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Resource intruders and robustness of social-ecological systems: an irrigation system of Southeast Spain, a case study

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Abstract: Globalization increases the vulnerability of traditional social-ecological systems (SES) to the incursion of new resource appropriators, i.e. intruders. New external disturbances that increase the physical and socio-political accessibility of SES (e.g. construction of a new road) and weak points in institutional SES of valuable common-pool resources are some of the main factors that enhance the encroachment of intruders. The irrigation system of the northwest Murcia Region (Spain) is an example used in this article of the changes in the structure and robustness of a traditional SES as a result of intruders. In this case study, farmers have traditionally used water from springs to irrigate their lands but, in recent decades, large agrarian companies have settled in this region, using groundwater to irrigate new lands. This intrusion had caused the levels of this resource to drop sharply. In an attempt to adapt, local communities are intensifying the use of resources and are constructing new physical infrastructures; consequently, new vulnerabilities are emerging. This situation seems to be heading toward the inevitably collapse of this traditional SES. From an institutional viewpoint, some recommendations are offered to enhance the robustness of SES in order to mitigate the consequences of intruders.

Keywords: Adaptability, common-pool resources, globalization, groundwater, institutions, resilience, water management

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1. Introduction

The continuity of the traditional irrigation system in the northwest Murcia Region (Spain) (Figure 1) is seriously under threat. For centuries, farmers in this area have traditionally used the water from springs to irrigate their lands. In recent decades however, large companies have settled in this region and used groundwater to irrigate new lands. This situation is forcing traditional farmers to adapt to an extreme situation of water scarcity. This case study exemplifies a widespread threat to many local communities in the current globalized era: the encroachment of new resource appropriators (hereafter, intruders) into traditional long-term social-ecological systems (SESs).

A SES is “a subset of social systems in which some of the interdependent relationships among humans are mediated through interactions with biophysical and non-human biological units” (Anderies et al. 2004). Irrigation systems are an example of a SES composed of common-pool resources (CPRs) (i.e. water), their users and institutions, and their interactions (Anderies et al. 2004). CPRs are

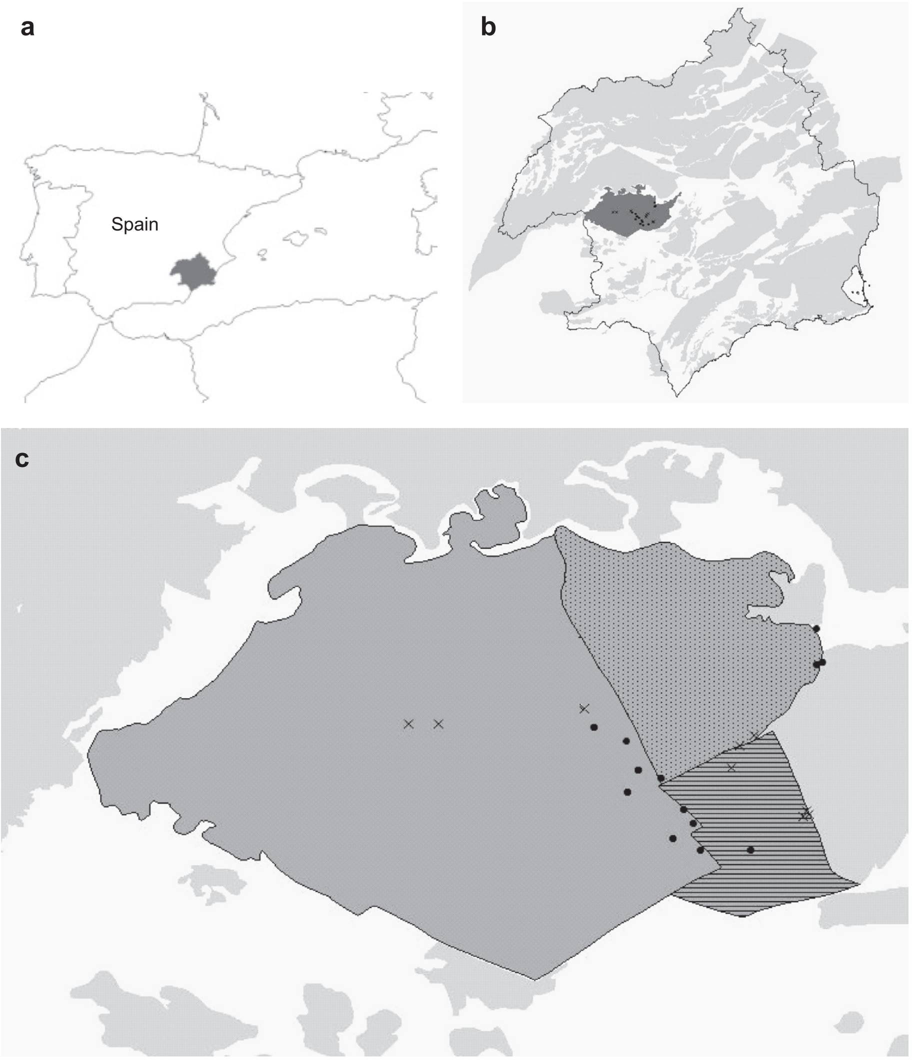

Figure 1: a) Segura river basin in southeast Spain. b) Aquifers of the Segura river basin. The Caravaca aquifer is highlighted in dark gray. c) Subunits of the Caravaca aquifer. Lines: Simo; points: Gavilán; plain gray: Revolcadores-Serrata. Points and crosses represent the main springs in the study area used and unused in agriculture respectively.

natural or manmade resources that may be exhausted and for which the exclusion of potential appropriators is non-trivial (Ostrom 1990). The extensive research into CPRs in the last few decades has proved that individuals are frequently able to organize and sustainably exploit communal resources on which their livelihood depends (Ostrom 1990; Ostrom et al. 2002). Institutions of long-survived SESs are configured to adapt to certain external disturbances (Turner et al. 1998) that have occurred over long periods (Janssen et al. 2007). One example is traditional irrigation systems which have adapted to fluctuations in rainfall.

With globalization, new vulnerabilities are emerging in traditional SESs. Particularly, increased connectedness and accelerated flow of goods, trade, information, people, etc., which are distinctive in our global era, make traditional SESs more vulnerable to the intrusion of new resource users. Water, forests and wildlife in Africa (Haller and Merten 2008; Haller and Chabwela 2009), groundwater in southeast Spain (this case study), forestry in south Asia (Peluso 1992; Sathirathai and Barbier 2001; Barbier and Cox 2002; Bottomley 2002), and fisheries worldwide (Berkes et al. 2006; Cudney-Bueno and Basurto 2009) are just a few examples of a long list of CPRs threatened by resource intruders. By intruders we mean those individuals or groups of individuals (e.g. village neighbors, national and international companies) who begin to harvest a resource traditionally used by a local community, and who have not been integrated into the local governmental system and, therefore, have no incentive to conserve the local resource. Usually, there are large differences between local communities and intruders in terms of power and competitiveness (Agrawal 2001). The intruders' invasion may end in the collapse of the ecological and/or social systems (e.g. through migration) that make up a traditional SES.

We analyze these processes from the perspective of how they affect the robustness of SESs. Robustness is "the capacity of a system to maintain its performance when subjected to internal and external perturbations" (Janssen and Anderies 2007, p. 46). A SES is robust "if it prevents the ecological systems upon which it relies from moving into a new domain of attraction that cannot support a human population, or that will induce a transition that causes long-term human suffering" (Anderies et al. 2004, p. 24).

To study these processes, we need to understand the driving forces and proximate causes (Geist and Lambin 2002) that encourage the arrival of intruders to a new area. For example, logging of Cambodian forests by investors and migrant workers, which is having dramatic repercussions for the indigenous people who depend on forest products, was encouraged by the central government (Bottomley 2002). In other cases, the construction of a road enables intruders to access formerly remote areas (Peluso 1992; Young 1994; Laurence et al. 2009), or increases in the demand for new products attract new harvesters (e.g. increasing demand for shrimps) (Sathirathai and Barbier 2001; Barbier and Cox 2002).

In this study, we analyze the effects that the incursion of new resource users has on the robustness of a traditional irrigation system in the northwest Murcia Region of Spain (Figure 1). To do this, we first extracted the key driving forces and proximate causes that encourage the incursion of resource users to new areas based on some other case studies. We then explored these key factors in our case study and analyzed the changes in the structure and robustness of this SES. Third, we offer some recommendations to enhance the robustness of our case study as well as other traditional SESs affected to such intrusions.

This article is arranged in the following sections: (i) we describe our case study, and the framework and methods used; (ii) we highlight the main factors leading the arrival of intruders; (iii) we present our case study and analyze the driving forces and proximate causes that facilitate the arrival of intruders and its effects on the structure and robustness of this SES; (iv) we offer some recommendations; (v) finally, we conclude.

2. Methods

2.1. Case study

The study area is located in southeast Spain (Figure 1), which is the most arid area of Europe. The climate here is Mediterranean, characterized by a high inter-annual and seasonal variability of precipitation, with an extended dry period during the hot summer season and rainfall during the mild winter months. In the northwest Murcia Region, the mean annual temperature is 14–15ºC, mean annual precipitation is 300–400 mm (Figure 2) and potential evapotranspiration is 900 mm. This region is moderately mountainous with a surface area of 2400 km^2 in which forest, scrublands and agriculture (traditionally dry farming and small irrigated lands) are the main land uses. Streams and springs are the main natural and landscape heritage of this arid area.

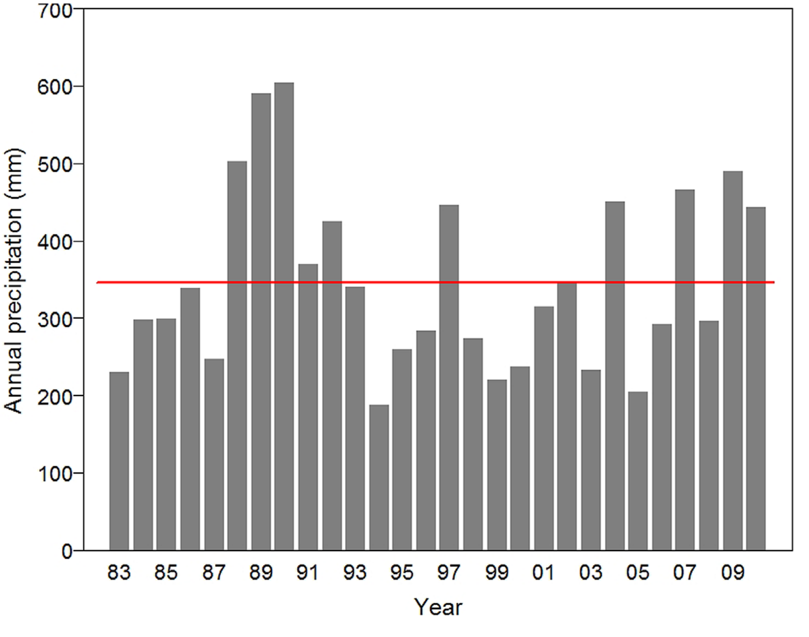

Figure 2: Annual precipitation in the study area from 1983 to 2010. The red line indicates the mean annual precipitation of this period.

The study area comprises 13 villages with a total population of 25,686 (range=1–21,348; mean=1,511). Historically, groups have settled around the springs to use their water to irrigate lands. Springs naturally emerge from the Caravaca aquifer, which belongs to the Segura River basin (Figure 1). This aquifer has a surface area of 625 km^2. There are around 28 springs, and 15–20 of them are directly used to irrigate the land. Most of the springs, and the ones used for agriculture, are located in three units of the aquifer: Gavilán, Revolcadores-Serrata, and Sima (Figure 1, Table 1). Agriculture started in this area during the Arabic period (López and Sánchez 2010). Currently, the surface area of traditional irrigation land is roughly 4000 ha, and there are some 3000 traditional irrigation farmers.

Farmers are organized in 15 irrigation communities (ICs) (Table 1). Each IC has three boards: the *Junta General* (General committee), the *Junta de Gobierno* (Government committee) and the *Jurado de Riegos* (Irrigation judge). The *Junta General* meets once a year and regulates, among other things, water uses. The *Junta de Gobierno* has the function of observing and ensuring that the norms established in the *Junta General* are obeyed. Finally, the *Jurado de Riesgos*, imposes the sanctions to those members of the community who do not obey the rules. Also each irrigation community has one or more *regador* (the person who irrigated; also called *requirol* or *acequiero*) who distributes and controls the irrigation (turns and hours of irrigation).

In recent decades, large agrarian companies have arrived from the more arid areas of the Murcia Region to settle in the area. They are transforming old dry lands into intensively irrigated lands (ca. 1000 ha of new irrigated lands) by using wells to pump the water from the aquifer (there were around 34 new wells in the study area in the 1990s). Several factors have facilitated the incursion of intruders, which, in turn, has had an important impact on the configuration and robustness of this traditional SES.

2.2. Framework

To characterize the nature of the factors leading to intrusion and to analyze the changes occurring in our case study, we used the conceptual framework proposed by Anderies et al. (2004) (Figure 3 – part a). This framework establishes the interrelationship between four main components of SESs: resource, resource users, public infrastructure providers and public infrastructure. Resource users and public infrastructure providers are human-based (ellipses in Figure 3). Public infrastructure includes physical infrastructures (e.g. irrigation channels) and social capital (i.e. institutional rules). The links between the components are numbered from 1 to 6, while numbers 7 and 8 represent environmental and social disturbances, respectively.

2.3. Literature review

To determine the factors that encourage the incursion of resource users to new areas, we have reviewed several SESs in the literature that were threatened by the

Table 1: Characteristics of the irrigation communities of the study area and situation of springs they use (information obtained from interviews to ICs)

Aquifer	IC	Num farmers	Surface (ha)	Surface/ farmer (ha)	New infrastructures	Spring	Flow trend	Past flow (l/s)	Current flow (l/s)	% Decrease
Gavilán	Fuentes del Marqués	700–710	488 (800 in the past)	Median 0.5–2 Max 20 Min 0.04	None	Fuente del Marqués	=	400	380–400	0–5
	Mayrena- Viñales	203–209	500	Median 0.5–1 Max 4 Min 0.34	None	Fuente de Mairena	≤	75–80	30–40 in 1992	47–63
Revolcadores-Serrata	Benablón	118	185	Min 0.1 Max 43.3	1 well, 1 reservoir	Pozancos del Chorreador	<	7–8	4–5	29–50
						Fuente del ojico	<	25	3	88
	Caneja	325	433	Median 1.5 Max 30 Min 0.1	1 well	Fuente de Caneja	<	120–130	0	100
	Cañada de Tarragoya	18–20	200–220	Mean 2 Max 70–80	None	5–6 small springs	≤	–	30–35 (in total)	–
	Guarinos-Barranda	250–260	230	Median < 1 Max 20 Min 0.2	1 well, 1 reservoir	Fuente de Guarinos	<	17–18	8	53–56
	El Hacho	86–87	90	–	1 reservoir	Fuente Molino Guarino	<	17–18	8	53–56
						Fuente Chorreadores	<	7–8	4–5	29–50
	Fuente de Navares	200	233	Median 1 Max 30 Min 0.5	None	Fuente de Navares	≤	25–30	–	–

Table 1: (Continued)

Aquifer	IC	Num farmers	Surface (ha)	Surface/ farmer (ha)	New infrastructures	Spring	Flow trend	Past flow (l/s)	Current flow (l/s)	% Decrease
	Fuente de Singla	74	116	From <1 ha to some ha	None	Fuente de Singla	<	28–30	4–5	82–87
	Fuente del Moral	10	22.5	Max 16 Min 0.5	None	Fuente del Moral	<	11	4–5	55–64
	Heradamiento de los Ojos de Archivel	292	551	–	1 reservoir	Los Ojos de Archivel	<	50–60	24	52–60
	La Muralla	320	338	Median 1.5–2 Max 20 Min 0.165	1 well	Fuente la Muralla de Archivel	<	120	80	33
	Las Tosquillas	410 (210 in the past)	700	Median 5 Max 60 Min 0.2–0.3	None	Fuente de Las Tosquillas	=	105–110	105–110	0
	Comunidad de Regantes General de Caravaca	212	300	Median 0.5 Max 30 Min 0.05	1 old well and 3 new reservoirs	Rio Argos, Sangradores de Benablon and Barranco de la Tejera	<	160	20–30	81–88
Sima	La Encarnación	130	133	Median 0.5–1 Max 17 Min 0.3	1 well, 1 reservoir	Fuente Pinilla	<	8–9	Approximately 0	100
						Fuente Sax	<	3–4		

Past flow is the volume of flow of the springs before new agrarian companies settled in the study area. Flow trend is the trends of the volume of flow of the springs in the last 30 years; "=" means that the flow is more or less the same, "<" means that the flow has decreased, and ≤ means that the flow decreased but in the last years it has recovered.

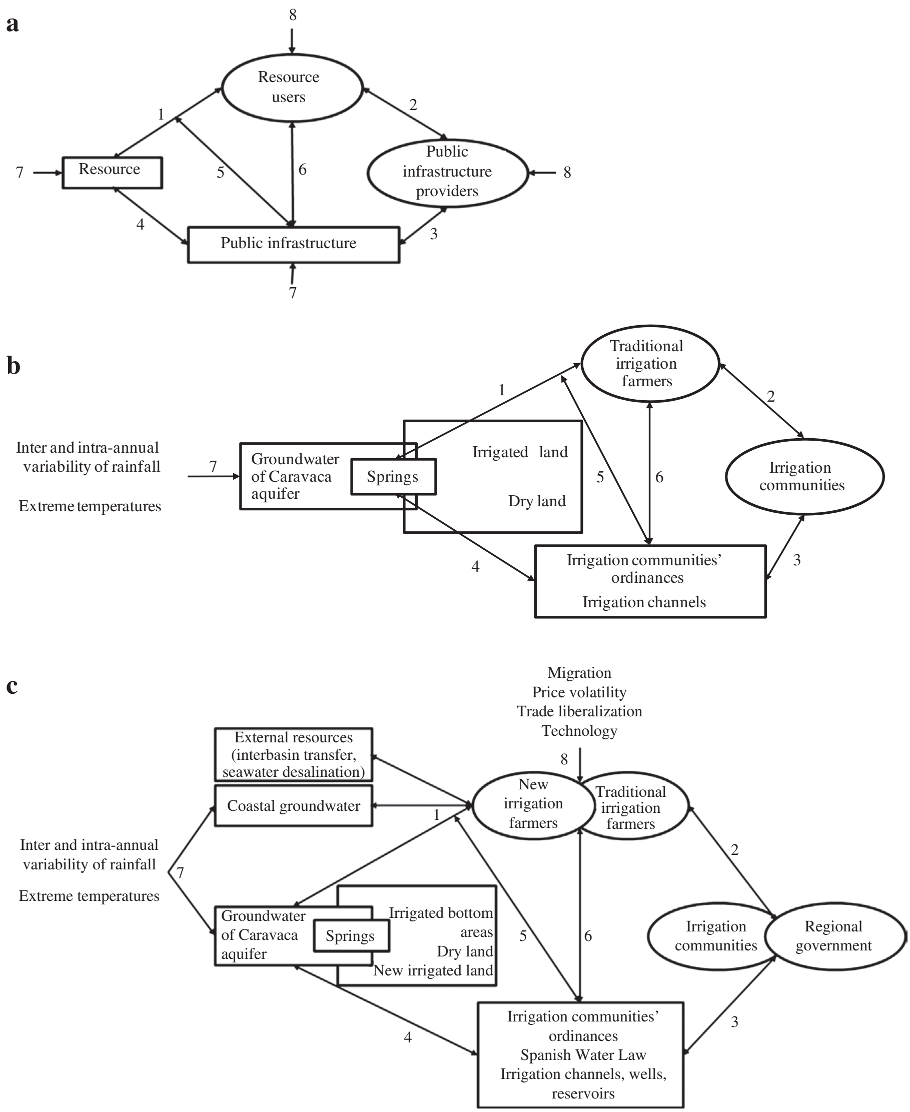

Figure 3: Application of the conceptual social-ecological systems model (Anderies et al. 2004) (a) to the Caravaca aquifer irrigation system in the two study periods: (b) the traditional system before the intrusion of new resource users and (c) the current situation after the intrusion of new resource users.

recent incursion of intruders. To find these cases, we reviewed the online databases ISI Web of Knowledge (http://www.isiknowledge.com) and the Digital Library of the Commons (http://dlc.dlib.indiana.edu/dlc/). From each case study we extracted the variables that influenced the intrusion. As a whole, all these variables represent the possible independent variables that may explain intrusions and that can be applied to other SESs (George and Bennet 2005). Following Geist and Lambin (2002) we distinguished between underlying driving forces and proximate causes of intrusion. We organized these factors using the framework of Anderies et al. (2004).

2.4. Interviews to ICs

To analyze our case study, we interviewed the ICs of the study area (Table 1). We interviewed the president and/or other key member of each IC (*regador*, secretary). In total, we conducted 21 interviews. Based on these interviews, we describe the traditional irrigation system, identify the factors that leaded the arrival of intruders, how the ICs have responded to the intrusion, and how this situation is affecting the robustness of this SES.

3. Under what socio-ecological circumstances are resource intruders likely to encroach?

By analyzing the factors that lead to the encroachment of intruders to different SESs, we highlight the main vulnerabilities of SESs that enables intruders' incursion. Our aim is not to provide an exhaustive list of factors that facilitate intruders' incursion into a given area, but the nature of the main factors involved. The case studies examined show that the vulnerabilities of SESs to the incursion of intruders derive from demographic, economic, technological and institutional and political driving forces. These factors affect internal components of the systems (public infrastructure providers, social capital and resource characteristics) and those outside of the system through the appearance of new external disturbances. The incursion of intruders seems to depend on the commercial value of the resource, as well as the physical and/or socio-political difficulties in access. That is, the greater the commercial value of the resource and/or accessibility, the more vulnerable the SES is to the intrusion of new resource users. Intruders' decisions to enter a new area depend on the balance of the resource's value and the effort invested in harvesting (physical and socio-political accessibility). Below we describe these factors and give some examples based on our literature review.

3.1. External forces on social actors

Economic factors seem to be one of the most important driving forces in explaining intruders' incursion (Barbier and Cox 2002). Increases in price and demand make resources more valuable and encourages intruders. Some examples include the shrimp aquaculture practices in south Asia, which have increased in response to the Japanese market (Sathirathai and Barbier 2001; Barbier and Cox 2002), or the large expanse of forest that is disappearing in south Asia and south America as a result of increased soybean and oil palm commerce (Sandker et al. 2007; McCarthy and Zen 2010). Also, a critical economic situation may drive people to harvest in neighbouring villages (Twine et al. 2003).

The incursion of intruders may be also favoured by political and institutional driving forces. In some cases, and frequently in poor or developing economies, the central government encourages intruders. Some examples are the Cambodian forest presented in the Introduction (Bottomley 2002), or the shrimp farms in south Asia, which are destroying enormous expanses of mangrove forests (Sathirathai and Barbier 2001; Barbier and Cox 2002). In other cases, an institutional change has taken place or, more rarely, political reorganization. For example, the eradication of local institutions of the African floodplains during colonial periods that traditionally regulated natural resource use is currently creating a situation of open access (Haller and Merten 2008; Haller and Chabwela 2009).

Other driving forces such as cultural and demographic factors may also contribute to the incursion of intruders to certain areas. For example, the expansion of shrimp farming in mangrove habitat of Thailand can be explained as a consequence of absence of other cultivating habitat due to urbanization of coastal areas caused by demographic growth and the low value of mangrove ecosystems given by local governments (Barbier and Cox 2002).

3.2. External forces on resource and infrastructure

Technological driving forces, such as the emergence of new harvest technologies, may enables the exploitation of certain areas or resources at certain levels, which proved impossible beforehand (Agrawal 2001). For example, the utilization of new fishing nets and powerful boats may lead to a rapid decline in fishing resources (Haller and Merten 2008).

Other important factors that encourage intruders seem to be the physical accessibility of the resource and the connectivity of traditional SESs to markets (Young 1994; Agrawal 2001; Laurence et al. 2009). Economic, demographic and political driving forces contribute to proximate factors such as the construction of new roads or new markets infrastructures that allow intruders easy access to exploit and commercialize natural resources. For example, the ironwood timber of a West Kalimantan village in Borneo has been traditionally harvested by local people. Yet changes in the physical access to the village and its forest products through the construction of a new road were one of the driving forces that led to the intrusion by timber companies. Consequently, large expanses of this forest have been devastated and the social organization of the traditional SES has profoundly changed (Peluso 1992).

3.3. Public infrastructure providers and social capital

Internal configuration may increase the vulnerability of SES to intrusion. In particular, if the SES has weak resource rights and unenforceable boundary rules intruders can easily encroach on local resources (Ostrom 1990, 2007, 2009). The literature provides some examples of traditional SESs with characteristics that make them impossible to limit intruder access, despite the efforts of users and governments (e.g. Peluso 1992; Sathirathai and Barbier 2001; Twine et al. 2003;

Haller and Merten 2008; Haller and Chabwela 2009). One notorious example is the situation of many ocean fisheries (Berkes et al. 2006; Berkes 2010).

3.4. Resource characteristics

Predisposed environmental factors (e.g. soil quality, landscape configuration) might make certain areas more vulnerable than others to resource intruders (Geist and Lambin 2002). For example, the optimal conditions of mangrove areas in south Asia for shrimp cultivation has concentrated aquaculture in this ecosystem and devastated expanses of mangrove forests (Barbier and Cox 2002).

4. Case study: irrigation system of the Northwest Murcia Region (Spain)

4.1. The traditional irrigation system

The SES of the traditional irrigation system of the Caravaca aquifer (Figure 3 – part b) is composed of the farmers and ICs, their physical environment, and their interactions. Farmers are the resource users. They use the Caravaca aquifer groundwater that emerges as springs (resource) to irrigate land. The hydrologic dynamics of springs depend on the state of the water table, which varies according to rainfall. Irrigated lands are located near the springs. Farmers also have dry lands, which they use to cultivate cereals. The most important external disturbances are drought periods (Figure 3 – part b). In addition, crops are affected by extremely low temperatures, which can cause spring frosts.

Farmers are members of ICs. ICs are the infrastructure providers. Traditionally, the only physical infrastructure is irrigation channels used to distribute water among farmers. Irrigation channels are constructed by ICs and are maintained by both ICs and the individual farmers, i.e. ICs maintain the public infrastructure between farmers while each farmer maintains the public infrastructure within his own land (links 3 and 6). Each IC has its own ordinances that constitute the social capital (public infrastructure). The ordinances establish the rules for both ICs and farmers; that is, ICs' functioning and structure, the boundaries of the SES (which is part of the IC and which can, therefore, use the water from the springs, and land can be irrigated), the distribution of water among members, plus monitoring and sanctioning. Only the farmers belonging to an IC can use water from the springs. Water availability was used by ICs to determine both the amount of land to be irrigated and the rules to distribute water among farmers. Thus, the amount of irrigated land varies among ICs in accordance with the flow of the spring used by each IC. ICs monitor so farmers do not extend their irrigation land. In drought years, ICs can order a reduction in irrigated land, or individually, farmers can reduce their irrigated land. This practice benefits the whole community and individual farmers. Regarding water distribution among farmers, ICs proportionally distribute water among farmers according to land surface areas. The fee that each farmer pays ICs for infrastructure maintenance, monitoring, etc., is proportional to the land surface owned.

This traditional SES is an example of a "simple" local irrigation system that has operated for centuries and has coped with rainfall variability. This SES was robust in terms of its use of the water emerging from the springs to irrigate small patches of land. However, as we explain in detail in the next section, given this configuration and several processes that have taken place in recent years (external disturbances), this SES has become very vulnerable to the intrusion of new resource users.

4.2. Vulnerabilities that lead to the encroachment of intruders

External forces on social actors. One factor to consider occurred in 1986 when Spain joined the European Union and was progressively opened to global markets. This situation, along with increased demand in agricultural products, has attracted industrial agrarian companies to expand to new areas. In addition, the new Spanish Water Act of 1985 established groundwater as a public resource but, in order to recognize the historical rights of private groundwater owners, the law gave them the right to register their groundwater use as private uses. Most of the owners of old wells in dry lands (traditionally used during severe droughts or to give cattle water) registered them as private uses but they registered more water than they were traditionally using. The government was unable to verify this data due to the amount of registration (Giménez et al. 2010). Thus, wells in dry lands could pump enough water to allow the expansion of irrigation agriculture.

External forces on resource and infrastructure. Traditionally, the study area has been an isolated area. The improvement of roads, and specially the construction of a new highway in 2000, connected this area with the capital city (Murcia) and all the Mediterranean Arc (and the markets). This situation improved the local communities' status but, at the same time, increased the accessibility to intruders to cultivate the land and transport products to markets. On the other hand, innovative technologies have converted groundwater extraction by means of wells from which to pump this groundwater into a technically and economically viable option.

Public infrastructure providers and social capital. One of the most important vulnerabilities of this SES is the lack of an effective organization capable of protecting the whole resource system. The ICs have the right to use and control the water emerging from the aquifer, but not to the aquifer's groundwater itself, although any disturbance to the aquifer will affect the flow of the springs. The Spanish government, which has the right to control groundwater uses, has proved a weak authority in controlling groundwater pumping (Llamas and Custodio 2003). The construction of new wells and the amount of water that can be extracted is regulated by the Hydrographical Confederation of the Segura Basin according to the Spanish Water Act of 1985. However, the difficulties that public administrations have had in monitoring open fields have prevented the control of groundwater extractions (Llamas and Custodio 2003). The lack of an effective government-based system to monitor Spanish groundwater (Llamas and Custodio 2003), and the ICs ordinances' (social capital) inability to govern the physical boundaries of the SES, have resulted in increased vulnerability to the intrusion of new users. This situation is facilitated by the fact that groundwater levels are not visible and are affected not only by water pumping but also by rainfall. This invisibility and complex dynamic make on the monitoring function of public infrastructure providers extremely difficult (Ostrom 2009).

Resource characteristics. Groundwater is an important water reservoir in arid areas, and is especially valuable to agriculture. In our study area, groundwater is a relatively abundant and cheap resource that has attracted intruders. Other factors, such as cheap land rents and moderate summer temperatures have also contributed to the incursion of intruders (Pedreño and Pérez 2008).

4.3. Changes in the configuration and robustness of the SES

In the early 1990s, industrial agrarian companies (i.e. intruders) started to settle in this area. They mainly rented dry lands to change them to irrigated land by pumping groundwater from the Caravaca aquifer. The presence of intruders in the traditional SES has trigged a series of changes that have led to a very different configuration and affected the robustness of this SES (Figure 3 – part c, Table 2).

Resource and resource users. Currently, the SES is composed of two types of resource users, i.e. traditional and new irrigation farmers. While traditional irrigation farmers employ the water from springs to irrigate land, new farmers use groundwater by pumping it from wells (physical infrastructure). New irrigation farmers come from more arid coastal areas where they use groundwater to irrigate land as well as other external water resources through the construction of large infrastructures (inter-basin water transfers and seawater desalinization) approved by regional and national governments (Pedreño and Pérez 2008). In spring and summer when the high temperatures of the coastal areas do not permit the cultivation of certain horticultural crops, they irrigate the traditional dry lands of the study area and use the Caravaca aquifer groundwater (Pedreño and Pérez 2008).

Groundwater extraction is significantly diminishing the volume of the springs, especially during the irrigation season (spring and summer) and some have even become extinct (Table 1, Figure 4). Due to the geology of the aquifer, not all units of the aquifer had been affected with the same intensity. The Revolcadores-Serrata was the unit in which the volume flow was most affected (Table 1, Figure 4). It should be noted that the years when intrusion occurred coincide with some years of scarce precipitation in the study area, which has aggravated the effects of extractions (Figure 2). Interviewees, however, remembered that springs had water during more severe drought periods in past years. Nowadays, the unpredictability and uncertainty of the levels of the resource under study have increased. The water level varies not only in accordance with rainfall, but with the groundwater pumping of other companies.

Table 2: Main processes and vulnerabilities detected in the entities and links (see Figure 3) of the traditional SES under study due to the incursion of intruders

Entities/links	Processes/vulnerabilities
Resource	Increase of uncertainty in the water flow Level decrease
Resource users	Collective action problems
Public infrastructure providers	Increase complexity
Public infrastructure	Increase infrastructures
Social capital	Ineffective boundaries rules Lack of robust govern system
Between resource and resource users *(link 1)*	Decrease of the volume flow Not enough water to continue with the traditional agriculture Increase of recovery periods
Between users and public infrastructure providers *(link 2)*	Increase economic investment to create and maintain infrastructures Collective action problems (e.g. infrastructure maintenance)
Between public infrastructure providers and public infrastructure *(link 3)*	Increase economic investment to create and maintain infrastructures Collective action problems (e.g. infrastructure creation and maintenance)
Between public infrastructure and resource *(link 4)*	Resource level decrease Decrease resilience of the resource Increase resource price
Between public infrastructure and resource dynamics *(link 5)*	Not enough water to continue with the traditional agriculture Decrease efficiency of infrastructures
Between resource users and public infrastructure *(link 6)*	Collective action problems (e.g. infrastructure maintenance) Increase of users' debts Land abandonment
External forces on social actors *(link 8)*	Young people emigration
External forces on resource and infrastructure *(link 9)*	Decrease resilience of the resource

Infrastructure providers and physical infrastructures. Traditional irrigation farmers and ICs have adapted to less abundant spring flows by constructing new physical infrastructures. This measure is also promoted by the regional government (new infrastructure provider) as a measure to prevent droughts and to efficiently improve the system by which the water is used. New public infrastructure include wells to pump the groundwater from the aquifer, reservoirs to store water in winter and to use it in summer, and modernized irrigation channels to prevent water evapotranspiration and infiltration. As physical infrastructure investments increase, infrastructure providers become more important and complex, as do the links between the SES components. As part of this configuration, the new physical infrastructures vastly affect the resource dynamics (link 5). For traditional

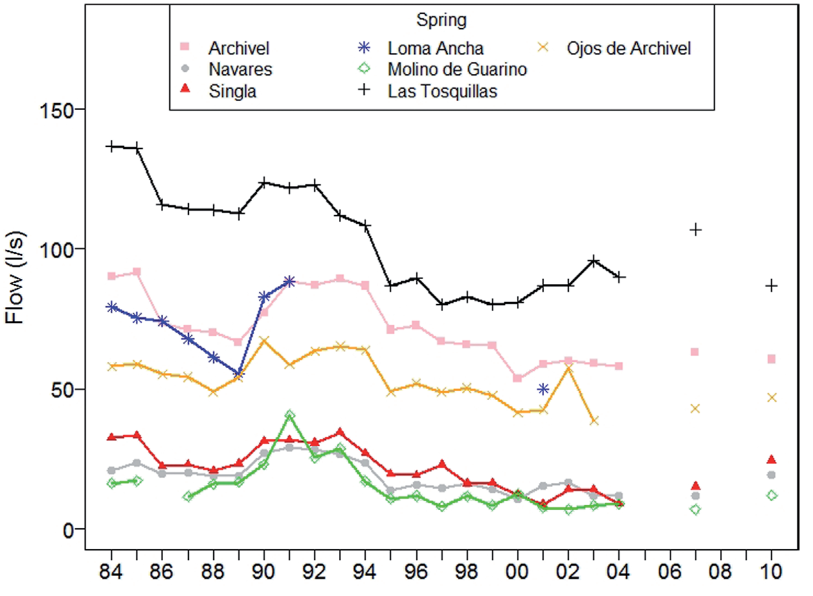

Figure 4: Official values of the mean volume of flow (l/s) of some of the springs of the Revolcadores-Serrata unit from 1984 to 2010. Source: adapted from Cabezas 2010.

farmers, more physical infrastructures mean increased economic investment to create and maintain infrastructures (links 3 and 6). New infrastructure providers appear because ICs need the regional government's economic support to afford the high investment made in physical infrastructures. Currently, the physical infrastructure providers not only include ICs, but individual farmers, ICs' unions, plus the regional government through aid concessions.

Weak points emerge in the social system as a result of collective action problems, i.e. disputes between new and traditional users and between traditional resource users and public infrastructure providers (Figure 3 – part c). Links 3 and 6 become weak as the need for physical infrastructure maintenance increases. For example, the regional government often pays for large physical infrastructures (such as a large reservoir), but maintenance is the farmers' responsibility, resulting in higher costs. In addition, energy costs increase the price of water substantially increases when a well is used to pump groundwater. Most importantly, there is no robust government system that represents all the resource users, and which monitors and controls groundwater pumping (links 2 and 3). ICs have made unsuccessful attempts to control intruders' use of water by monitoring new farmers and by reporting the new users' illicit activities to the Hydrographical Confederation in the area.

In some cases, the cost of constructing or maintaining physical infrastructures, or the cost of water, exceeds the profits gained through the agricultural activity.

Some effects of this situation are an increase of debts for individual farmers and ICs. Moreover, farmers are not willing to pay high fees to maintain physical infrastructures or water costs, so land is abandoned. One important factor that explains these conflicts and land abandonment is the lack of resource dependence (Chhatre and Agrawal 2008; Ostrom 2009) since most traditional farmers are dependent on other economic activities or they are retired farmers but continue cultivating for their own personal use. Resource dependence is key factors in governing CPRs.

As the SES changes, the gap in vulnerability between ICs and farmers probably widens. This variation is apparently related to factors such as size (i.e. number of farmers in an IC, farmers' amount of land surface), resource scarcity (i.e. spring flows), and geographic location (i.e. cooperation rate between ICs, drop in the intensity of spring flows). All these factors correlate (e.g. if spring flows are abundant, ICs have more members and more land is irrigated) (Table 1). In general, loss of robustness and increased vulnerability seems to be greater in small ICs and for farmers who have less land. As these processes occur, the traditional SES, especially small ICs, also become more vulnerable to other disturbances such as the out-migration of young adults (arrow 8).

New physical infrastructures help traditional farmers cope with less abundant water flows, at least in the short-term. However, new physical infrastructures may mask the real situation of the scarcity of this resource. Currently, the water from springs emerges after irrigation season, coinciding with winter rainfall. Yet given the increase in groundwater extractions, there is a considerable drop in flow in summer (dry and irrigation season), or in some cases it even disappears. While this resource recovers each year thanks to winter rainfall and to less pumping, it may become more sensitive (less resilient) to continued extractions and drought periods as the water table decreases, and may need more time or an extremely wet season to recover (Anderies 2006). Thus, a reservoir can store less water each year, and more wells or deeper ones will be required.

As the circumstances adapt to lower water levels because of intruders, they may become even more vulnerable to other disturbances (Anderies 2006; Anderies et al. 2007; Janssen and Anderies 2007; Janssen et al. 2007; Young 2010) (Table 2). It is likely that the investments made in physical infrastructures to maintain the level of agricultural productivity make the SES more robust in the short-term, but less robust in the long-term because this resource's resilience declines, thus slighter disturbances may lead to its collapse or undesirable state (Scheffer and Carpenter 2003; Anderies et al. 2007; Janssen and Anderies 2007; Janssen et al. 2007; Young 2010), such as longer drought periods or more groundwater pumping.

Accordingly to the interviewees, during the last few years, the flow of some of the springs has partially or totally recovered (Table 1, Figure 4). This recovery might be a consequence of three main processes. First, in 2002 most of the ICs established an association to report on a number of illegal extractions and illegal wells to the Spanish government. This resulted in the close of some illegal wells. Second, some of the new settled agrarian companies have stopped their agricultural activity because they are expecting to construct new housing estates where their irrigated lands were. This has temporally diminished the groundwater pumping. Finally, rainfall has increased in the area during the last few years. As we can see in Figure 2, in 3 of the last 4 years, rainfall has been above the mean precipitation of the study area of the period 1983–2010; situation that did not happen since 1988–1992. In any case, these processes seem to be causing a temporal increase of the flow of the springs and not a long-term recovery of the SES.

5. What can be done? Enhancing robustness

In the current globalized era, protecting and preventing the disappearance of a traditional SES means, among other things, to find mechanisms that enhance its robustness and diminish its vulnerabilities to intruders. Intruders may have catastrophic consequences on traditional SESs. Ecological systems may potentially collapse, the traditional livelihoods of local communities may disappear and, subsequently, all this may lead to the collapse of an entire traditional SES. Local communities have great difficulties in avoiding such threats because they find they are frequently powerless, and they cannot compete with intruders since they are unable to adapt to technology and respond to global market changes (Agrawal 2001). Occasionally, as in the case study presented here, when local communities attempt to adapt, they intensify the exploitation of their own resource, which aggravates the problem and makes them more vulnerable in the long-term.

The capacity of local organizations to respond is essential in order to anticipate and prevent intrusion and to avoid the SES from collapsing. Large companies move and act swiftly in response to global markets, whereas the local organizations' reactions and adaptations usually take place over considerably longer periods of time. At times, local government systems are unable to detect this situation until it is too late as ecological or local social systems may have collapsed. This was indeed the case with the green sea urchin in Maine (Berkes et al. 2006).

Among other factors, delayed responses mainly occur as a result of the visibility of local resources and, subsequently, of intruders' effects. For example, the effects of timber harvesting can be almost seen instantly by local communities, so organizations can rapidly act to counteract any consequences. Nevertheless, the groundwater level is not visible and the consequences of increased pumping may be detected too late; that is, when the aquifer has been overexploited and its recovery is practically impossible. This characteristic often leads to an intensification of groundwater extractions and intruders' harvesting. The invisible nature of the consequences of groundwater use intensification have been termed the "silent revolution" (Fornés et al. 2005); this is precisely the frequent situation in irrigation systems that depend on groundwater (Shah 2009).

Organizations may respond more rapidly if a robust local SES is established. Local users' knowledge of the ecological system means they are capable of rapidly detecting symptoms of degradation and can, therefore, start action to prevent the SES, or adapt it, from degradation. One such example in our case study are the irrigation communities, a local robust organization that detected a drop in the water flow of the springs and took it to be a symptom of a deprived ecological system. They responded by promoting a series of changes in the system to adapt it to the new situation and to accelerate higher-level governments' response.

However, the incursion of intruders should not always be considered as a threatened factor for local communities. In some cases, intruders may benefit the local communities, at least in the short-term. For example, in Cambodia, loggers economically compensate local communities (Bottomley 2002), and in Taiwan, fishing communities learned knew fishing technologies from outsiders, although these techniques were more aggressive and in the long-term caused the depletion of the resource (Tang and Tang 2001).

If we consider all these factors, we feel that high-level organizations should assist local communities by guaranteeing the protection of local resources and community access. Learning, communicating, and collaborating through adaptive co-management are essential practices for local communities to anticipate and avoid intruders' incursion or to rapidly respond and adapt to handle any eventual consequences (Olsson et al. 2004; Armitage et al. 2009). Measures to prevent the incursion of intruders or to minimize its consequences may, on the one hand, protect local communities and local resources by establishing property rights, protected areas and technological controls (prohibition of certain techniques), and increase monitoring. All of this could be facilitated by establishing a polycentric governance system (Ostrom 2005) in which government and traditional users work together to maintain the resilience of the SES, through establishing rules, monitoring, transmission of information, and learning. In addition, efforts can be made to reduce the intruders' profitability from a traditional SES by, for example, promoting sanctions toward ecological restoration and by establishing compensation fees for local communities.

Looking for formulas of effective groundwater governance is an important aspect for the durability of the traditional irrigation system under study. The Spanish Water Act permits the government to declare an aquifer overexploited, and subsequently emergency actions are developed. This procedure involves the cessation of new concession of wells, the formation of a water users' association, increase monitoring of groundwater uses, and, if necessary, government can authorize restriction in groundwater uses (Villarroya and Aldwell 1998). These measures could help revert the situation of inevitable collapse of this traditional SES and promote the participation of all users in conserving the aquifer. However, traditional farmers are concerned with this action because they think it will reduce the volume of their withdrawals. In our opinion, the national government should recognize the groundwater use right of traditional farmers, and the withdrawal reduction should come from the recent concessions of groundwater pumping throughout wells. This is justified by the importance of conserving a traditional SES of important cultural and historical heritage and that constitute an example of sustainable use of groundwater in arid environments.

6. Conclusion

The pressure on natural resources and traditional SESs is increasing as the human population grows and the world becomes more global. Previously isolated resources and areas are being exploited by resource intruders, which severely affect the livelihoods of local communities. This study into a traditional irrigation system reveals how the intrusion of new users seriously affects groundwater levels and changes the structure and robustness of the traditional SES. In an attempt to adapt, local farmers have intensified the use of this resource, which has led to more physical infrastructure. As a result, new vulnerabilities are emerging. This situation is heading toward the inevitable collapse of this traditional SES and, thus, to the loss of a good example of the sustainable use of a scare resource (in this case study, is water in arid and semiarid environments). Finally, to this we add the loss of local ecological knowledge, local culture, as well as valuable historical, social and cultural heritage.

Future research into this topic may provide in-depth knowledge of the factors that lead to the incursion of new users for the purpose of examining the effects of this incursion on another SES. The framework of Anderies et al. (2004), which we have utilized in this article, has proven adequate to analyze the changes in the structure and robustness of a SES. Although no single solution exists, and solutions may differ between cases (Ostrom 2007), we offer a series of institutional measures to help avoid incursions or, at least, decelerate the velocity and intensity of any consequences. Other specific cases may offer other formulas to enhance the robustness of a traditional SES in an ever-changing and globalizing world.

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