Wilhite and Glantz 1985). If the precipitation scarcity lasts for an extended period, a meteorological drought could occur. But there are also hydrological droughts that are defined as the departure of surface water and groundwater supplies from average conditions. This situation can occur even with average or above-average precipitation.[1] It is when these conditions affect agriculture that an agricultural drought is declared. The start and end of drought are difficult to determine, particularly in regions where climate variability is high. When meteorological water scarcity is coupled with hydrological scarcity, and in turn agricultural and social systems are impacted, a severe drought could occur.

Historical records and narratives are valuable tools for analyzing such events (Prieto et al. 2000). Indeed, severe droughts have occurred in the region lasting long enough to jeopardize the survival of fruit trees and grapevines. During the years 1966–70, the quantity of snow in the Andes was extremely low. Moreover, during those years, there was very little rain during the summers in the valleys. Desperate measures were used to try to cope with the situation, such as draining Cordillera lakes using explosives. This recent historical episode reveals how vulnerable the region is to lasting hazards (Prieto et al. 2010).

However, it is not always easy to measure the cause of a climatic disaster. Several factors, including economic conditions, agricultural mismanagement, hailstorms, frost, plant diseases, and drought affect wine production; untangling the roll of each factor and isolating the effect of drought is particularly difficult. Frederick (2011), for example, pointed out that "the drought occurring between 1967 and 1970 brought agricultural expansion to a temporary halt." On the other hand, after analyzing the contribution of wine production to the provincial gross domestic product (GDP) of Mendoza during the twentieth century, Coria (2014) concludes that the main stressor seems to be several economic crises due to government mismanagement. But coincidentally, the analysis shows a 50% reduction in the added value of wine in the industry in 1969. However, there is no mention of water shortages.

Vulnerability to Drought in Mendoza

Mendoza looks like an idyllic oasis fed by waters from Andean snows. It has a territorial configuration characterized by two opposing landscapes. On the one hand, there are green oases with neat rows of grapevines, tree-bordered roads and streets, and irrigation channels and drains. On the other, there are non-irrigated lands (the "desert") occupied by a scattered population of goat breeders in a "no-man's land," defined as a subordinate space that is empty and void of interest.

This territorial configuration follows a very similar pattern from north to south along the central Andes, both in Chile and Argentina. In these drylands, agriculture is only possible through systematic irrigation, and the oases develop as intensively exploited territories. In the province of Mendoza, for example, oases account for only 3.6% of the total area, but they are home to 98.5% of the province's population and are the centre of most economic activities, among which grape growing and winemaking stand out. Most of the population resides in the city of Mendoza, with a population of about one million people. The second largest city has close to 100,000 inhabitants, followed by a number of small towns in the margins of the oases.

Agriculture is less diversified than in the central Chilean valleys or the Canadian Prairies, as grape growing accounts for about half of the cultivated area of the Mendoza River basin, followed by horticulture (23%) (CNA 2002). Agriculture in the basin is highly integrated with the industrial sector, because 99% of grape production is destined for winemaking. Approximately 23,000 irrigators in the basin account for 89% of surface water use (DGI 2007). In the basin, however, only 45% of farmers irrigate with surface water; 27% irrigate with groundwater only (CNA 2002), and 28% use both surface water and groundwater. Marked differences occur among grape-growing and horticultural productive systems and among wine growers in particular. Among wine growers, there are small producers with traditional vineyards at one end of the spectrum and representatives of the "new viticulture," which is part of a modern global agribusiness, at the other end of the spectrum. In the case of horticulture, small- and medium-scale producers, in some cases of Bolivian origin, produce vegetables for regional consumption, relying on social and family networks to organize their production to successfully develop their agricultural activities.

The agricultural, industrial, and urban sectors are highly dependent on the water resources provided by the Mendoza River, but this dependence affects the region's social and political life, going well beyond a functional dependence on water resources. As Worster (1985) argues, the situation here constitutes a modern "hydraulic society," in which the social tissue is strongly associated with a comprehensive and intensive manipulation of water resources within an order imposed by a hostile environment. The conflicts of the hydraulic society (Montaña 2008a) become palpable precisely when the hostility of these drylands is exacerbated by water scarcities and drought.

Under these conditions, the agricultural communities of the Mendoza River basin are inherently vulnerable to drought. Studies carried out by Montaña (2012a, 2012b) in Mendoza show that drought is the climate exposure most mentioned by agricultural producers in the Mendoza River basin as affecting their operations, followed by hail and frost. References to water scarcity are not only limited to the flow of the river or the water received through irrigations ditches but also involve groundwater, particularly in summer. Structural water scarcities and growing demands add up to recurrent drought crises. When asked about the causes of water scarcity or drought, not all of the explanations provided by farmers are associated with climate, climate change, or hydrological factors. Explanations also include human factors, such as upstream expansion of agriculture and urban sprawl, rightly perceiving the converging natural and human processes that are involved in defining a situation of vulnerability and which give rise to water conflicts that could turn a "natural" phenomenon into a disaster. Farmers are used to dealing with water scarcity and drought, and they consider them a structural problem that will be increasingly problematic in the future. However, they do not seem to be aware of the severity of the droughts that could arise in the context of significant modification of climate conditions, as discussed in the previous section of this chapter.

Drought, as a climate hazard, could overlap with other stressors, such as economic and social crises, generating double exposures (Leichenko and O'Brien 2008). When agricultural producers of Mendoza are asked about the most important problems affecting their productive activity, they identify exposures to economic and social stressors to be just as relevant as climate and water factors. These stressors include economic exposures (national macroeconomics trends, the labour market), social exposures (migration of young rural dwellers and aging of the remaining rural population), and socio-cultural exposures (the Bolivian origin of the horticultural producers and the Aboriginal origin of goat breeders from the desert lands). Even in situations where water scarcity is not the main stressor, it certainly becomes the *coup de grace* that puts small-scale producers, already impacted by the new rules of the globalized agriculture, on the edge of the agricultural system or just expulsed to the urban sector.

Indeed, drought does not impact everyone in the same way. Sensitivity to drought in the oasis of the Mendoza River varies depending on the actors being considered. Consumers of potable water are less sensitive because legislation gives them priority over other uses. It is different for those in the agricultural sector, where every producer would like to be prepared for a drought situation but where only the wealthiest succeed. It is a circular process: the better adapted, the less sensitive (and vice versa). Differences also emerge in relation to the type of water rights and sources accessed by producers, where having access to a well, being in an upstream/downstream location in the basin, and having access to infrastructure, as well as other factors, make a difference. No less relevant is the nature of the productive system; for example, viticulture is less sensitive to drought because grapes tolerate water stress relatively well, whereas horticulture is more sensitive to drought because it requires a reliable water supply.

In the context of these exposures, sensitivity and adaptation are defined by access to factors such as natural, human, social, and institutional capital, as well as economic resources, technology, and infrastructure. As a result of the sensitivity/adaptive capacity equation that involves these factors, vulnerabilities are also unequally distributed in space and in relation to different social groups or actors. Producers who irrigate with only surface water are more vulnerable to reduced river flows than are those with alternative water sources, such as wells, who are better adapted to face droughts. But it is not a question of simply having a well; it is also necessary to have the economic resources required to maintain it, to keep the pump in good condition, and to bear the energy costs associated with using it. Many small-scale producers in the Mendoza River basin, who were better off in the past, had managed to establish wells on their farms. But due to decreasing agricultural profits in the context of the agribusiness model, these farmers are now unable to bear pumping costs. This is an example of exposure to water-related factors aggravated by economic exposures, reinforcing circular patterns of vulnerability and poverty.

During periods of water crisis, irrigators located at the tail end of the systems may receive less water than they are entitled to, so farmers seek to settle at the head of the distribution systems or canals to ensure that they will receive their due. Farmers with better access to water are more likely to succeed in their agricultural activities and, in turn, to have access to better (and more expensive) locations. Oppositely, farmers in the lowest part of the irrigation system are impoverished by poor agricultural performances. Lacking resources, they are unable to move to better locations. Higher temperatures and evapotranspiration reinforce these patterns, concentrating wealthier producers in the upper and cooler areas with higher thermal amplitude and relegating poor producers, who try hard to keep their farms afloat, to the lower and warmer zones. Extreme hydroclimatic events, such as extended droughts, will only consolidate or accelerate the existing tendency toward a spatial and socio-economic segregation of agricultural producers in the oases of central-western Argentina, widening the gap between the dominant players of the local agribusiness and those who are barely able to survive as subsistence producers. In many cases, these small-scale producers have no other alternative than to neglect their farms and seek jobs to generate the necessary income, or even worse, to exit agriculture and migrate to cities, where they join the growing population of urban poor. Thus, scenarios of increasing water deficits suggest an intensification of the current process of socio-spatial segregation: wealthy producers get wealthier uphill, while the smaller producers do increasingly poorly downstream (Montaña 2012a).

Drought Adaptation and Preparedness

Differences in vulnerability among the different players in this hydraulic society may change considerably based on specific adaptive practices. The flows of Río Mendoza are regulated by the Potrerillos Dam, which was built in the upstream section of the basin to both reduce seasonal and inter-annual variability in the river discharge and to compensate for spring and autumn water deficits in crops. However, given the spatial distribution of agricultural lands and the less favourable, scattered location of goat breeders in the drylands downstream from the main users of the Río Mendoza waters, more intense and regulated use of water upstream by the groups with highest social power (i.e., those in the oasis) clearly reduces the possibilities of water "escaping" to the downstream part of the basin where desert communities (and goat breeders) are located. This evident inequity constitutes an interesting case in which a particular set of adaptive practices benefit some sectors and increase the vulnerability of other groups, exposing the complexity of this coupled natural and social system. Although their subordinate social position largely determines the sensitivity of these poor rural communities to various economic and environmental factors, extended droughts will ultimately be the trigger for increased conflicts in this hydraulic society (Masiokas et al. 2013; Montaña 2012b, 2008).

At the farm level, a broad classification of adaptive strategies can differentiate between traditional and "innovative" technologies. There is a clear distinction between the capitalized farmers who apply the latter and the small-scale producers and peasants who are restricted to the former. Every agricultural producer tries to have access to groundwater and make more efficient use of the resource, but not all of them can afford access to the aquifers. Just a small proportion of producers (less than 10%) can pay for permanent irrigation, which differs from many producers in the central Chilean valleys, where modern irrigation is more widespread as a result of a more capitalistic approach to viticulture. Smaller producers and peasants have to settle for more passive forms of adaptation, such as irrigating only the more profitable crops, or simply abandoning their water quantity and quality expectations and their productivity prospects and looking for alternative livelihoods. This is one of the reasons for the increasing impoverishment of small farmers, who become increasingly dependent on off-farm sources of income or sell their lands and migrate. For them, drought is devastating. Among the more highly capitalized farmers, innovative strategies in response to water scarcity involve, among other things, automatic irrigation systems (drip irrigation and others). The capitalized agricultural producers cannot sustain their activity without access to groundwater, as it is inherent to their technology and management style, allowing them to become less dependent on the surface irrigation scheme. This technology enables them to adopt another innovative adaptive strategy: diversifying locations and relocating properties in the foothills upstream to minimize hydro-climatological risks, an action that impacts negatively on aquifer conservation and on the agro-ecological conditions of downstream lands of the basin (Montaña 2012a).

An obvious adaptive measure is to more efficiently use the resource. In terms of developing agriculture with a reduced water demand, there is ample room for improvements through the modernization of irrigation systems. In the case of the Mendoza River basin, where grapes are the main crop, this modernization would have a very positive impact, both for individual producers and for the basin as a whole. But, as has been said, only the medium or large and well-capitalized farmers fully engaged in the "new viticulture" are able to make these investments. Even at low interest rates, loans to reconvert irrigation systems are not suitable for small growers, as their profitability is not sufficient to sustain this level of debt. As already experienced by under-capitalized producers in Chilean agriculture and many small farmers in the Canadian Palliser Triangle, small producers would probably not survive water efficiency measures, given that their adoption would entail economic, social, and political costs difficult to cope with. There is also potential to conserve more of the water currently used by households and industry in the region. A flat rate tariff for drinking water, low efficiency in residential facilities, and obsolete pipelines in the distribution system, together with little control over its use for garden irrigation and recreation, are all factors that explain the high rate of consumption per capita of a growing population and which certainly could be improved.

Local actors claim that more investment in infrastructure is required to deal with water shortages, but the Mendoza River basin has already benefited more from infrastructure works to improve the supply of the resource (dam, reservoir, waterproofing of irrigation channels, irrigation water distribution systems) than from measures aimed at controlling the demand, both rural and urban. And it is the rising water consumption of a growing population and increased economic activities that make the hydroclimatic scenarios where droughts are a central feature more complex.

From the perspective of increasing regional resilience, it is also necessary to understand the different types of drought and their patterns to decide which adaptive strategy to adopt and which type of investment to make. For instance, the region has limited adaptive potential in the long term to respond to hydrological droughts (characterized by decreasing streamflow in the river and dams). A potential adaptive strategy would be to capture and store summer rainwater that is not currently contributing to the river flow, making better use of groundwater and fostering the combined use of surface/groundwater. This strategy needs to occur not just on an individual basis as it is today in the basin, but as a planned collective strategy for managing the hydraulic system as a whole.

It should be noted, however, that the pursuit of efficiency in water use, although a worthy objective in terms of adaptation, is not a new issue. Mendoza, like other basins in Chile and the Canadian Prairies, is a region where rural people have had to historically coexist with water scarcities. Making more efficient use of water is an old goal, inherent to water management in drylands. Moreover, it constitutes a permanent adaptive measure to pursue, with or without climate change. This long adaptive history, however, has not resulted in rural people developing a healthy adaptive capacity to droughts. Rather, it seems that adaptation to increasing drought risk and climate variability will only be taken seriously when an extreme drought is declared. If historical memory is not enough to remind us of the impacts of intense and prolonged droughts in the regions of central-western Argentina, the scientific studies presented above should alert us to the need to take action before it is too late.

In coping with drought, there is always the idea that water limitations can be overcome and the oasis can be expanded. In fact, the "new viticulture" and its modern irrigation based on intensive use of groundwater have pushed the agricultural frontier over the foothills, degrading the agronomic and ecological conditions downstream[2] of the basin. From a social perspective, this degradation affects the small producers in downstream areas, who, already harassed by economic difficulties and a reduced income, become increasingly vulnerable. It is a desertification process that takes place within the oasis itself. Recovering land from the desert in the upstream (or losing it, according to one's point of view) means a desertification of the downstream by moving the oasis upstream (Montaña 2008a). Any surplus of water that might be used to expand the oasis must first be used to recover the old oasis areas that are becoming degraded.

Lessons Learned and Pending Tasks

In the context of intense droughts, climate predictions at local and regional spatial scales are valuable not only for societal benefits but also for planning and managing socio-economic sectors sensitive to climate variations. Several international scientific research centres currently provide global-scale climate predictions. Their ability to make climate predictions at regional and local scales, however, is very limited, not only because of the restricted levels of predictability but also because of the limited ability of current climate models to represent fundamental regional and local physical processes. Climate predictions for the Andes region are particularly challenging in terms of the current models. However, the fact that ENSO and other contributing forces of climate variability can be accurately predicted by the current climate models provides a basis from which to further explore predictability and develop climate prediction tools for the region with a minimum degree of certainty.

Physical indicators and climate indices, such as snowfall, snowfall distribution, mountain temperature, runoff (if possible from all the tributaries), reservoir and lake levels, temperature and precipitation at the oasis, groundwater levels, different uses of water (human consumption, irrigation, hydropower, industry, agriculture, natural ecosystems, cultural uses), and surface cultivation with annual and perennial crops, among other factors, are the main input variables for such models. These physical indicators and climate indices must then be combined with socio-economic variables to predict impacts on communities, assess vulnerabilities, and adopt the most appropriate adaptive strategies.

Based on this case study of Mendoza, it is apparent that preparedness for future drought cannot rely on the short historical memory of local communities. Preparedness planning should also integrate insights from long-term studies. In addition, preparedness plans must incorporate a dynamic model of the oasis that considers both natural and social systems, making sure that the adaptive actions of some groups do not create new vulnerabilities for others, at least not without proper remediation. Moreover, it has become clear that the scope of this undertaking should not be limited to the oasis—the more visible part of the territory—but should also encompass the Cordillera as the main source of water and look downstream to the "invisible spaces" of the desert (Montaña 2005), protecting the cultural diversity associated to the indigenous groups which live there and conserving the ecosystem services that support their style of development.

Advances in better planning and mitigation tools have been made, and these tools are now available worldwide. The main challenge, however, is to transform the social, economic, and political structures that have created an unequal distribution of vulnerability in the basin; without such transformation, drought (a rather normal climate event) becomes a hazard and a disaster for many. It is also fundamental to support governments and decision makers and to empower local people and other social actors to overcome the "short-termism" of the market drivers and narrow economic interests. Once this is achieved, more effective drought preparedness and mitigation plans can be prepared. In the agricultural sector, new and more efficient irrigation systems are needed, reclaimed waters could be better exploited, and training and social organization could contribute to developing more efficient traditional irrigation systems. In the urban sector, new water-conserving technologies need to be explored to more efficiently use water, and urban residents need increased awareness of water limitations. As a case study, Mendoza illustrates that drought takes a number of different forms and that adaptive strategies must be tailored to cope with the particularities of each one within the natural and social context.

NOTES

1 It is the Cordillera's precipitation (especially snow) that feeds the irrigation system. The region can benefit from rain in the foothills and in the plains, but the irrigation system is not designed to capture these resources.

2 This process has been particularly studied for the River Tunuyán basin, south to the Mendoza River basin. See Chambuleyron (2002).

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