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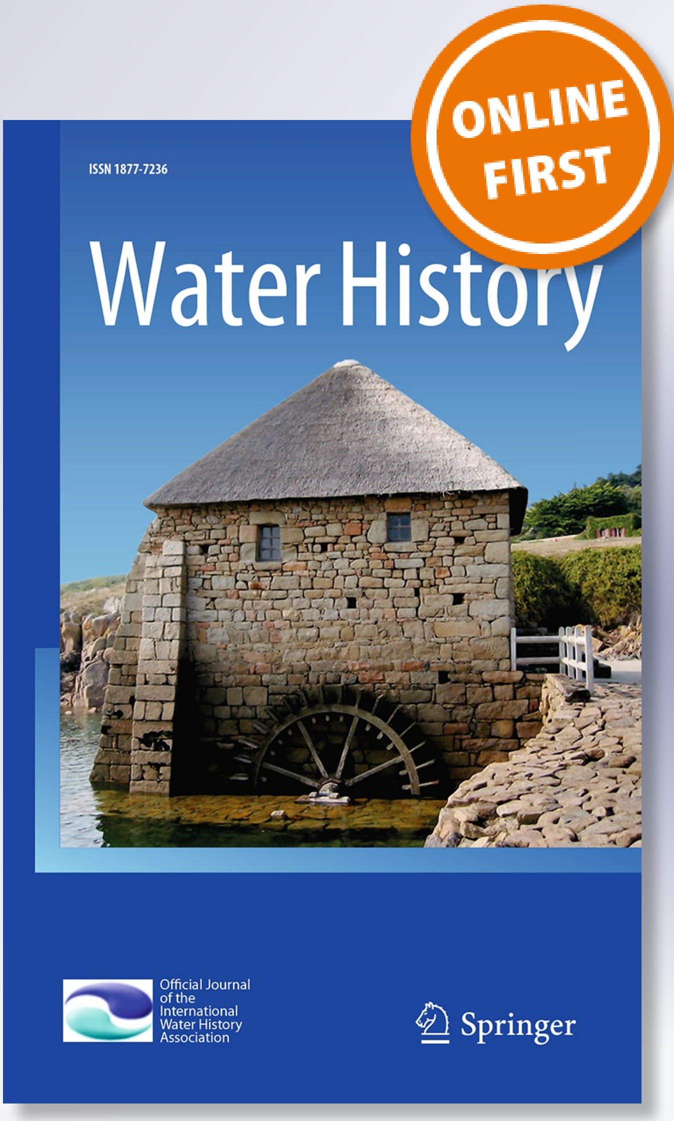

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Water management in the Argentine semiarid Chaco: a historical perspective on social-ecological systems

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Abstract This article explores how historical processes related to water management, land use and bio-geophysical conditions, would have structured the current socio-ecological situation at the Figueroa Irrigation System (Santiago del Estero, Argentina). The study focuses on a peasant community through an oral history approach. In addition, historic technical reports about irrigation systems and river dynamics, and other secondary information were reviewed and compared with local peasant testimonies. The results suggest that government actions—taken at regional level on the Salado River basin—had a negative impact on the local agro-ecosystem and on management that had been adapted to local ecosystem dynamics. This study proposes that past events still influence river dynamics and therefore land use and natural resources management of local peasants. The role of local historical perspectives is a key element to understand social-ecological system changes and to forecast future trajectories.

Keywords Peasants · Common-pool resources · Irrigation system · Land use · Erosion

Introduction

Over the years, the Chaco region, a semiarid land with xerophytic forests located in north-central Argentina, has undergone many changes, going through various stages of human exploitation of natural resources, which generated a variety of changes in the landscape (Morello et al. 2007). The so-called "pampeanization" is the stage that has produced major

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changes, and possibly the most important in terms of landscape transformation (Morello et al. 2012). "Pampeanization" is the process of moving the entire technological package used for agriculture of the Pampean region (transgenic seeds, no tillage and agrochemicals) to other regions such as the Chaco, under the assumption that ecosystems behave the same way with identical results (Pengue 2004, 2005).

The historical processes of exploitation of natural resources, and the expansion of agricultural, agro-industrial and urban frontiers in the Argentinean Chaco region—along with the resulting degradation of important ecosystems—have ecological impacts at different scales, from local to regional (Adámoli 2006; Morello and Rodríguez 2009; The Nature Conservancy (TNC) 2005). These impacts include: modification of plant community structure and species composition (Torrella et al. 2013); habitat fragmentation (Correa et al. 2012; Gasparri and Grau 2009; Torrella et al. 2013; Zak et al. 2004), and serious defaunation (Giraudo 2009). These events lead to biodiversity loss and, in terms of usefulness to human societies, to the loss of ecosystem services (Cardinale et al. 2012). Native vegetation replacement by annual crops also means the loss of key ecosystem functions, such as the ability to control erosion, the regulation of hydrological regime, and the loss of ecosystem resilience (Volante et al. 2012).

Although this is a problem with common characteristics across the region, local specificities can get lost in a regional perspective. A community-level approach can provide information and elements for analysis for a deeper understanding of the multiple processes that lead to change in land use at the regional scale. Thus, the local historical, social and ecological processes were analysed in the area of the Figueroa irrigation system, Figueroa County, Santiago del Estero, Argentina, situated in the semiarid Chaco subregion, Dry Chaco ecoregion (Morello et al. 2012).

The Figueroa Irrigation System is on the Salado River, and it was built in the late 1940s and early 1950s. In 2008, after 30 years of inactivity, its reconstruction began. According to Roldán (2006), prior to reconstruction, the irrigated area reached a maximum of 7000 ha, and after its completion it might irrigate about 27,000 ha.

The current reconstruction of the irrigation system and associated works, such as construction and paving of roads, extension of power lines, etc., in Figueroa County may have various consequences. On the one hand, they would allow agricultural activities that involve the replacement of forest cover or changes in forest structure (e.g. development of sown pastures using exotic forage crops). On the other hand, it would have consequences for the structure of land ownership. The peasants living in the area for several generations do not have ownership titles to their land. The new infrastructure raised the value of the land, and thus renewed the interest of extra-local entrepreneurs, generating conflicts linked directly or indirectly to the property, possession and use of land, and natural resources.

The aim of this study was to analyse historical, social and natural processes in order to identify the main factors that structured the current social-ecological situation in the area of influence of the Salado River in Figueroa County, Santiago del Estero. To achieve this aim, the case of a community located on the Salado River banks, and historically incorporated in the irrigation system, was considered. The focus was on land use strategies, agricultural practices and water management. Also, various elements of social-ecological systems were evaluated, as land tenure, rural labour conditions, as well as changes in bio-geophysical conditions as climate, river dynamics and soil erosion. The agro-ecosystems management styles prior to the construction of the irrigation system and during the operative stage were described. Also, the causes that led to the system deterioration and loss of its operating capacity were analysed.

Theoretical background

An agro-ecological approach was adopted, which considers that it is impossible to achieve an understanding of the link between society and nature without consideration of the historical dimension of this interaction (Guzman Casado et al. 2000).

Current agro-ecosystems are the result of various historical processes. The characteristics and dynamics of agro-ecosystems respond both to socioeconomic and ecological pressures that are exerted on natural ecosystems over time. Simplification of ecosystems by societies, in a greater or lesser extent, alters ecosystems' structure and functioning. Processes of ecological succession may be delayed, or resilience and resistance of these ecosystems may be altered through processes that may differ in the spatial and temporal scales (Guzman Casado et al. 2000).

An agro-ecological approach incorporates the principle of social and ecological co-evolution, which considers the interplay between society and nature over time (Norgaard 2006). The human and ecological components of social-ecological systems interact under various external, political-economic and bio-geophysical conditions (Redman et al. 2004). The past and its analysis can be incorporated as methodological tools, either to make a proper diagnosis of agro-ecosystems or to propose solutions to environmental and social problems. This practical application of history highlights the importance of a historical perspective for the diagnosis and proposal of solutions to the myriad social and environmental expressions of the ecological crisis (González de Molina and Toledo 2014).

A historical perspective is incorporated when time series of physical and biological parameters (rainfall, temperature, soil erosion, abundance/density of animal or plant populations, etc.) are developed, and when the most important anthropogenic modifications and factors that explain their temporal variations are placed at a given time. The approach is not limited to the consideration of environmental variables, but it also helps integrating these with social, cultural and economic variables. It seeks to identify the main factors that influence the structure and functioning of the agro-ecosystem. The ultimate aim is to search for explanation and understanding of the intensity of change and to identify the subjects that provoked these changes (González de Molina and Guzmán Casado 2006).

The purpose of the approach is to learn about the historical path of the agro-ecosystem; that is, to reconstruct its structure, functioning and the changes it has undergone over time. It also attempts to evaluate different forms of agro-ecosystem management that operated historically; to understand how humans have been affected by their natural environment over time, how humans have affected the environment, and what were the results (Worster 1990).

Methods

Study area

The South American Chaco is the biggest continuous dry forest in the world; it is the second largest forest ecosystem in South America after the Amazon. This region is a large alluvial plain extending over northern Argentina, western Paraguay, eastern Bolivia and a portion of south-eastern Brazil. It occupies over 1,000,000 km^2 north and south of the Tropic of Capricorn. Almost 62 % of this area is in Argentina.

The Argentine Great Chaco is divided in two ecoregions: the Dry Chaco to the West and the Humid Chaco to the East. There are some differences in climate, vegetation formations and land use between the two ecoregions, though they share general characteristics, such as high biodiversity, the main tree species and fauna, and cultural diversity.

The climate is subtropical, with average summer temperature ranging from 28 to 22 °C from North to South. Due to the continental nature of climate, there are large temperature variations between summer and winter; maxima of 47 °C can be reached in summer while frosts can occur in winter. Mean winter temperatures vary between 17 and 10 °C latitudinally, from North to South. Mean rainfall decreases from 800 to 500 mm from east to west in the Dry Chaco ecoregion, though it increases again up to 800 mm in the vicinity of the Andes, to the West. In the Humid Chaco, mean rainfall increases from 800 to 1200 mm from West to East. Rainfall concentrates in summer. The water balance has negative values for 10–12 months in the year.

Case study

Figueroa County is located in the northwest of Santiago del Estero province and has an area of 7168 km^2; this is about 5 % of the provincial total, and it has 17,820 inhabitants (2 % of the provincial total). The household percentage with at least one unsatisfied basic need (UBN) is 37 %, one of the highest rates across the country. Those households hold about 40 % of the county population. All of them (100 %) are in rural areas, 74 % of which are scattered (3192 dwellings), while 26 % (1099 households) are grouped in small towns. Most of the homes (67 %) are "Rancho type", with adobe walls, dirt floors and thatched roofs (Instituto Nacional de Censos y Estadísticas (INDEC) 2010).

Figueroa Irrigation System (Santiago del Estero, Argentina) is located in the semi-arid Chaco sub-region, Dry Chaco ecoregion (Morello et al. 2012). The Dry Chaco Ecoregion is covered by xerophytic open forests, in which quebracho species (*Schinopsis lorentzii*, *Aspidosperma quebracho-blanco*); mistol (*Ziziphus mistol*) and *Prosopis* spp are the most frequent tree species. In the driest central fringe, distinctive patches of burned vegetation stretching in a south-north direction, originating from by natural and human fires, interrupt both physiognomies.

The Salado River belongs to the Pasaje/Juramento/Salado system; these are the different names the river acquires along its course. This system has its headwaters in the Precordillera, Salta province, from the confluence of two smaller rivers, where it acquires the name of Pasaje. In the headwaters of the Pasaje River, in the village of Cabra Corral, lies the hydroelectric dam General Manuel Belgrano. This dam, which became operational in 1973, is the largest work in the system. Downstream, the river takes the name of Juramento, where there is another major hydroelectric project, El Tunal Dam. Upon entering the province of Santiago del Estero, the river takes the name of Salado, and flows southwards (Fig. 1). In this province, the only water regulation work is the recently rebuilt Figueroa Dam. In this sequence, the river changes from a mountain river (Pasaje/Juramento) to a plain river (Salado).

The Figueroa system construction began in 1944, when the government built the so-called "El cero" o "Kilometro 0" Dam. Two kilometres upstream from it, with bigger capacity, the Figueroa Dam was constructed in 1955. Both reservoir dams were made entirely from earth. Few years later, the main canal (called Gini) was made. This canal goes from "Kilometro 0" Dam to the "Km 40" location, crossing a considerable part of the irrigation area in northwest-southeast direction, with approximately 41.4 km total length (Fiorentino 2001). The Figueroa Irrigation System consists of various infrastructure and

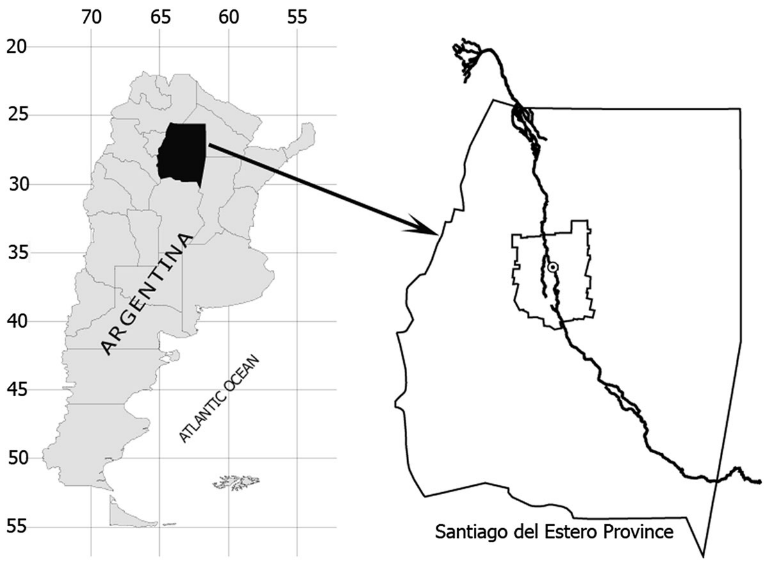

Fig. 1 Location of El Pirucho (*white* and *black point*) in Figueroa county of Santiago del Estero province (*black*) and Salado River

associated irrigation areas. These include the Figueroa Dam that regulates the Salado River waters, a main unlined canal, secondary canals and irrigation ditches (Fig. 2).

This case was selected because of its particular conditions compared with neighbouring counties: the presence of a large continuous forest and the lower deforestation rates of the province (Volante 2014); common property land (de Dios and Ferreyra 2011); almost complete absence of soybean cultivation, main driver of deforestation in the whole Chaco region (Pengue 2005); the presence of irrigation infrastructure in a rain-fed region; and serious soil erosion processes in the irrigated area (Arístide 2014; unpublished thesis).

Data collection

According to the proposed objective, the analysis level and the work scale, interviews with local people were the main tool to gather information, as part of an Oral History approach (Alberti 2005; Sabaté Bel et al. 2008). Through Oral History, the researcher has contact with individuals who have experienced events or who have heard others speak of them (Medeiros et al. 2014). Different approaches to the Oral History are possible. In particular, we have drawn upon Thematic Oral History because it gathers data on a topic, defining dates, facts, names, and situations. In contrast with Life Oral History that is often referred to as biography, life stories or a biographical report, the nature of Thematic Oral History promotes discussions, debates, and the comparison of versions and can be combined with other sources (Medeiros et al. 2014).

Secondary sources of information were consulted, mainly technical reports (about hydrogeology, river dynamics, local social and environment conditions and economic activities) prepared for the reconstruction and rehabilitation of the irrigation system, which are available in the Federal Investment Council (Basán Nickisch 1994; Fiorentino 2001; Roldán 2006). The Federal Investment Council (CFI) is a federal agency created in 1959

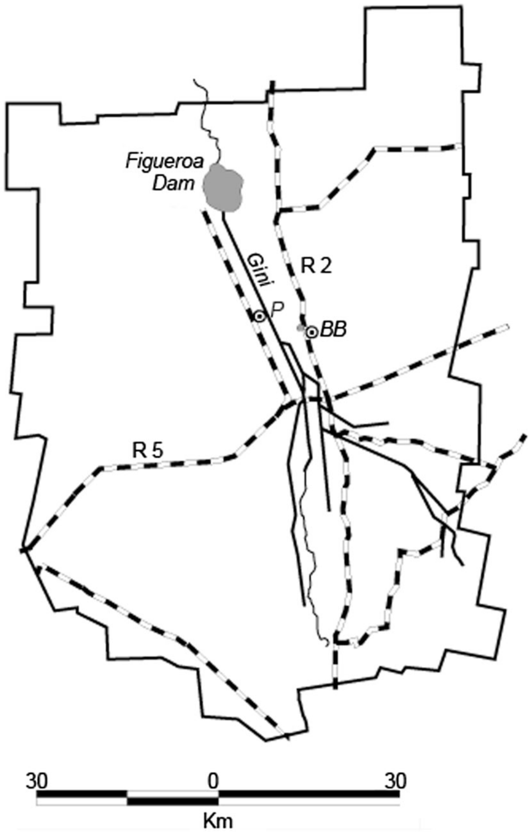

Fig. 2 Figueroa Irrigation System in the Figueroa county, province of Santiago del Estero, Argentina. Figueroa Dam, canal network, routes and localities (*R5* provincial route N°5, *R2* provincial route N°2, *P* El Pirucho, *BB* Bandera Bajada, *Gini*: main canal of the Figueroa System)

with the aim to guide investments in each of the provinces of Argentina. Technical reports derived from each of the executed projects are archived in the Council library.

El Pirucho is an area of scattered rural population in Figueroa County, located on the right bank of Gini canal, 12 km south from Figueroa Dam, extending up to km 21. It is located 15 km from Bandera Bajada town, and 100 km from the provincial capital city. El Pirucho is composed of 100 families, 70 of which are descendants of farmers of at least two generations in the area. Field data were obtained through semi-structured interviews with ten inhabitants of the community El Pirucho.

For the interviewee selection, the snowball technique was applied (Nichols 1991; Sabaté Bel et al. 2008; Albuquerque et al. 2014). Complementarily, participants complied with additional criteria, such as being farmers for more than 50 years and being born in the study area. Through preliminary discussions with a local expert on the peasant problems, born and raised in the town of study, the first names of those who could provide expertise in terms of the objectives were suggested. These people, men and women, were already known to us, so there was a climate of mutual trust, which gave the information a high degree of reliability.

The number of interviews was dictated by the degree of “saturation or redundancy” in responses, indicating that the representation level was achieved. This sets the tone for the reliability of information (Valles 1999; Ottmann 2005). The interviews were conducted in August 2009 following a script previously prepared. The topics focused on family history (provenance or years of establishment in the area), and various parameters and their changes over the years, such as: type and scale of production activities, energy source, production unit self-sufficiency, agricultural system design, technologies, tools and knowledge, number and varieties of crops, water management, among others.

The interviews were digitally recorded and then literally transcribed. Thematic sheets, with excerpts from the interviews, were elaborated to analyse the information. This allowed to contrast the story of respondents with each other and with secondary information, and to develop a timeline of major historical events related to water management and agricultural activities. From the voice and the memory of the inhabitants of El Pirucho, the events that have marked local life and the different stages of water management and productive activities could be clearly identified.

Social-ecological trajectories in water management and land use in Figueroa, Santiago del Estero

Wetland farming period

Until the Figueroa Dam was built in the 1950s, agriculture in the area consisted of what could be called wetland farming. Agriculture was supported by periodic floods of the Salado River, and livestock on flooding grasslands was the main activity. This type of activity had been developed by indigenous people who inhabited the region (Palomeque 1992), and it continued up to the 1950s. During this stage, families usually had two houses that were alternatively used depending on time of year and state of the river. One of the houses and crop areas were in the flood zone, and the other in the upper area near the forest. The families moved from one house to the other along with the cattle.

Although the producers understood the river dynamics, they remained vulnerable for unexpected floods that prevented crop harvest. Due to the frequency of flood events that could not be predicted, people saw with enthusiasm the possibility of regulating floods with the dam constructed by the government in the late 1950s. Many of the local residents worked in dam and canal construction, encouraged by the possibility of future benefits.

Livelihoods and land use strategies during Figueroa Irrigation System operation

After the dam and main canal construction, towards the end of 1950s, "wetland agriculture" changed to a spate irrigation model. However, water has not been totally canalized (only through the main canal), and therefore the crops were irrigated by water running down the field. After the annual flooding period, farmers used the grasslands for livestock, and planted arable plots (called *cercos*, meaning hedged parcels) (Fig. 3) that were also located in temporary flood zones. However, unforeseen floods persisted, forcing farmers to withdraw sooner from the floodplain. Most probably it was for this reason that families sought to settle permanently in the uplands, while they kept crops in flooding areas.

Despite the difficulties related to the floods, the style of management was still an integrated system where different ecosystem resources and landscape units were used depending on time of year and the river dynamics. In the dry season, the lowlands were used for various crops, and for livestock raising on fallow land within the *cercos* or on natural grasslands. During floods, grazing occurred in forest areas with natural pastures

Fig. 3 *Cercos* (arable plots) in El Pirucho

(communal forests), where cattle also had access to the fruit of trees and shrubs. Thus, there was a large livestock mobility allowing full utilization of different ecosystem resources. Even when families settled permanently in one place, they kept a diversified strategy including agriculture and livestock, as well as fishing during flooding.

At that time, among the crops mentioned by interviewees are wheat, corn (with at least four landraces), beans, cotton, alfalfa, sunflower, and local varieties of horticultural crops such as squash, melon, watermelon and sweet potato, among others. Livestock included cattle, horses, goats, sheep, pigs and poultry. Production, especially garden crops and small livestock, was destined to family consumption. Cotton and alfalfa were the main cash crops. Cotton was strongly linked to the use of agrochemicals, which contrasts with consumption-related crops (like corn, vegetables, etc.), where until today no fertilizers or pesticides are used. The application of agrochemicals on cotton was done with backpack sprayers, and soil management was done with traditional animal drawn plough.

The interviewees recall this period as a time in which they could obtain all the necessary goods for consumption from production or from sale of their produce, which allowed them to acquire other goods not produced by them. Cotton, wool, alfalfa seeds, small animals (pigs, goats) were mentioned as products for sale. Another activity that complemented the strategy for monetary income was seasonal wage labour. In the dry season, during the winter, one or more family members worked for 1 or 2 months in cotton harvesting in north-eastern Argentina (Chaco province), or in the harvest of sugarcane in the north-west (Tucumán province). However, the involvement in this activity was variable among families, and there were those who did not participate in wage labour because they could meet their needs with work in their own field. Seasonal work outside the household was much more common in early years, while trips were infrequent in the late 1960s (Vessuri 1973).

A predominant issue in the interviews was the high degree of cooperation that existed between family groups, neighbours or friends living in the town. The supportive and cooperative exchanges between neighbours included most products and crops. Bartering was a common practice; local produce was exchanged as obtained and needed. Those who harvested first, offered the product to neighbours, who later returned the favour with their own produce. When an animal was slaughtered, the pieces were lent to other families until these slaughtered their own animals and returned the loan. Bartering was a defining feature of the natural resources management style; it is typically a peasant-like behaviour widely reproduced in such communities (Toledo et al. 2002; van der Ploeg 2008). This practice diminished the risks of farming, and avoided recourse to the market to stock these products.

The seed of local landraces were also freely exchanged between neighbours, avoiding seed purchase every season. A portion of the best seed was kept for future sowing; those who harvested more seed bartered it with those who obtained less in a particular year.

New changes in water management

Irrigation in the area created new agro-ecological conditions in the early 1970s. In 1971, the local community members of El Pirucho built small canals at km 12 from the Gini main canal. These canals watered the *cercos* through a network of ditches. A secondary canal from the main canal ran parallel to the first one. El Pirucho residents began to manage water with this secondary canal, from km 12 to 23. Each producer was responsible for ditch construction to irrigate his field. At km 12 of canal Gini there was a bridge, but without locks that would allow water diversion to the field plots. The peasants used to build a sort of wall with trunks and branches (called *enchampe*) attached to the bridge in order to contain the water coming from the Figueroa Dam, and to generate pressure to feed their own canal. This irrigation system implied the cooperative work of almost all men in the community.

At that time, the irrigation water flowed only through canals, and the maintenance of the main infrastructure was the responsibility of provincial institutions. However, maintenance of ditches and minor canals was the responsibility of local farmers. These minor canals had gates that were operated by an employee of the provincial government, who was in charge of collecting irrigation fees. Thus water management differed from the previous periods, despite the flood deficient control exerted by the dam.

Land tenure, land use and social relationships

At this time small producers formed a large majority. According to official data, farmers with less than 20 ha came to 91.1 % of the producers registered for irrigation, which amounted to a total of 922 farms (Vessuri 1973). Large farms were a minority, with areas from 4000 to 16,000 ha. However, a much smaller portion of the total area was used in each large farm. Available data show that even farmers who owned more than 1000 ha planted under 20 ha of irrigated land. According to research by sociologists of the Bariloche Foundation requested by the Federal Investment Council (CFI 1972), these landowners argued that it was not worth clearing land because irrigation was not guaranteed, and in one or two years, the forest would cover the abandoned parcels. A further explanation given by the authors is that labour costs were increased by the need to hire staff for cleaning and farming.

An important element related to large farms, was that the legal status of land tenure was extremely precarious. One type of farm described in CFI (1972), was that of supposedly private lands but without title deed. Whether legal ownership of land was in doubt or not, it was customary that small producers worked under sharecropping or lease arrangements (verbally agreed, rarely written). These contracts stipulated a payment of 15–20 % of the produce to the owner or supposed owner. This situation, as it is put forth today by peasants in El Pirucho, was a direct driver of worsening of work and life conditions.

Relations between the farmers and these alleged landowners, far from being cordial, included violent peasant evictions from agricultural areas. Arsons over peasant property fences, and armed threats by landowners were very common. In this way, "contracts" whereby the alleged owner appropriated the local peasants work were imposed upon. This is a central aspect reflected in the historical narration of its protagonists that the CFI's research (1972) did not record.

Currently, two characteristics are fundamental in Figueroa: the relatively small area of deforested land, and therefore, the prevalence of large continuous forests. The county had the lowest deforestation rate in the region in recent years (Volante et al. 2012; Volante 2014). Three factors operating during this historical process would also be key to understanding the characteristics of the current socio-ecological system. Firstly, the land occupation history played a pivotal role, and in this case, the peasant style of nature appropriation stands out. Historically, the majority of the local population adhered to this way of appropriation, in which production was based on small-scale farming combined with livestock in community forests. Secondly, the possibility of agricultural water access caused the gathering of a major proportion of all inhabitants in the irrigation area and in the wetlands. In 1980, there were 11,340 inhabitants in the irrigated area, corresponding to 2500 families and 70 % of the Figueroa county population (CFI 1983). This strongly concentrated the county economic activity in this area, while the forest land was used for livestock, and intensive logging did not occur (although it was practiced in previous years).

Finally, given the irrigation system shortcomings, which increased the risk of not being able to irrigate the deforested areas, large farmers deforested and cultivated only small parcels, leaving large areas of land covered by forests. Therefore, it is likely that part of the explanation for this state of affairs in Figueroa would be the processes described above, which revolve around the presence and attraction exercised on productive activities by the Salado River and the irrigation system.

Climate change, river dynamics and soil conditions

From the mid-1970s, the situation in El Pirucho changed, as reflected in interviews with producers. They highlight changes in climatic and soil conditions. They remember these years as very wet, with a decreasing trend in the late 1980s and early 1990s. This is consistent with the weather data of the area. Reports of the provincial office of the National Institute of Agricultural Technology show the evolution of annual precipitation and precipitation cycles for the province. The records show that before 1965 rainfall average was 600 mm/year; between 1965 and 1975 the average increased to 750 mm/year after which it remained stable. This resulted in a changing climatic classification from semiarid to humid-dry. From 1976 to 1985 and from 1996 to 2002, two subsequent rainy periods were separated by a dry season from 1986 to 1996 (Adámoli et al. 2004). The local producers showed to be aware of these transitions.

Hydro-climatic studies by Basán Nickisch (1994) analysed the Salado basin precipitations for the intervals 1973/1974, 1980/1981 and 1983/1984, in which extraordinary floods of the Salado River occurred. For 1974, as a result of the heavy rains and the rising river, irrigated lands were flooded (Basán Nickisch 1994). Damage throughout the system began with this flood, which produced serious impacts on the population and on crop areas as well. From this time, flooding of the fields has a greater negative effect.

Irrigation infrastructure, both reservoirs and minor canals, began to deteriorate at this time, but especially from 1980 (Roldán 2006). The successive floods destroyed the bridges used by producers to dam up water. In addition, an intense erosion process started around 1980 south to Route No. 5 (Fig. 2), forming a large gully. In 1985, this gully destroyed and cut off the road to the capital city. Currently, the gullies are between 5 and 6 m deep in some places (Fig. 4), and traverse the entire area, preventing local people from access to irrigation water.

In 1987, the gully moved northward, cutting the canal that started from km 12. This canal provided irrigation water to the residents of El Pirucho, and carried drinking water to the Cuchi Pozo reservoir in the town of Bandera Bajada. The gully also cut the road leading from El Pirucho to Bandera Bajada. The canal was out of service and then, the entire irrigation area north of km 21 ran out of access to irrigation water. For this reason, the producers built a new canal which started from Gini main canal at km 14, where there was another bridge without locks. This bridge was later destroyed by floods. At the end of the 1980s, it was impossible to irrigate the fields, and most of the plots were abandoned. The agricultural census shows a 70 % decrease of the cultivated area in Figueroa between 1988 and 2002.

With the beginning of the Cabra Corral Dam operation of in 1973, and later of the El Tunal Dam, the regime of the river began to change its dynamics, characterized by marked periods of drought (July to December), medium water (January, May and June) and rising water (February to April). An example of the impact of this human activity is the construction of a canal in 1981, to drain the Horcones River wetlands (tributary of Salado in its upper reaches), driving their water directly to the Salado river. This work impacted its surroundings, triggering a process of gully erosion. The continuous drainage of the ground water generated increased salinity of the Salado River. Additionally, the flood attenuation

Fig. 4 Main Gully 6 m deep near El Pirucho

effect of the wetland was minimized, increasing the peaks in flooding times, which affected directly the Salado River (Basán Nickisch 1994).

According to Basán Nickisch (1994), the Salado River was in a changing phase, seeking its natural balance profile of "slope/flow". This is the reason why the headward erosion process was originated with the consequent collapse of much of the Figueroa irrigation system. However, causes for this process are found in large changes generated by the infrastructure within the entire basin. This is clear in the case of Cabra Corral Dam. The river carries a large volume of suspended solids and the dam works as a decanter which prevents the movement downstream of these solids, thus constituting a direct alteration of the slope-flow natural dynamics (liquid and solid) of the river. From these changes, the river looks for a new equilibrium profile, which makes it highly erosive downstream of the dam.

Another important management impact, which adds to the gully erosion process, is the deterioration of the chemical water quality, whether it is intended for human consumption or agricultural use. The addition of salts derived from soil leaching and from the water table is a result of these processes. According to Roldán (2006, p. 30), "the sequence of hydrologic events of varying intensity, the erosion processes, whose effect has been enhanced by some deficiencies in the original design of hydraulic structures, added to construction defects in some of them, and the inappropriate hydrological emergency management in the irrigation subsystem, have resulted in its current poor state". At the same time, Basán Nickisch (1994) considers that deforestation for agricultural purposes in the upper basin, in Salta province, has aggravated the consequences of the extraordinary flood that occurred in the mid-1980s downstream in Figueroa County, which affected severely the entire zone.

The decline of agricultural activities

Roldán (2006) concludes that agriculture in the area becomes less important as a result of Figueroa Dam becoming out of service, the general difficulties of irrigation and the accelerated degradation process of the Salado River flood plain. Only a few large producers maintain cotton as the main crop, and small and medium farmers base their agriculture on alfalfa and corn.

Some surveys conducted in the area in 1994 and 2000 characterized the producers of El Pirucho according to the productive system of those years. The 1994 results (Paz 1999) show that the average farm size remained broadly consistent with respect to previous years, of around 5 ha. The average agricultural diversity amounted to three crops per farm, which contrasts sharply with the variety of products obtained in past decades, according to farmers interviewed. Cotton remained as the main crop, followed by alfalfa and other crops mainly for home consumption (squash, watermelon, etc.). The family monetary income was satisfied by sales of agricultural products and occasional sale of cattle and small livestock, which was completed with the wage labour of some family member outside the unit, and other incomes such as pensions and retirement.

In 2000, the El Pirucho farmers activity corresponded to a model named "alfalfa and corn producers with developed livestock system and market-oriented", with similar features as those described by Paz (1999), but with cotton no longer part of crop selection. According to the study, this was linked to the fall in international and local prices. Also, horticultural crops had already been largely lost (Fiorentino 2001).

This process (Fig. 5), and in particular the abandonment of agriculture, would be one of the main causes of the high poverty levels registered in the county. According to the 2001

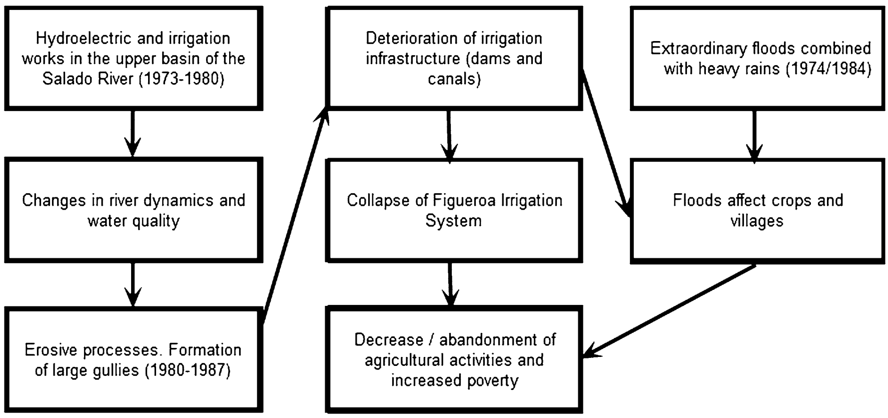

Fig. 5 Main drivers of the Figueroa Irrigation System crash

population census (INDEC 2001), Figueroa had 53 % of households and 57 % of the county inhabitants with at least one UBN, the fourth highest rate across the country.

Conclusions

In this case study, a historical analysis of the factors causing the current deterioration of agro-ecosystems in Figueroa Irrigation System was conducted. Until the late 1970s, when the irrigation infrastructure damage started to become evident, the family food self-sufficiency was based on an intricate agriculture and livestock system, with a large plant and animal diversity, an integrated use of landscape units and ecosystems, strong bonds of cooperation and reciprocity among relatives, neighbours and friends (strong presence of bartering as a traditional system of cooperation), and the combined and diversified production of use values and goods. However, we should not forget the unfavourable social relations among peasants, caused both by land tenure and forced payment to alleged owners, as well as by the terms of trade in commercial relationships, controlled by traders and middlemen.

The analysis indicates that the actions and decisions taken at the provincial and regional level on the Salado River basin and its infrastructure (reservoirs, dams, canals, etc.) had a severe negative impact on the local agro-ecosystems. This impact is evident in the strong active processes of soil erosion, which in many cases led to the abandonment of agriculture. Thus, management strongly linked and adapted to the spatial and temporal dynamics of ecosystems (forests, wetlands, grasslands) was replaced by a failed attempt to control the fluvial dynamics, with the disastrous results already described.

Agreeing with Winiwarter et al. (2013), we found a coevolutionary relationship between practices and arrangements, linked together by the system of hydraulic infrastructure (as a material expression of articulation between society and nature over time). This link is also present in different spatiotemporal scales. In a study about a long relationship (over than 500 years) between the city of Vienna and the Danube river, Winiwarter et al. (2013, p. 109) show that "practices and arrangements are transformative with regard to each other; if one changes, the other changes too, and the socio-natural site transforms".

One of the main features of social-ecological systems is that they operate through complex dynamic processes and therefore they are in constant change and adaptation (Liu et al. 2007; Ostrom 2009). In this sense, the temporal dimension is a key factor in the study of these systems, and the analysis of the historical processes that led to their current situation is important (González de Molina and Toledo 2014).

In our case, the use of oral history allowed us to understand the changes in practices as perceived by the protagonists. In this manner, oral history contributed elements that helped to value the experiences, learning and knowledge of the local population. Local beliefs and knowledge are commonly not taken into account, but form the basis from which the practices that transform the socio-natural sites, and vice versa, unfold. Without oral history, such point of view is very difficult to develop, especially in rural and isolated zones where oral sources are the main ways in everyday life to transmit knowledge and experiences.

The analysis shows that the historical development of water management in agro-ecosystems is a key element to be studied in the context of social-ecological systems. Current presence of certain system components and their interaction could not be otherwise understood. Likewise, it would be difficult, if not impossible, to think up future trajectories in the natural resources management ignoring the set of natural and social factors that shaped agro-ecosystems, the way in which they influenced the structure and functioning of the landscape, and how they defined part of the people's identity.

Compliance with ethical standards

Conflict of interest The author declares that there is no conflict of interest.

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