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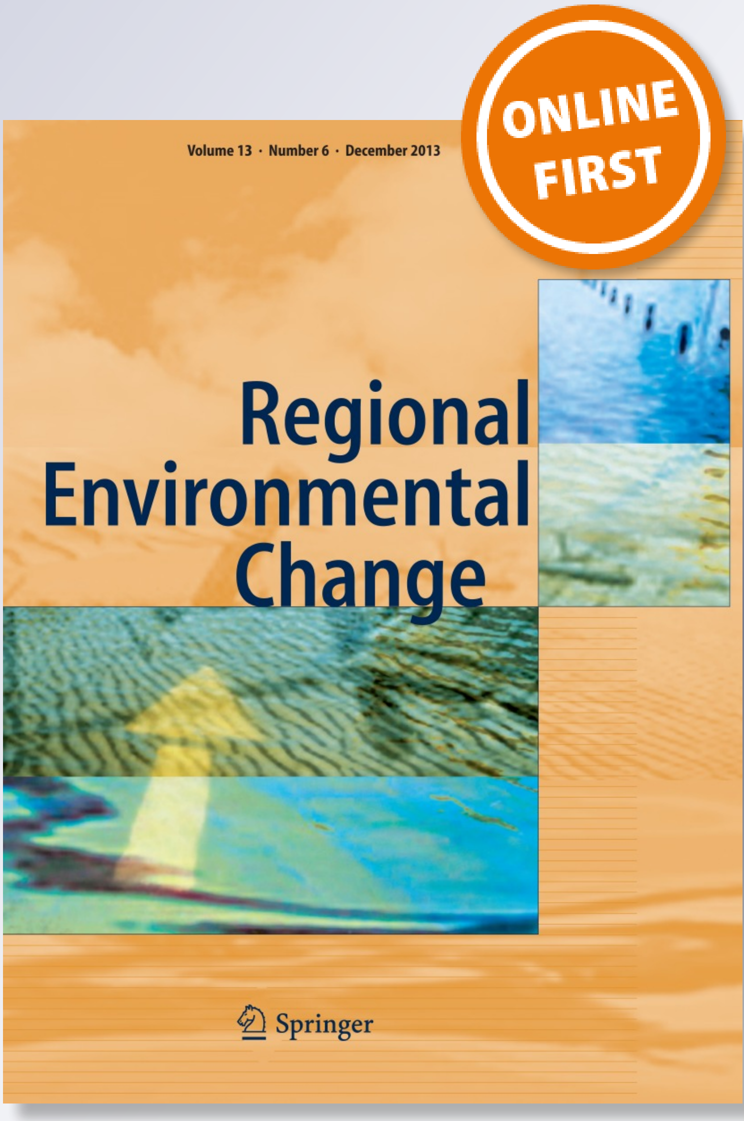

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ORIGINAL ARTICLE

Rainfall trends, land use change and adaptation in the Chaco salteño region of Argentina

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Abstract Regional change under agricultural expansion in the Chaco of Argentina is determined by interactions of rainfall change, infrastructure development, socio-economic actions and values, and the social perceptions of change. Our study focused on adaptation in the socio-environmental system which is the key to understanding opportunities, uncertainties and risk in the context of historical change. Change in land use from extensive grazing through mixed farming and on to industrial-scale soybean production was made possible by a trend of increasing rainfall that reduced the risk of crop failure from drought since the 1970s. Rainfall change coincided with a period in which the Chaco forest was suffering extensive degradation from long-term extractive use. The degradation aided agricultural expansion since the degraded state of the ecosystem justified public policies of deforestation. In parallel to these resource-based processes, public policy changed in the late 70s and 80s toward favoring privatization of state land and exclusion of small producers. This permitted the land concentration needed for industrial-scale production. Technological innovation in both water and land resource management reinforced the process of concentration because small producers rarely have the financial or educational capital to develop or implement emerging technologies. One of the results of the intensification and expansion of agriculture is that soil surface sealing, waterlogging and flood risk are now effective at a landscape scale. To address these risks, private enterprise and government efforts must now come together toward innovative policies in integrated landscape management.

Keywords Land use change · Precipitation change · Vulnerability · Social impacts · Landscape management

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Introduction

Changes in regional climate have created opportunities for agricultural development in the dry Northwest of Argentina. We examined these development opportunities and risks in the context of the social organization of the use and distribution of natural resources in Anta district of Salta Province, Argentina. This district was chosen because it underwent a series of typical historical socio-environmental transformations, among which the recent expansion of soybean cropping is the most extensive. The area has a semi-arid climate with just enough moisture for agriculture. A trend of increasing rainfall has transformed the region's "marginal areas" into an "agricultural frontier" that competes with the more humid Pampas to the southeast. Agricultural production in both the Pampas and the drier regions has become oriented toward the international commodity market since the 1990s, economically integrating the semi-arid areas with the traditionally

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agricultural Pampas (Buttel 2000; Schiavoni and De Micco 2008; Paruelo and Oesterheld 2004; Grau 2008). This was accompanied by an agricultural expansion mostly with soybean, a crop that in 2008 accounted for three quarters of the national growth in agricultural output of 30 % (SAG-PyA 2009).

The agricultural expansion was aided by a process of capital and land concentration between the mid-eighties and 2002, which resulted from neoliberal macro-economic policies (Schiavoni and De Micco 2008; Slutzky 2008; González and Murgida 2012) that favored the market as the organizing standard of the development logic. During this process, financial interests converged in the national economy, integrating the rural real estate market with agricultural production activities.

The purpose of this paper is to explain the pathways of rural transformation caused by an interplay between hydro-climatic trends, agribusiness development and enabling policies in the semi-arid Chaco plain of Salta, Argentina.

Methodology

We studied the regional history of environmental change to understand the processes that shaped the outcomes of development opportunities and risks. In particular, we explored links between environmental factors such as the increase in precipitation, the degradation of native vegetation, soils and pastures, and their implications for the systems of adaptation of different social groups. The historical–anthropological approach allowed us to describe the evolution of processes from their beginnings to the point when they become dominant and generalized (Wolf 2000; García Acosta 2002) in the region. Changes in the physical environment that developed into social risks were examined in the context of social factors that contributed to the construction of risk (García Acosta 2002; Natenzon 2005). In this way, we showed how natural changes initiated social change and how these developed into cumulative transformative situations in the social–natural system.

The historical analysis was based on scientific literature, government reports, legislative texts and media reports that complemented anthropological and ethnographic field work designed to capture reality through the perspectives of different social actors: an analysis based on participant observations and open interviews which expose the investigator to both the diversity of processes that needs to be captured and to the perspectives of the actors which are central to all anthropological analysis (Rosato y Balbi 2003: 16).

To study the practice and valuations of all actors involved, we not only worked with producers and government agents but also with scientists from different disciplines that examined the issues from different directions: climatology, biology, ecology, geography and anthropology. The analysis was based on qualitative tools such as participant observation and in-depth interviews which were recorded and documented in the field diary, taking care to protect the identities of the interviewed. The analysis of these diary notes, in addition to showing the process of change, provided insight into the social perceptions of vulnerabilities caused by environmental change (Douglas 1996; Rappaport 1993). Throughout this paper, references to the field diary refer to the notes from the anthropological field work which was conducted in 12 periods of between 15 and 30 days each over 3 years. This resulted in 80 in-depth recorded interviews with different social actors such as large-scale agricultural producers, producers with precarious land tenure, small producers that had been displaced from their land and moved to the margins of rural towns, technical personnel of research organizations, and civil servants.

Monthly rainfall data from 1960 to 2007 were obtained from 6 stations of the National Meteorological Service (SMN) and the Secretariat of Hydrology of Argentina (SRH) between 22° and 26°S and 62° and 64°W and used to calculate mean rainfall and trends. All stations selected had <20 % of missing monthly rainfall data, and data quality was carefully checked. Monthly rainfall data in Mollinedo station were used to evaluate the evolution of rainfall in the most productive center of the Anta region. Annual precipitation was analyzed using a linear trend method of minimum squares, and statistical significance was tested using a Student *t* test.

Results

Environmental conditions

Beginning in the late nineteenth century, the Chaco forest was used for production of fence posts, railroad construction and operation, and for extensive grazing. This caused increasing degradation of the forest over the years and led to disputes over land and forest resources between the original inhabitants (Wichi and Toba) and settlers. The introduced cattle competed with the biodiversity of the Chaco forest, upon which the native people depended for their livelihoods (Interviews with traditional family farmers, field diary 2009–2010; Leake and de Ecónomo 2008; Trinchero 2000).

In the first decades of the twentieth century, commercial links between Argentina and the European markets generated an export boom for raw materials and meat, which supported owners of large land holdings although they invested little in production technologies (Rapoport 2008; Gordillo and Leguizamón 2002; Trinchero 2000).

By the 1960s, forest degradation had led to decreased productivity and to the introduction of agricultural alternatives in the form of Phaseolus bean production, and to an expansion of extensive grazing. Also in the 1960s, government investment in public works to regulate the flow of the principal river (Río Juramento) reduced flooding and provided river waters for small irrigation projects along its margins (Interviews with Salta's Secretariat for Water Resources and local producers, field diary 2009–2010). "When the Cabra Corral Dam was built, the land changed, water concessions were allocated… (the river level) and was regulated here by the Cabra Corral, and cultivation started" (Producer, field diary 2009).

Hydroclimatic trends

The Chaco of Salta in north-western Argentina is a semi-arid region characterized by frequent drought and highly variable seasonal rainfall. Annual evapotranspiration exceeds precipitation, and water availability limits agricultural potential and crop yields. The growing season is determined by rainfall. Dry season precipitation is minimal and coincides with the Winter months (Fig. 1). The years 1960–2007 were selected because all the stations had complete data for that period.

Regional precipitation trends between 1960 and 2007 (Fig. 2), analyzed by González et al. 2012, are positive although statistically not significant in many parts of the Chaco. This confirms previous results by Barros et al. (2008) and Liebmann et al. (2004). Figure 2 shows that positive trends increase toward the west. Trends in the area of Anta are significant ($p = 0.05$, for data from 3 stations) and >3 mm/year.

Records from Mollinedo station (24.5°S; 64.1°W) in Anta district, which is located in the center of the expansion of the agricultural activity, show a statistically significant ($p = 0.05$) positive linear trend in annual precipitation of 4.0 mm/year between 1949 and 2000 (Fig. 3). Despite the highly variable rainfall, the positive trend has greatly reduced the risk of crop failure for

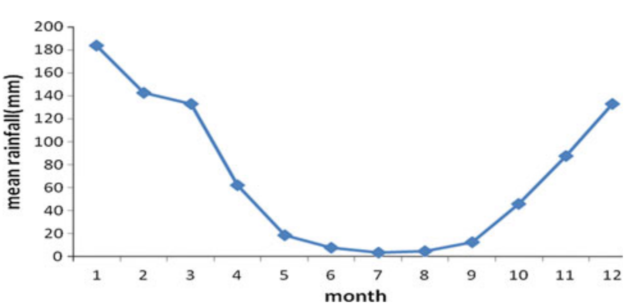

Fig. 1 Annual rainfall cycle in the area of study calculated as the mean monthly rainfall (mm) over 6 stations for the period 1960–2007

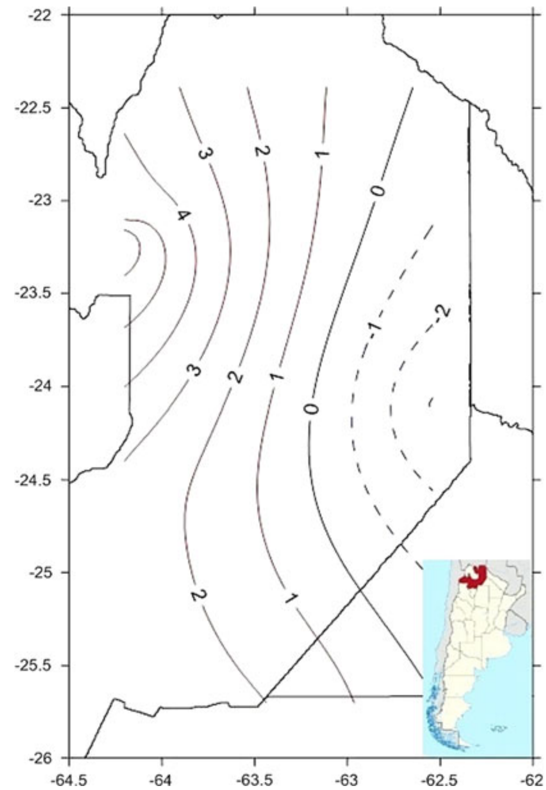

Fig. 2 Rainfall trends in the area of study (mm/year). *Solid lines* delineate areas with positive, *dashed lines* those with negative trend values (mm/year). The *inset* map (*source* Wikimedia Commons) shows the location of Salta Province in Argentina

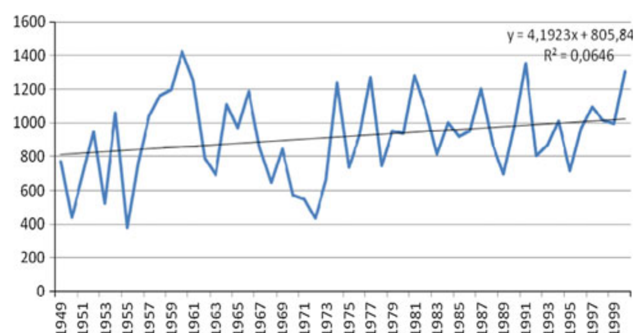

Fig. 3 Linear annual rainfall trend at Mollinedo for the period 1949–2000. Rainfall values in mm

soybeans which require between 500 and 600 mm of water during the growing season. This has facilitated significant changes in land use which went from mixed farming and forestry practices to intensive agriculture. The trend to almost exclusive soybean production was consolidated in the late 1980s when minimum tillage and direct seeding were introduced, which contributed to soil moisture conservation and reduced production costs. Soybeans and, when soil moisture permits, corn and wheat in rotations are now grown on an agro-industrial scale, and agriculture is still expanding.

At Mollinedo station, the increase in rainfall has leveled off since the 1980s, which has also been observed at other weather stations of the Anta region (González and Murgida 2012). Figure 4 shows rainfall trends in Mollinedo for the period 1980–2000: rainfall increased only 1.6 mm/year, which is lower value than the 4.0 mm/year calculated for the whole period of 1949–2000. This may in future limit the expansion of agricultural activities with implications for economic and social development and for the use of the water resources. Further south in Argentina, reversals in positive rainfall trends have already resulted in yield reductions.

Land cover and land ownership

The change in land use is seen in satellite images from 1972 and 2009 (Fig. 5). Figure 6 allows a more detailed analysis of the patterns in land use change and land ownership. An important characteristic of the land re-distribution process is the concentration in ever larger land holdings. In Anta district, 12 % of the enterprises have areas between 11,000 and 17,000 ha. One enterprise owns 63,000 ha and one other 41,000 ha, while four enterprises have between 35,000 and 38,000 ha. In addition, one of these has more than 100,000 ha under concession from the Provincial Government (Provincial Land Registry 2010). This distribution shows the increasing gap between a small number of very large landholdings and a larger number of small farms. Investment from the Pampas region and from outside Argentina is now influencing decision-making in the Province which has promoted land sales and the expulsion of traditional smallholders (field diary 2008–2010; Delgado 2007; Slutzky 2008).

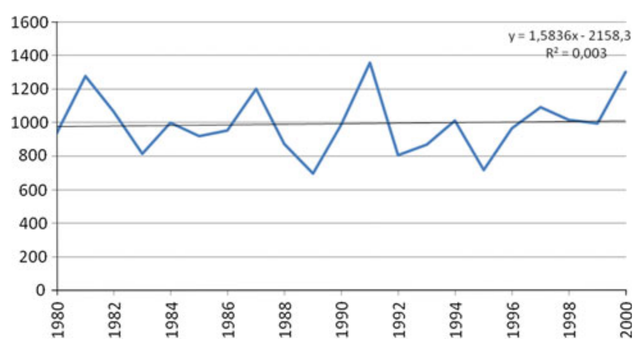

Fig. 4 Linear annual rainfall trend at Mollinedo for the period 1980–2000. Rainfall values in mm

The most recent property transfers in Anta district during 2000–2006 (Fig. 6, black) correspond to the expansion of the agricultural frontier into more arid areas and in some cases into the humid mountain forests of the Yungas. Some of these newly acquired properties are rented for agricultural production (field diary 2009–2010). Renting and ownership have become interchangeable options since low-performing capital markets have driven investors into agricultural investments (Arbolave 2003: 18).

Replacing the degraded forest with commercial crops radically modified the social landscape of the region. Producers who farmed state or private land with (often informal) permission found themselves displaced to less favorable areas or small towns. The changes in land ownership and production patterns are corroborated by an analysis of land titles. Since 2000, the concentration of land holdings has expanded beyond the region with rainfall sufficient for soybean production toward the East where

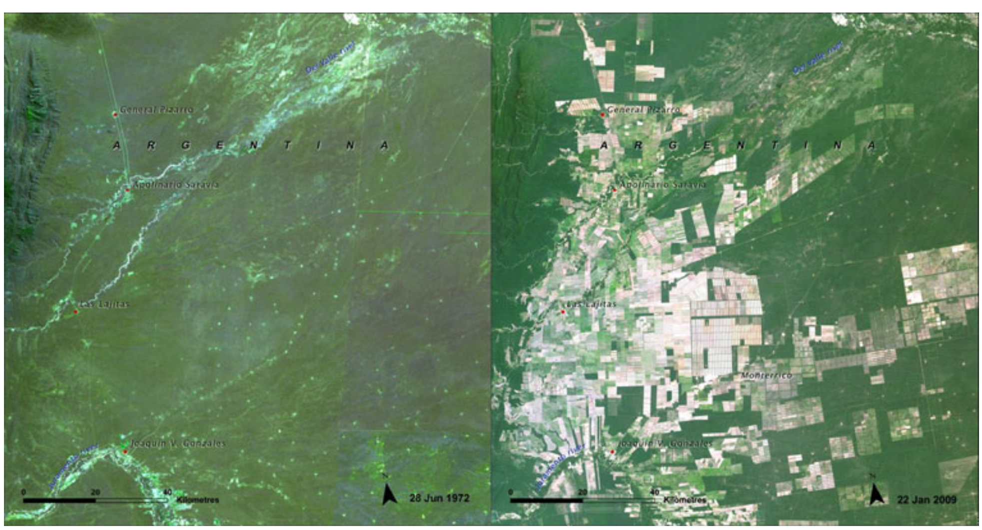

Fig. 5 Images from 1972 to 2009, respectively, for the Anta district. *Source* Water Center for the Humid Tropics of Latin America and the Caribbean

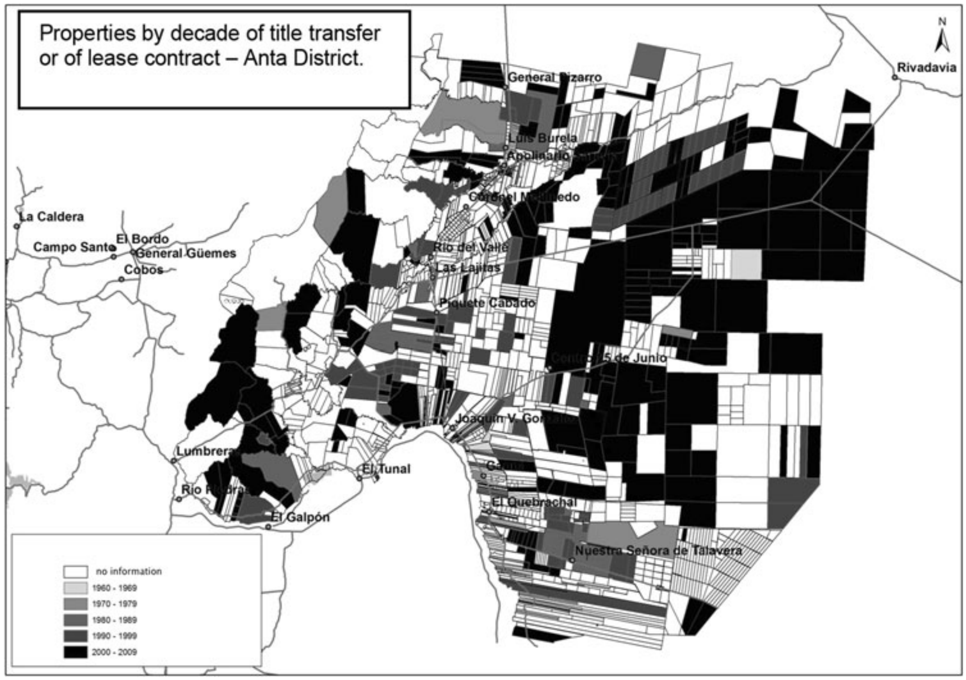

Fig. 6 Properties by decade of transference or of lease contract—Anta District. In Murgida, 2012 own elaboration based on land registry records

maximum rainfall is only around 500 mm, i.e., into areas of greater production risk (Murgida 2012).

In turn, changes in vegetation cover, such as deforestation for agriculture, have an impact on regional climate. Lee (2010), Collini et al. (2008) and Lee and Berbery (2012) concluded that crops replacing forests affect albedo, surface roughness and the energy balance between atmosphere and ground and may result in a decrease in precipitation. This would potentially aggravate a situation in which economically important precipitation increases are leveling off.

The agricultural use of the land has had a notable commercial success. For this success, social and environmental factors needed to come together. One factor was the availability of large areas from which natural vegetation can be cleared (Fig. 5) both on private and on public lands. Most of the public lands that have changed hands and have been cleared have traditionally been used for extensive animal production by small producers with ill-defined tenure or permission of occupation. Policies of the provincial government of Salta promoted forest clearing by making available to agricultural producers tracts of degraded forest that had been used extractively and partly logged. The successful land use change marginalized a vulnerable and undercapitalized population of small farmers. Our field work showed that small producers who used traditional technologies were experiencing an increase in their social vulnerability because, under changing legal conditions, their precarious land tenure is interpreted as illegal occupation by the provincial government and private real estate companies (field diary 2009–2010; Slutzky 2008; Trinchero 2000). This interpretation permitted a forced expulsion by the buyers or concessionaries of public lands. A number of traditional producers decided to take legal action to reaffirm their right of residence and production. Although a few won court cases, they saw their parcels reduced. This reduced their production potential which depends on traditional extensive grazing requiring large tracts of pasture, particularly in drier years. These producers have no access to capital for new technologies such as seeded, drought resistant pastures, or irrigation wells. Their precarious economic situation was further aggravated because their uncertain income excludes them from access to credit (Murgida 2012; Slutzky 2008).

Recognizing the risk to forest cover and to social equity, National Law N°26.331 of 2007 introduced minimum levels of environmental protection for native forests and Provincial Laws N°7.543 and N°7.658 created a program for regularizing land tenure and supporting small producers and rural families, which ended the expulsions of "campesinos." In 2011, the National Government developed a strategic plan for the Agriculture and Food sector, which re-established some of the regulatory government functions that had been left to market forces during 1985–2003.

Changes in technology and redistribution of resources

The redistribution of land was accompanied by capital investment for agricultural development and technological innovation such as genetically modified crops and minimum tillage with direct seeding. This investment in technologies soon required supplemental irrigation to sustain productivity in all years. Until now, irrigation is largely limited to areas near rivers where surface water is available and groundwater is shallow. Further away from rivers, groundwater suitable for irrigation or animals is found only below 200 m. Because of the high costs of drilling and pumping, such areas remain dependent on rain only (field diary 2008–2010).

Public infrastructure works concentrated on the rivers and their catchment areas. Dams were built to control the annual flow needed for irrigation and to avoid seasonal flooding. The availability of irrigation waters was promoted by laws on the provision of water to agriculture.

The ecological and social fragility of the semi-arid region was enhanced by the changes in the landscape required by intensive agriculture. The transformations affected both social and natural components of the system. Land clearing and land concentration in a few hands forced the subsistence population into urban areas with few possibilities for economic integration. In rural areas, the transformations were mediated by public and private mechanisms and social organizations that control access to land and water resources.

Historically, legal access to water was directly related to land tenure, as defined either by occupation with permission or by private ownership: who had the rights to the land, also had the right to water. Since the founding of Argentina, the legitimacy of access had been rooted, either by law or by custom, in the ethics of political decision-making. Laws considered conditions such as the origin and length of the occupation and the type of production (forestry or livestock). Between the 1930s and 1940s, a new public policy considered water as part of the public domain (unless an entire water course belonged to a single property). During the first government of Peron (1946), "acquired rights" to land and therefore water were formally repealed, although in practice they continued to be applied (Murgida 2012; Hoops and Ashur 2004). In the early 90s, the control and management of water for both productive and domestic use was placed in private hands. This policy was favorable to the expanding agricultural production for a growing export sector and promoted efforts to increase water availability in support of sustained returns on agricultural investments oriented toward international markets.

During those changes, government strategy aimed at a decentralization of functions. The Province was left with legal responsibilities and regulatory administration, while management and control of the distribution of water were left to associations of irrigation users. These independent producer associations have elected officials, pay the Secretariat for Water Resources for water use, and generate revenues from charging differential water fees according to the category of producer: highest fees for large water users with more than 6,000 ha, followed by medium irrigation units with about 1,000 ha, small farms with 20–30 ha, and *Criollos* with ill-defined land occupancy. Although the amount of irrigation water is regulated, there are exceptions for more productive enterprises and larger water concessions can be granted by special act of the Province (government officials, field diary 2008–2010).

Water management consortia were founded to provide a participatory space for achieving consensus on the control of water resources and resolving conflicts between users, for the dissemination of technical information, and for promoting public works by the provincial government. It is the larger producers, who tend to participate in these consortia and make decisions. Small farmers rarely participate and are often excluded with arguments of a lack of technical knowledge needed to understand the issues discussed at meetings. This broad social sector is excluded from participating in decisions on the distribution and access to water, because of its limited capacity to assimilate technologies and invest to take advantage of such "opportunities." The need for financial capital and large land holdings limits small producers' competitiveness in the commodity market, and the pressure of the real estate market has pushed many to sell or lease their land (Murgida 2012; Trinchero 2000; Gordillo 2006).

Interaction between hydroclimatic and social dynamics

In recent years, it is becoming apparent that intensified production, new agricultural technologies and irrigation are slowly having undesirable environmental impacts. After an average of 15 years of minimum tillage, the region's loamy soils have a tendency to compact and surface-seal. Reduced infiltration then generates run-off and flooding. This shows the technical limitations of the current land use system to regulate hydrology between capture, distribution and drainage (Murgida 2012; Aciar et al. 2008). Compaction combined with soil organic matter loss leads to soil erosion. The low annual transpiration from seasonal crops, as compared to that from permanent vegetation, is causing waterlogging and raises groundwater levels. This amplifies risks and social vulnerabilities: water can accumulate in neighboring fields, and flooding of urban areas during the rainy seasons has become common. Towns are usually bounded by roads, which act as barriers, aggravating floods during intense storms (Murgida 2012; field diary 2008–2010; Marcuzzi and Bolli 2007). These urban areas have grown as a result of population displacement and expulsion of the non-tenured rural population and by attracting agricultural workers from other towns and Provinces.

Large investors and land owners are now beginning to experiment with what is known locally as "comprehensive water management": irrigation and drainage of rain or irrigation water is regulated with a system of dams which allow water storage and re-use for irrigation. Project promoters say the program will harmonize land management with the landscape's hydrological functions, while also controlling sedimentation and maintaining water quality (Salomón 2011). Producers placed the integrated water management proposal in the system of public governance, since it requires implementation beyond the farm level and the coordination of canal construction between neighboring land holdings. Currently, this new technology is being tested in the catchment of River Del Valle near Las Lajitas where floods have occurred almost annually since 2005 (Murgida 2012). It is expected that the initiative will reduce inundations in urban areas (Murgida 2012). Positive evaluations by the promoters of the project and the government are not entirely confirmed by scientific research, and the resulting uncertainty highlights the need to assess possible negative effects on the watershed.

Conclusions

Linking the natural science of climate and ecosystems with a social analysis allowed us to describe the transformations of productive practices and their social, technological and market relevance in the context of the control over natural resources and the consequent restructuring of the territory. Social structures, transformations and development were considered in the context of environmental transformations with their causes in and effects on both natural resources and society. In other words, we linked environmental and societal phenomena to opportunities and risks. The combined effects of soil degradation and run-off and the implementation of new technologies aiming to optimize the balance between the need for water and the potential for floods remain a source of uncertainty.

Other studies in the region have shown rising groundwater levels, local waterlogging and salinization (Nosetto et al. 2008; field diary 2008–2010). In socio-political terms, the responsibility to react to such changes rests with state policies that should anticipate the potential effects of changing resource management. Therefore, national and regional development policies which are often fragmented and favoring private rights in production and resource use must be accompanied by thorough risk assessment at scales well beyond the individual production unit or resource user association. The magnitude of the current changes implies a potential hazard that is not being fully addressed by provincial and national policies, even though it produces a scenario of production, environmental and social uncertainties.

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