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

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Abstract: Globalization increases traditional social-ecological systems' (SES) vulnerability 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. Farmers have traditionally used water from springs to irrigate their lands but, in recent decades, large companies have settled in this region and use groundwater to irrigate new lands. This intrusion had led 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 is inevitably heading towards the 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, water management*

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 affecting the water supply for traditional farming. This case study exemplifies a widespread threat of many local communities in the current globalized era: the encroachment of new resource appropriators (hereafter, intruders) into traditional social-ecological systems (SES).

The term SES stresses the strong link between humans and the environment (Berkes and Folke 1998). Irrigation systems are an example of a SES composed of common-pool resources (CPR) (e.g., water, fisheries, forests or pastures), their users and institutions, and their interactions (Anderies, et al. 2004). CPRs are natural or manmade resources which may be extracted and for which the exclusion of

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potential appropriators is non trivial (Ostrom 1990). The extensive research into CPR in the last few decades has proved that individuals are able to organize and exploit sustainably communal resources on which their livelihood depends (Ostrom 1990, 2005). There are many examples of SES which have long survived. Their institutions are configured to adapt to certain external disturbances (Turner, et al. 1998) which have occurred over long periods (Janssen, et al. 2007). Some examples are traditional irrigation systems or nomad pastoralists which have been adapted to fluctuations in rainfall and to temporal and spatial variability of pastures, respectively. However with globalization, new vulnerabilities are emerging in traditional SES, particularly increased connectedness and accelerated flow of goods, trade, information, people, etc., which are distinctive in our global era and make traditional SES 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 (Pedreño and Pérez 2008), forestry in south Asia (Peluso 1992; Bottomley 2002; Sathirathai and Barbier 2001; Barbier and Cox 2002), or 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. With intruders we refer to those individuals or groups of individuals (e.g., village neighbors, large national and international companies) which newly start to harvest a resource traditionally used by a structured local community, have not been integrated into the local institutional system, and 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). Indeed, the intruders' invasion may end in the collapse of the ecological and/or social systems (e.g., through migration to urban areas) which are part of a traditional SES.

Understanding and managing the complex socio-economic and biophysical forces and consequences of this process are a tremendous challenge for human society and are essential for enhancing the robustness of vulnerable SES. 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, first we need to understand the driving forces that encourage the arrival of intruders to a new area. For example, logging Cambodian forests by investors and migrant workers, which is having dramatic repercussions on 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 of new products serve as a call for new harvesters (e.g., increasing demand for shrimps) (Sathirathai and Barbier 2001; Barbier and Cox 2002).

The aims of this article are to: i) highlight the main driving forces that encourage the incursion of resource users to new areas, ii) analyze the effects that this process has on the structure and robustness of traditional SES, and iii) offer some recommendations to enhance the robustness of traditional SES to be able to confront such intrusions. To go about this, on the one hand we analyzed several

traditional SES in the literature threatened by the recent incursion of intruders. On the other hand, we conducted an in-depth research of this case study based on a series of in-depth interviews with irrigation communities of the traditional irrigation system in the northwest Murcia Region. To characterize the nature of the factors enhancing intrusion and to analyze the changes occurring in our case study, we used the conceptual framework proposed by Anderies et al. (2004) (Figure 2a). This framework establishes the interrelationship between four main components of SES: resource, resource users, public infrastructure providers and public infrastructures. Resource users and public infrastructure providers are human-based (ellipses in Figure 2). 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.

This article is arranged in the following sections: i) we highlight the main factors enhancing the incursion of intruders; ii) we present our case study and analyze the driving forces that enhance the intrusion of intruders and its effects on the structure and robustness of a SES; iii) we discuss the possible consequences of intruders for the traditional SES and offer some recommendations to enhance the robustness of traditional SES and to prevent the incursion of intruders; iv) finally, we draw some general conclusions.

2. UNDER WHAT SOCIO-ECOLOGICAL CIRCUMSTANCES ARE RESOURCE INTRUDERS LIKELY TO INCUR?

By analyzing the driving forces that enhance the encroachment of intruders to different SES, we highlight the main vulnerabilities of SES following the framework of Anderies et al. (2004) that enables intruders' incursion. Our aim is not to provide an exhaustive list of factors that facilitate intruders' incursion in a given area, but the nature of the main factors involved. The vulnerabilities of SES to the incursion of intruders derive from the internal components of the systems (public infrastructure providers, social capital and resource characteristics) and those beyond the system through the appearance of new external disturbances.

2.1. Public infrastructure providers and social capital

If the SES has weakly defined enforceable boundary rules, intruders can easily encroach on appropriate local resources. The resource rights of local communities, monitoring and sanctioning are some essential elements that institutions may use to control intruders. The literature provides many examples of traditional SES which institutions cannot prevent intruders from accessing. One notorious example is the situation of many ocean fisheries (Berkes, et al. 2006; Berkes 2010).

2.2. Resource characteristics

This vulnerability relates with the resource's economic value. Obviously, the more valuable the resource is in global markets, the more vulnerable it is to exploitation. Scarce and geographically localized resources are more vulnerable than abundant and widespread ones. Human activities also originate and aggravate the scarcity of natural resources.

2.3. External forces on resource and infrastructure

One of the most important factors that permit intruders is the physical accessibility to the resource and the connectivity of traditional SES to markets (e.g., construction of a new road) (Young 1994; Agrawal 2001; Laurence, et al. 2009). If physical accessibility improves, intruders obtain easy access and can 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 was one of the driving forces that enhanced the intrusion of timber companies. Consequently, large extensions of this forest have been devastated and the social organization of the traditional SES has profoundly changed (Peluso 1992).

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

2.4. External forces on social actors

In addition to improved physical accessibility, the incursion of intruders may be favored by changes in the socio-political context. The literature shows many different examples with which socio-political accessibility increases. 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 of this work (Bottomley 2002), or the shrimp farms in south Asia which are destroying enormous extensions 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 fishery institutions, wildlife and pasture users in African floodplains during colonial periods is currently originating a situation of open access which local communities cannot manage because village neighbors argue that, in democracy, no citizens can be denied access to local resources (Haller and Merten 2008; Haller and Chabwella 2009).

On the other hand, new demand pressures or increased 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 enormous extension of forest that is disappearing in south Asia and south America as a result of new soybean and oil palm plantations (Sandker, et al. 2007; McCarthy and Zen 2010). Occasionally, rising unemployment or a critical economic situation may drive people to harvest in neighboring villages (Twine, et al. 2003).

Basically, the incursion of intruders depends on the interest in the resource, as well as the physical and/or socio-political difficulties in access. That is, the greater the interest in the resource and/or accessibility, the more vulnerable the SES is to the intrusion of new resource users. Finally, users' decisions to intrude a new area are a

trade-off between the resource's value and the effort invested in harvesting (physical and socio-political accessibility).

3. CASE STUDY: IRRIGATION SYSTEM OF THE NORTHWEST MURCIA REGION (SPAIN)

3.1. Study area

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 drought 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, annual precipitation is 300-400mm and potential evapotranspiration is 900mm. This region is a medium mountain area with a surface area of 2387 km^2 in which forest, scrublands and agriculture (traditionally dry farming and small irrigated lands) are the main land uses. Water landscapes are basically streams and springs, which are the main heritage of this area and are outlined against the arid surroundings.

Historically, settlements have located 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. These springs have allowed colonization and human settlement in this area. It was during the Arabic period (17th century) when agriculture started in this area. Currently, the surface area of traditional irrigation land is 4000ha, and there are some 3000 traditional irrigation farmers. 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 intensive irrigated lands (ca. 1000 ha of new irrigated lands) by using wells to pump the water from the aquifer. Several factors have enhanced the incursion of intruders which, in turn, has had an important impact on the configuration and robustness of this traditional SES.

3.2. The traditional irrigation system

In the traditional irrigation system of the Caravaca aquifer (Figure 2b), the resource users are traditional irrigation farmers who use the Caravaca aquifer groundwater that emerges as springs (a resource) to irrigate land. The hydrologic dynamics of springs depends on the state of the table water which varies according to rainfall (environmental external disturbance). Irrigated lands are located in the bottom areas near the springs. Farmers also have dry cereal lands. The most important external disturbances are the inter- and intrannual variations of precipitation that originate drought periods. In addition, crops are affected by extremely low temperatures (spring frosts). Traditional farmers are members of irrigation communities (ICs). ICs are infrastructure providers. During this period of time, the only physical infrastructures are irrigation channels, used to distribute water among farmers. Irrigation channels are constructed by ICs and are maintained by both ICs and the individual farmers (links 3 and 6). Each IC has its own ordinances that constitute social capita, and these ordinances have established 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. Besides 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 which have taken place in recent years (external disturbances), this SES has become very vulnerable to the intrusion of new resource users.

3.3. Driving forces that enhance the encroachment of intruders

Our case study represents a SES that has traditionally used a very valuable resource: groundwater in arid environments. Changes in the technological and physical accessibility to this resource, along with market pressures of agricultural products (new external disturbances) and a lack of enforceable boundary rules of the common resource, have encouraged the intrusion of intruders.

Public infrastructure providers and social capital

One of the vulnerabilities of this SES is that an effective institutional system capable to protect the whole ecological system is lacking. The ICs have the right to use and control the water emerging from the aquifer, but not to the aquifer's groundwater iself, 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 Law of 1985, when groundwater was conferred a public water status. However, the traditional consideration of groundwater as private water and the difficulties that Public Administrations have 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 local social capital's (ICs ordinances) inability to govern the ecological boundaries of the SES, have resulted in increased vulnerability to the intrusion of new users.

Resource characteristics

Groundwater is an important water reservoir in arid areas, and is especially valuable to agriculture. In our study area, abundant, cheap, unprotected groundwater being available, cheap land and moderate summer temperatures have all attracted intruders.

External forces on resource and infrastructure

Traditionally, the study area has been an isolated area. However in 2000, a new road was built to connect this area with the capital city (and the markets) of the Murcia Region. This road improved the local community's status but, at the same time, made it accessible 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 technical, economic and viable option.

External forces on social actors

A new Spanish water law came into force in 1985 which conferred groundwater the status of public water. Although this law controls the uses of fresh water and groundwater, it did not take into account the difficulty of controlling and monitoring groundwater pumping. This situation, along with increased demand in agricultural products, has attracted large companies to expand new areas and to exploit natural resources.

3.4. Changes in the configuration and robustness of the SES

The presence of intruders in the traditional SES has trigged a series of changes that have led to a very different configuration of this SES (Figure 2c). 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 directly 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. 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. They usually rent the land to local farmers who do not have irrigated land and who evidently do not belong to an IC. Groundwater extraction is significantly diminishing the volume of the springs in the study area, especially during the irrigation season, and some have even become extinct owing to the hydrologic cycle's interconnected nature (Pedreño and Pérez 2008). It has to be highlighted that the years when intrusion occurred coincide with a prolonged drought period in the study area, which has aggravated the effects of extractions. 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 on the groundwater pumping of other companies, the amount of which is unpredictable as it responds to other external forces such as global markets.

Traditionally, 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 as a measure to prevent droughts and to efficiently improve the system by which the water is used. New public infrastructures include wells to pump the groundwater from the aquifer, a reservoir 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 affect the resource dynamics vastly (link 5). For traditional 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, between traditional resource users and public infrastructure providers. 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. Besides, 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 increment in individual farmers' and ICs' debts. Besides, farmers are not willing to pay high fees to maintain physical infrastructures or water costs, so land is abandoned. This situation is aggravated because most traditional farmers are dependent on other economic activities, or they are retired farmers but continue cultivating for their own personal use. Furthermore as the SES changes, the breach in vulnerability between ICs and farmers 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. In general, loss of robustness and increased vulnerability are greater in small ICs and in 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 migration of young adults in search of new job opportunities in urban areas (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 in winter. Yet given the increase in groundwater extractions, there is a considerable drop in flow in summer, or it even disappears. So, this resource recovers each year thanks to winter rainfall and to less pumping. However, this resource 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. So 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). 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.

4. WHAT CAN BE DONE? ENHANCE 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 SES. 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 threatens 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 is the case study presented herein, 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. If we consider all these factors, we feel that high-level institutions should assist local communities by guaranteeing the protection of local resources and communities.

In this process, local and high-level institutions' capacity and velocity 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 institutions' reaction and adaptation usually takes 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 have (almost) 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 institutions 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 invisible characteristic implies 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 which depend on groundwater (Shah 2009). Institutions 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 institution which 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.

Learning, communicating, and collaborating through adaptive co-management (Olsson, et al. 2004; Armitage, et al. 2009) are essential practices for local communities and institutions to anticipate and avoid intruders' incursion or to rapidly respond and adapt to handle any eventual consequences. Measures to prevent the incursion of intruders may, on the one hand, protect local communities and local resources by establishing property rights, protected areas and technological controls (prohibition of certain techniques), increase monitoring and establish a multilevel government-based institutional system (Folke, et al. 2005). On the other hand, 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.

5. CONCLUSIONS

As the human population grows and the world becomes more global, the pressure on natural resources and traditional SES is increasing at vertiginous rates. New resources and new areas are being exploited by resource intruders which severely affects the livelihoods of local communities. This research shows how globalization affects the robustness of a SES. This study into a traditional irrigation system reveals how the intrusion of new users seriously deprives the levels of a given resource and makes a SES profoundly vulnerable. In an attempt to adapt, local farmers have intensified the use of this resource which has led to more physical infrastructures. 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 perfect example of the sustainable use of a scare resource which, 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 enhance 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, 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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Figure 1. Aquifers of the Segura river basin in southeast Spain. The Caravaca aquifer is highlighted in dark gray. Black points represent the springs in the study area.

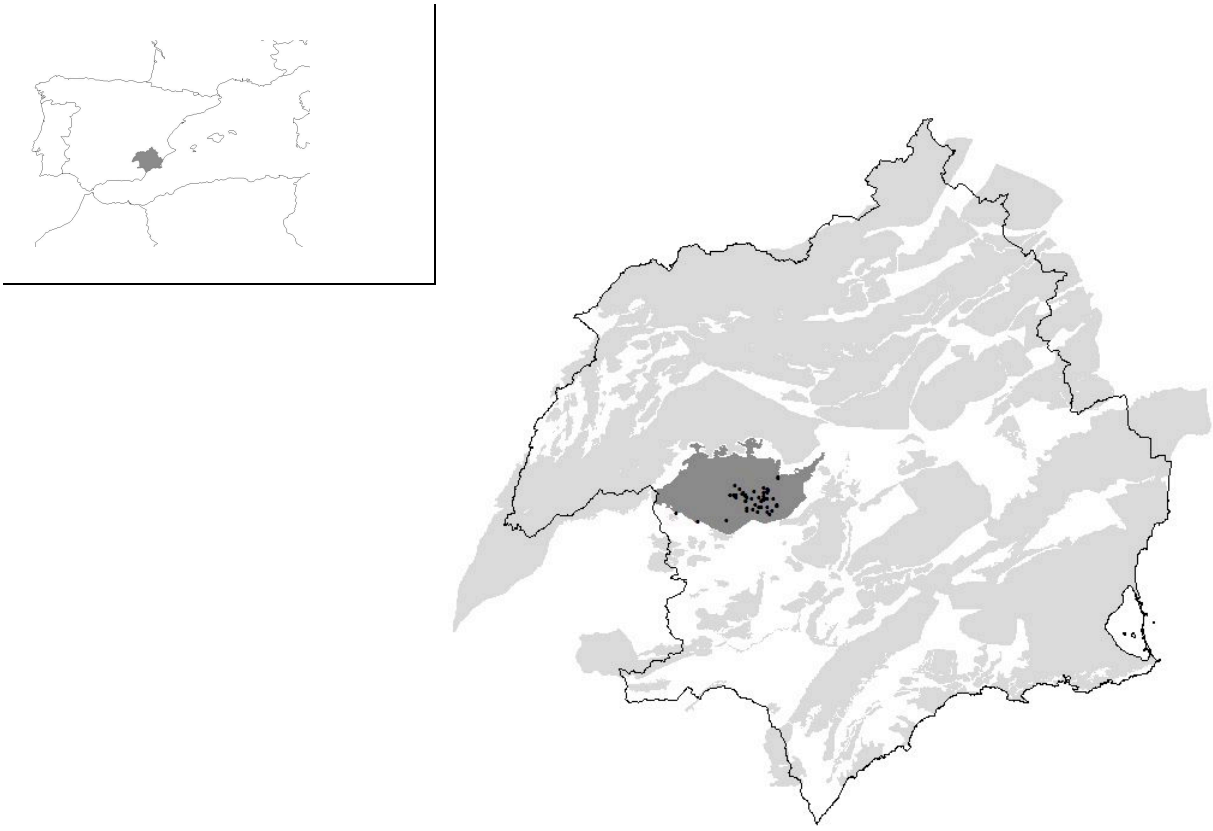
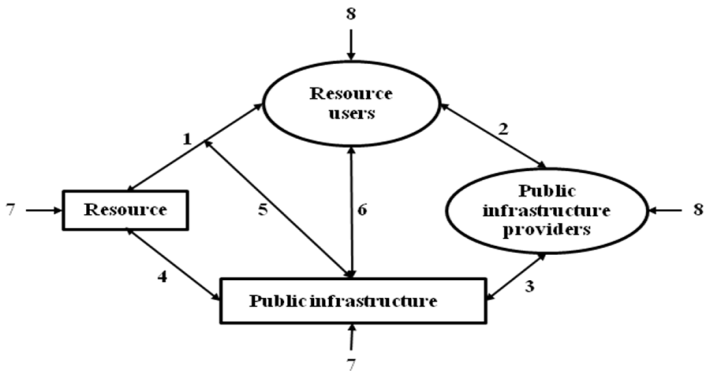
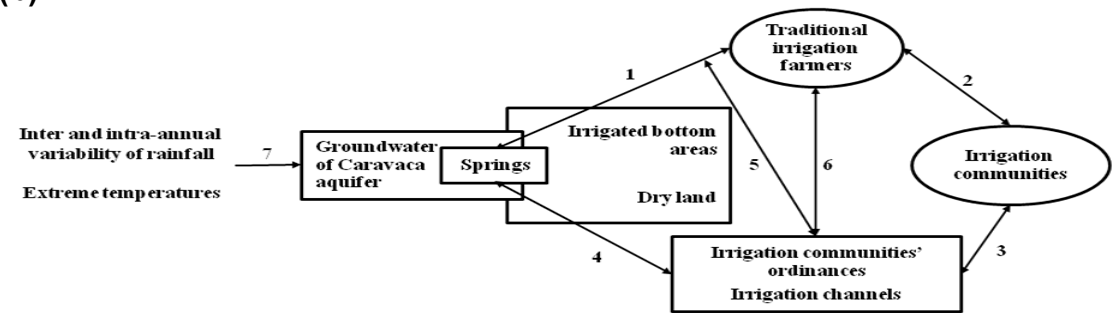


Figure 2. Application of the conceptual social-ecological systems model (Anderies et al. 2004) (a) to the Caravaca aquifer irrigation system in the two study periods: (b) the traditional system before the intrusion of new resource users and (c) the current situation after the intrusion of new resource users.

(a)



(b)



(c)