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Yolanda Lopez-Maldonado (LMU Munich)

**Socio-ecological transformations within the Mayan area of
Yucatan, Mexico: Past and present of a water oriented
complex society**

ABSTRACT

This research deals with the extensive environmental problems with groundwater resources in Yucatan, Mexico, and some of the ways to cope with these issues. The problems we are referring to are associated to a particular case study in the Mayan area of Yucatan. In this place, where groundwater is the only source of freshwater, the inhabitants have to deal with water problems such as resource scarcity, groundwater pollution, climate change, biodiversity loss, and resource degradation. Further, it revealed that one way to improve conservation is to ensure the inclusion of cultural values between people and their environment and this is of significance for evolving strong relations with nature. We examined socio-ecological groundwater relations in contemporary Mayan society by analysing how the ancient Maya obtained freshwater, and how and why contemporary local Mayan communities of Yucatan, Mexico, have transformed the groundwater system by intensify groundwater pollution problems. Several authors have attempted to improve the understanding of complex processes underlying the Maya collapse, and the interactions of this society with nature. But, if the demise of the Mayan populations in the past was the result of complex social and ecological factors, then what are those relations, at present, and how they are conceptualized? What kind of government regulation is necessary, and how can communities make decisions to ensure solutions for conservation, at a time when cultural values, worldviews and traditional practices are being lost? To answer those questions, we review the background to the groundwater problem, and the historical and cultural context of Yucatan groundwater system. We use the Mayan society as a case study to elucidate this and of the induced collapse, exacerbated by the overuse of natural resources in a non- sustainable way. Nevertheless, a very complex traditional ecological knowledge and general worldview of the use of natural resources in Yucatan have significantly shaped the socio-environmental conditions in the region, in particular freshwater resources.

KEYWORDS: Groundwater, common-pool resources, social-ecological system framework, Mayas, Yucatan

INTRODUCTION

Groundwater common-pool resources: complexity over complexity

The collapse of complex societies is one of the most interesting questions in all the social and natural sciences. How can complex civilizations long adapt and then, suddenly, shock and collapse? How societies evolve, move down progressively or swift and how those processes affect their natural world? To understand this we need to draw on different disciplines and consider that the behaviour of societies to confront those processes often feature outcomes, or responses, by evolving the ways of managing their resources. Such responses can follow different pathways including collapse or failure, migration, and mitigation strategies that are not linear on time (Grammlich et al. 2010). For example, evolving societies may organize themselves to extract their resources and establish multifaceted institutional arrangements to manage them and to avoid failures (Dietz et al. 2003, Cash et al. 2006).

The Mayas of Yucatan in Mexico grew up in scale and complexity despite one crucial environmental condition: no surface water exists. To survive in a place where water was scarce or difficult to obtain, the Mayas had to organize themselves to design and to manage their water resources (including water bodies and natural and human-made reservoirs such as wells, sinkholes, and aguadas) (Alpinkar et al., 2009). With a particular cosmology, worldview and traditional ecological knowledge handed down through generations they learned how to manage their water resources for their subsistence. Evidence about the importance of water management in the Mayan region can be found elsewhere (Scarborough 1998; Scarborough and Lucero 2010). Nevertheless, water management is a complex set of local situations and concerns, dictated by several circumstances including, cultural, socio-economic, geographical and environmental conditions, thus, at some point, the Mayas gradually diminished and it is well known that they might collapsed (Diamond 2005, Medina-Elizalde and Rohling 2012).

Despite several scholars have studied prehispanic water management to understand the way in how the Mayas has used their common groundwater resources since history can repeat itself (Lucero 2011), surprisingly groundwater in Yucatan has received little

attention from a common pool resource perspective. Common-pool resources (CPR) are resources that are held in common and for which exclusion is difficult and joint use involves subtractability, such as groundwater basins (Berkes 1989). Groundwater is a common-pool resource embedded in complex social ecological systems (Berkes and Folke 1998, Levin et al. 2012) due to the interconnectedness of the hydrological cycle with the society that uses the resource. In general, environmental issues are particularly difficult to address when the underlying social and ecological systems are complex adaptive systems (Berkes and Folke 1998; Levin et al., 2012). This creates complexities for the analysis of groundwater SES's since both systems are relatively separable but intermingled (Ostrom 2009, pp. 419). In the absence of studies that harness this complexity at appropriated scales, most of the groundwater resources around the world are in peril (Giordano 2009). Regulating and understanding SES's requires considering scale issues. For example, in a groundwater common pool resource situation, wastewater discharges from one user might affect the use of others that share the same resource or, where, if one user extracts water from an aquifer, it affects the ability to others to use the resource. Shared water intake among all users produces spread of contaminants among all users, regulations of intakes and discharges and its control is the primary for understanding the process.

Historically, societies declined and their natural resources also declined, especially when the resource is a CPR. Groundwater is particularly degraded, especially in places where they are open access or governed by top-down approaches. In a groundwater common pool situation, when the resource is open access, sometimes this can generate severe free-riding problems since the water extraction of individual agents affects everyone (Levin et al. 2012). While an open access resource is competitively used, and property rights are developed, many others constrains might arise or experiencing adjustments or variation through time. This creates a misleading representation of the dynamism of socio-ecological systems because what appears to be stable in one spatiotemporal level or scale may undergo changes into another (Cash et al. 2006).

Societies develop action issues to access to resources in order to achieve benefits (Ostrom and Hess 2008) and some of those actions may also undergo swifts through time. In reviewing those changing relations, we investigate how a particular society deal with change in social-ecological systems, how they adapt to change by choosing and

following particular pathways, and how they can shape change towards sustainability. In doing so, we show the role that ancient Mayas played in managing their water resources, their knowledge of hydrology and water resources engineering and management, and the consequent transformation of their landscape and their governance of water systems. We use the example of groundwater management by analyzing the ancient and present day Maya society, focus on the human side of the story regarding modification of the natural world, which provides lessons from the past and allows comparing to the present. We also present insights of the modern times, in which water uses emerged, including technological development, advances in hydrology and further specialization, which led to different ecological problems and influence the way in which contemporary Mayas viewed and related to nature, with the unprecedented ecological implications.

This study analyses the extensive environmental problems with common pool groundwater resources in Yucatan, in Mexico. The aim is identifying the variables that cause decommonization (and therefore commonization) by exploring the empirical basis of how management of a resource that is used for a complete society – theoretically, a common pool resource – may go through processes of development or decline. It attempts to exemplify the importance of consider both multilevel cross-scale interactions to show that common pool resources are dynamic over time (Nayak and Berkes 2011). Little effort has been made to understand the dynamical changes in collective action for solving groundwater common pool dilemmas. To exemplify this dynamism, we applied two related concepts as found on the commons literature: commonisation and decommonisation (Ostrom 1999, Nayak and Berkes 2011). Here ‘commonisation’ of groundwater resources, is defined as a process through which the resource gets converted into a jointly used resource under commons institutions and collective action that deal with excludability and subtractability (Ostrom 1999). The term ‘decommonisation’ refers to a process through which groundwater is a jointly used resources under commons institutions loses these essential characteristics. To better understand the decommonisation of groundwater in Yucatan and the dynamism of common-pool resource management, the study aims to answer the following questions:

- What are the main variables that have promoted collective actions for successfully protection of cenotes ad groundwater in the past and that influenced

how the Mayas have transformed the way in which groundwater resources were managed?

- What are the current variables, causes and conditions affecting levels of fruitfully collective actions among users, communities and the Mayan society as a whole and how these have affected the structure, worldviews, property rights regimes and social economic relations?
- Can cenotes get converted into a jointly used resource under commons institutions and collective action?

The study explores how local groundwater management is currently organized in a rural setting by applying a particular framework as a diagnostic tool to investigate factors over time that might influence the way in which groundwater resources were managed. We structured the paper as follows: First, we describe the area of study, methods and framework. Secondly, we look back and forward to provide the context of variables and factors that have influenced groundwater management and present results to show that the groundwater system, after a period of time, broke down and decommonized, and loss some of its main characteristics. Finally, we conclude by considering lessons that we can learn from the Maya to avoid future natural resources management failures, or collapses in our societies.

METHODS AND STUDY AREA

Study area

The study was developed in Yucatan, Mexico which covers an area of 39 612 km² and with a population of nearly 2 million inhabitants (INEGI 2015). The focus of this research concentrated on the current groundwater management in a small Geohidrological Reserve in Yucatan. The Reserve is located in a very complex groundwater system product of a meteor impact 65 millions years ago: The Ring of Cenotes. It comprises an individual aquifer that is shared by thirteen communities. Those communities have adjacent areas and some of them are separated by the boundaries of a Natural Protected Area, the Yalahau Lagoon (Figure 1). The groundwater system of Yucatan is suitable for setting the study to address groundwater common pool issues since property rights are not well defined and where groundwater

management has evolved from long surviving traditional common institutions but at one point they were absent.

The landscape in the study area is defined by a high permeable karstic soil. Two consequences of that is the notable absence of rivers or permanent freshwater resources within the area and a high amount of sinkholes or natural wells (locally called cenotes). With more than 2000 cenotes within the Yucatan state, and around 400 groundwater cenotes in the study area, groundwater is the only source of freshwater for the population. National and international institutions such as The UNESCO Biosphere Reserve Program, the Ramsar Convention and The Mesoamerican Biological corridor have recognized the scientific, cultural and historical importance of the area. In total our study focuses on 12 cenotes to provide evidence of the decommissioning process in which they are embedded.

Figure 1. Study zone showing the Geohydrological Reserve zone (blue line), the communities (grey colour) and the Yalahau Lagoon (red line) in Yucatan, Mexico. Source: Polanco et al., 2015.

The framework and methods

To study the case of groundwater common pool resources in Yucatan we need a particular framework within which to work to organize diagnostic, descriptive and prescriptive inquiry, and to construct the causal explanations expected in the theory of the commons (McGuinniss and Ostrom 2012). Our study is set up in the social-ecological systems framework (Ostrom 2007, 2009) since it can be applied to a relatively well-defined domain of common-pool resource situation, according to rules and procedures determined by an overarching governance system (Anderies et al. 2004). We choose

this framework since it seems to be the only framework that treats the social and ecological systems in almost equal deep (Binder et al. 2013). The, multilevel framework, as developed here, involves both the human components of the system (operations, rules, policies, and laws), the biophysical components of the ecosystem, and we add the system knowledge pertinent to the dynamics of environment and resource use, worldviews (Figure 2). We use the framework as a diagnostic tool to investigation factors over time that might influence why cenotes were successfully protected in the past and why, at present, cenotes are in peril. We also explore the causes and conditions affecting levels of fruitfully collective actions among users, communities and the Mayan society as a whole.

Figure 2. Framework for the analysis of the groundwater system in Yucatan (Lopez-Maldonado 2014).

We applied five different, interrelated, methodologies: 1) material flow analysis: to quantify groundwater flows associated with present-day economic sectors, to understand the resource system and to make a more precise assumption about the causal logics in our particular case (Lopez-Maldonado, Binder and Fath 2016, forthcoming); 2) structural mental model approach: to analyze stakeholders' risk perception regarding groundwater pollution, by eliciting mental models (Lopez-Maldonado and Binder 2016, forthcoming); 3) underwater exploration: to obtain insights about current and real status of local wells and sinkholes (Lopez-Maldonado 2015); 4) community-based conservation: to integrate local values, beliefs and perceptions into groundwater conservation (Lopez-Maldonado and Berkes 2016, forthcoming); 5) environmental activism: to directly involve stakeholders in local wells clean-ups, and community

events (Lopez-Maldonado 2014). All those methods were developed in a transdisciplinary process with stakeholders spanning sectors including: NGO's, local communities and policy makers.

Fieldwork and data collection

This study relies on data collected in Mayan villages of Yucatan, Mexico. We performed an extensive literature review and consulted research and governmental documents (i.e. articles, theses, book chapters, technical reports, conference papers), to identify the set of variables of the study of the SES's. Detailed data obtained from the analysis of each system separately and by adding studies that other scholars generated, we examined the case of the Maya using the proposed framework. Because of the complexity of this research, we used research tools from different fields including the social and natural sciences. This included: i) review of published literature and national statistics; ii) interviews, consultation and informal conversations with key stakeholders; iii) participatory observations; iv) groundwater modeling; and iv) underwater exploration. More than 150 stakeholders from different sectors were involved including: local members, NGO's, environmental authorities, experts and researchers working in the water sector, students, local divers, policy makers, representatives of the ECAS, among others.

Data was collected during different workshops with stakeholders and members of different water institutions in Yucatan such as Groundwater committee of Yucatan (COTASMEY), Water supply company (JAPAY), Ministry of environment (SEDUMA), and the National Water Commission (CONAGUA). Communitarian activities including cenote clean-ups helped me to obtain data and engage with the communities. Several consultations with environmental authorities and focal groups for further discussion were carried out. All those activities were crucial to get empirical information about current situation of the groundwater system. Additionally, we identified possible local groundwater management rules and practices adopted by communities in the study area, which has not being cited on scientific literature.

Fieldwork was developed during different stages from 2012 to 2016 and over a period of 30 months. We used participant observation and performed a total of 50 interviews

with key stakeholders including: (n=5) government officials, local communitarian members (n=25), experts working on the water sector (n=5), underwater explorers (n=2), members of NGO's (n=3), and researchers of the main universities in Yucatan (n=10). We applied the snowball technique in order to interview local people on the communities and further participants. We developed workshops with the COTASMEY and with representatives of the communitarian spaces for water management (ECA's) in Yucatan. The ECA's are part of a Federal program established by CONAGUA in 2002 with the aim of promote and strength communitarian participation in water related issues and to promote good uses of the resource among the population. In Yucatan, during the fieldwork phase there exists 79 ECA's comprising 80 municipalities (considering that more than 2 ECA's can be found in urban centres and large communities). We analysed literature of the SES framework but our focus was to examine cases where the dilemma involves the use of groundwater or freshwater bodies. Field visits to cenotes allow having records of the environmental conditions of those sites, the biodiversity or possible disturbances. Speleological records, maps and drawings of the cenotes were used to generate database with information of each place. Personal observations, informal conversations and interviews provided detailed characteristics of the socio-cultural context affecting collective action. Workshops were developed to gain insights about the natural system and the human induced flows affecting the resource.

Data analysis

Review of available published data was performed as well as analysis of national and local statistics, karst surveys and research fieldwork reports in the area. Records about groundwater uses, extractions, and distribution of the JAPAY were studied. Hydrological prospect plans for the region as well related policies at all levels were scrutinized. We used hypothesis test to determine the sharing and viewing mental models of the experts and scientist working on the water sector and the communities.

RESULTS

Variables that have affected collective action

This study contemplates the changes that have taken place over time to demonstrate the process of decommonisation of groundwater resources in Yucatan, Mexico. To understand this process we analysed a set of factors that are rooted on the design principles proposed by Ostrom (1990). We focus on the 10 second-tier variables that can be described according how do they influence the way in which the groundwater system has undergone (positive or negative) change (Ostrom 2009). Explaining the changes in the Maya society is a challenge because we are assessing different spatiotemporal places, each with their own history. The common-pool resource of our interest is a common groundwater reservoir that is the main source of freshwater for the population, and the cenotes or wells in which water can be obtained. Currently there are more than two million people withdrawing water from this source, thus maintaining the quality and quantity of water is critical for all. Results are grouped into two major headings: 1) identification of factors and variables that have promoted collective actions for successfully protection of cenotes in the past; and 2) current variables, causes and conditions affecting levels of fruitfully collective actions among users, communities and the Mayan society as a whole.

Groundwater management in the past: Cenotes as commons

Many variables influence the patterns of interactions and outcomes observed in our study. Through literature review we found plenty of evidence regarding the complex set of SES's interactions in the region. After a careful analysis, we identified several factors outline held cenotes as commons in the past and as shown in Tables 1 to 3.

Table 1 to 3. Factors influenced the way in which cenotes were managed as commons and that have affected positively collective action and ecological performance in the past.

Natural system: The natural system that concerns us is the groundwater system in Yucatan (RS1). In the past, having firm boundaries and uniform territorial control (RS2), archaeological and textual evidence suggest that ancient Maya cities were established on places where they could extract water for its subsistence. Aquifer size (RS3) was not an ecological obstacle for its protection since the resource was used and shared by large communities located within the Yucatec Mayan area. This can be an assumption that,

despite that groundwater system boundaries were unclear, communities were able to locate and identify the bounded water territories and governments to control large territories.

Because of the lack of surface rivers the Maya learned how to manage groundwater resources by building human-made reservoirs, constructing dams on the top of hills (RS4), they were able to deal with stressing variations on environmental conditions (RS6), by transforming their world. Ancient Mayas typically managed cenotes and were responsible for their maintenance. In addition to pyramids and ball courts, they significantly modified their landscapes to centralize their water needs, capture rainfall, and create channels to provide water to several communities for its use (Lucero 2012). Example of this was the change to the natural world including the construction of road systems and other human constructed facilities (RS4). As access routes for the interchange of goods between communities and commercialization, these roads (locally called *sac-bes*) were created to provide access to sacred centres and temples but also to the resource in question. The ancient Maya developed a complex system of water management dependent on water collection and storage devices (RS8) and this supports a better control of the resource. Slow incremental modifications were possible without significantly altering existing pathways and disrupting the natural flow of nutrients and energy (RS5, RS6). The system was resilient and sustainable, which prevented an overexploitation of biophysical resources (Scarborough et al., 2009). In terms of replacement rate of the resource (RU2), this variable was affected due to a widespread conditions and episodes of drought, which are consistent with a reduction on annual precipitation (Medina-Elizalde and Rohling 2012). Similar than today, variations in annual precipitation might significant alter the groundwater table in the area.

Social system: The social system includes those dealing with the governance and management of the resource. Some social factors might successfully influence the way in which cenotes were managed as commons in the past. The existence of a large and homogeneous number of users (U1) including the local residents located within the communities, and other cities near to the water bodies, also facilitates the way in which the resource was managed. With a homogeneous but hierarchical society (U2), management of groundwater was based on ancient traditions handle down through generations (U4). Most rules and norms are likely to have been in place during earlier

times and local communities might have had greater control over the resource. Another aspect was the high and strong social capital (U6) and particularly with good leadership, mainly political leaders (U5), impact political cohesion as well as community involvement in resource management.

Despite the lack of archaeological evidence, the Maya case regarding natural resource management lends insights for the use of historical analogy to inform about how was the user's knowledge of their groundwater resources and their attributes (U7). Some authors have emphasized that such events involved societal decisions about the use and maintenance of the environment (Turner and Sabloff 2012). The importance of groundwater in a hostile environment creates high dependence of local communities on the resource (U8) for its survival and cultural traditions, and in the use of wells (pozos and cenotes) for human needs. This can be seen as a critical issue for its management as a common resource. Productively, earlier civilizations like the Mayas tended to have growing population and rapidly expanding cities that needed to be supplied with enough natural resources, including freshwater, for their basic human needs. However, satisfy this demand in a place where no rivers on the surface exist was an extremely difficult activity. This was accomplished by adapting to the human necessities, developing new tools and implementing them (U9).

Governance system: Groundwater management that was performed by the Mayas might required a well-structured landscape planning, substantial political and social organization as well as reinforcement and value of institutions and traditional local practices. The need to manage water resources in a water-dependent society might lead to the establishment of institutions for its management (GS1). Population had access rights for extraction, grazing and fishing, and the majority of those rights were monitored, imposed and controlled by the Mayan elite and supernatural beings. Formal and informal rules were replaced at the time of the Spanish conquest, which supplemented traditional ancient institutions. Networking with external communities and governments (GS3) were evident in all Mesoamerica and solidarity among communities to use and protect their natural resources has been described for several scholars. In the past cenotes have been managed as commons (GS4) and cenotes were protected for the whole society in a common and joint use (Lopez-Maldonado 2016). Operational community rules (GS5), as well as formal or informal norms for monitoring (including supernatural sanctions) (GS8), were probably critical variables that influenced

positively groundwater management and conservation. Collective actions led to protect and improve environmental conditions of cenotes (GS6) and sanctions imposed by governmental authorities (GS7) also influenced its conservation.

Groundwater management at present: cenotes as non-commons

In general many of the Ostrom design principles for commons were violated in the case of understanding cenotes at present. Several limitations were also found in terms of lack of related scientific literature.

Natural System: The natural system that concerns us is the groundwater system and cenotes in Yucatan (RS1). The main uses are agriculture and industry, which causes pollution and overexploitation. Clarity of boundaries and size (RS2 and RS3) limit conservation since the YPA is one of the biggest aquifers in the country and each cenote is interconnected within this aquifer. So far, due to the large amount of cenotes, it is not possible to control the resource. Physical resource boundaries do not overlap with social-user boundaries causing lack of control of water extraction, tax declaration and high levels of pollution in open access places (Lopez-Maldonado and Berkes 2016). Physical and virtual boundaries (administrative, protected areas, etc.) are not well defined and population do not recognize them clearly. Communities also can withdraw water from a neighbouring water body if there are not well-defined property rights.

The water supply company, Junta de Agua Potable y Alcantarillado de Yucatan (JAPAY), supplies 90% of the urban households. Rural households are water self-sufficient but they receive technical support from JAPAY. In addition, municipalities also receive water for a main pumped source that consists in legal concessions available for those who wants to extract water for several uses from the aquifer. Roads, human-constructed facilities and other modifications to the natural system including pumping wells, technology for groundwater extraction and modification to build infrastructure for tourism threshold the resource (RS4). Our evidence suggests the lack of system knowledge with regards of its dynamics including equilibrium properties, predictability and storage characteristics (RS5, RS6, RS7). For example, equilibrium of the system has been broken and this has been evident in many parts of Yucatan (RS5), which in turn makes difficult to predict future behaviours.

Social System: Social barriers include a large number of resource users (U1), and exclusion of almost all of them on resource management and planning. With 106 municipalities only in the Yucatan state, the main water source is the groundwater system. It means that water can also be extracted from local wells and stored in tanks without a concession. Groundwater is pumped directly to the households. Furthermore, mostly all rural households also extract water from their own wells (pozos) (Lopez-Maldonado, Binder and Fath 2016, forthcoming). Pollution and restoration can be expensive and impossible without collective action. Different socioeconomic attributes are evident in the communities explored (U2) and traditional ecological knowledge has been degraded (U3). Lack of leadership (U5) was also evident on the communities studied and trust among users in reaching agreements and monitoring was not found when eliciting mental models (U7). Young are not interested in preserving ancient traditions and communities are the lowest level of the hierarchy of governance structure. Regarding the autonomy in making rules there have been some activities in order to protect cenotes but the participants in most of those instances were in the majority of the cases not locals (U2) and they did not share norms related to extraction levels and practices (U6). Dependence on the resource (U8) is high but this is not reflected on the value of locals. From the fieldwork data collection we found that cenotes in general display significant human alteration (U9), although some of these places are under environmental protection. Mental models allow seeing discrepancies among those organizations regarding problem definition and knowledge of the system. Social and physical boundaries were not clearly defined for the users, which suggest lack of system knowledge (U7). Monitoring is not vested in community members who were accountable to the community, and sanctions are not used (U6, U8). Conflict resolution and sanctions are violated due to the lack of community associations and there is ignorance about legal actions related bad management practices (U8).

Governance system: In modern times, cenotes are managed according the common property regimes described by Lopez-Maldonado and Berkes (2016). The current governance system is polycentric but does not work properly (GS1). Some cenotes are located in private lands, others on ejido lands, some of them are managed by the government and others are open access (Ostrom 2009). There are NGO's but they work in an isolated way and are not able to develop rules to promote better management

practices or to solve problems regarding groundwater problems (GS2). NGO's do not influence groundwater management and society does not organize to manage the resource. Group sizes on collective action are mediated by other variables and there is a lack of networking with government and external aid (GS3). Cenotes that are located in open access spaces or that do not have clear and well-established common property regimes (GS4) (Lopez-Maldonado and Berkes 2016) are more vulnerable to overexploitation. Collective choice arrangements are notably absent (GS5). Government and policy makers do not influence decision-making processes made by associations and communitarian cooperatives. Rule making is not developed collectively since it involves a very small group of experts and just few representatives of the population elected by the former (GS6).

Rules of use and local conditions do not overlap. Users are allowed to take water from any part of the aquifer and the related water bodies for use in industry, agriculture or for their human needs. Mismatches among institutions and jurisdictions, changes on values and perceptions, and lack of rules created a transition from local common groundwater management to an open access use of the resource (Lopez-Maldonado 2015). Some efforts have been made by local groups to protect and restore the resource by clean-ups but locals do not tend to be involved (or have been unable to do this effectively). Local people have little incentive to conserve cenotes since they do not own the cenotes so they cannot regulate their own joint use (GS5, GS6, GS7). There are not horizontally and vertically integrated institutions for decision-making and government do not recognize traditional ecological knowledge as an important informal norm of monitoring (GS8) to promote better groundwater management (Lopez-Maldonado, Berkes 2016). Supernatural sanctions on some cenotes visited were identified but population does not follow them up (GS9). As shown in Tables 1 to 3, the groundwater common pool resource case in Yucatan violates almost all design principles. Significant differences were found in rural and urban settings as well in the rules of use. No differences were found among the communities explored.

DISCUSSIONS

Understanding decolonization of cenotes in Yucatan

In the past, most attention was given to scale in studies of SES's interactions and on the spatial, temporal, and jurisdictional issues. So far, water management studies in the region have tended to focus on past Maya society, excluding communities that currently face the challenges associated with water today. These challenges can be illustrated through the example in groundwater management, governance and property right regimes. We examined socio-ecological groundwater relations in contemporary Mayan society by analysing how the ancient Maya obtained freshwater, and how and why contemporary local Mayan communities of Yucatan, Mexico, have transformed the groundwater system. By examining the attributes of a particular resource and how this, and the interrelated characteristics such as units, might develop over time we identify further combinations of variables that affect the incentives and actions of actors under diverse governance groundwater systems.

Societies values to water might vary with time, changing under the influence of education and due to the dynamics of the resource system in question (Morton et al., 1998). The case of Yucatan underwent decommonization after a period of time in response to a shift or loss on how people value the system and changes on the management. In general communities thought that their relationship with the resource had deteriorated over the years and the common pool resource is not considered commons anymore. To explore the mechanisms that contributed to this shift, we should explore SES's based on the hypothesis that values reflect human preferences at different time periods. As suggested by Nakay and Berkes (2011), disconnection of people from the resource is a driver of decommonisation, which is evident in the case of cenotes of Yucatan (Lopez-Maldonado and Berkes, 2016).

In general, many of the Ostrom design principles were found in Yucatan for governing the cenotes. For example, common property institutions specify the rights of a community to a resource. Sometimes these institutions appear stable overtime, however institutions might change since communities can change the rules to harvest specific resources through their story. Nayak and Berkes (2014) have proposed the concept of decommonisation, as the process through which a jointly used resource under commons institutions loses these essential characteristics. Refers to a process through which a jointly used resource under commons institutions loses these essential characteristics. In Yucatan cultural and historical factors underlies institutional arrangements. Whilst some

scholars presume that such constraints in groundwater systems share a single underlying theoretical structure, the possible approaches and solutions are so diverse, however, that it is unlikely to imagine that time do not cause any influence on the way in which a resource is managed.

Other factors influencing the way in which cenotes are being decommonized are lack of institution diversity to manage groundwater, low interest in well establishment and definition of common property rights and lack of community involvement are also a drivers contributing with decommonisation of cenotes. Government does not enforce rules, decision-making follows a top-down approach management, as used in the common literature (Ostrom 2009), but no collective action and management strategies of cenotes do not include indigenous peoples in decision-making processes. All those factors might influence the way in which cenotes are managed at present. Some environmental implications have been described including groundwater contamination, salinization of aquifer, impact on biodiversity, and loss of cultural values and beliefs (Metcalf et al. 2013; Polanco et al. 2015; Lopez and Berkes 2016). Those impacts are indicators of the changing relations between Mayan society and their common groundwater resources, a clear example of the discussed decommonization process.

CONCLUSION

Based on our analysis of collective action principles (Ostrom 1990) we can conclude that the groundwater system in Yucatan is a clear example of decommonisation since a jointly used resource under commons institutions has lost these essential characteristics. Thus, the question of can cenotes get converted into a jointly used resource under commons institutions and collective action or “re-commonised”, is crucial. To answer this it is important to understand that any resource can enter into a process of commonisation; already established commons or resources that are being commonised could also revert back to decommonisation (Nayak, Armitage and Berkes 2015). In the case of governing the groundwater commons in Yucatan, there has been a failure to understand large-scale management processes with the interplay between institutions at multiple levels and scales. For example, the long traditional ecological knowledge of Mayan history are not linked with current management policies or the faster development of the current Mayan society. It seems that collective action is needed and

collaboration within stakeholders is required. Furthermore, is not possible to consider cenotes as a single non-interrelated resource due the complexity of the aquifer system. Cenotes are connected; they cannot be managed except as state property or communal property. Regulation of water intake and discharge and its control is the primary driver for understanding the process. Cenotes/groundwater can be studied as a multilevel commons problem. In the case of Yucatan, to start a process of "re-commonisation" of cenotes/groundwater will requires partnerships of federal and state agencies, communities, and other stakeholders to ensure water for future. It cannot be done by top-down Government Regulation. There is an urgent need for revival cultural values regarding sacredness of cenotes, restore traditional commons institutions and revitalize community responsibility, backed up by government regulation.

The case of groundwater common pool resources in Yucatan provides some lessons in commons management. Almost all the Ostrom principles, with emphasis in multi-level governance, collective choice rules and revitalization of ancient traditional institutions, are required. Challenges in this study are the complexities for SES's due to the non-linear in nature, cross-scales (space-time) and evolutionary character for both the natural and social systems (Van der Gun). We exemplify the rapidly changing world urges us to improve our understanding and learning of complex interactions between society and the groundwater system.

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Table 2. Resource (R) system and main attributes as proposed by Ostrom (2009).

Resource attributes		Description
RS1	Sector	Water/groundwater
RS2	Clarity of the system boundaries	Yucatan Peninsula Aquifer is shared by tree different states: Yucatan, Campeche and Quintana Roo (composed of 13 Hydrological Units). 106 municipalities in Yucatan share the groundwater system (2 million inhabitants). Locals having a cenote or pozo on their lands they have self-defined the outer boundaries of their (water) territory over time
RS3	Size of resource system	Aquifer groundwater volume available for extraction. Very large territories or resources are unlikely to be self-organized given the high cost of defining boundaries, monitoring use patterns, and gaining ecological knowledge
RS4	Human-constructed facilities	Communication (roads might begin to integrate distant resources and their users with other users), pumping wells, veletas for extraction, roads)
RS5	Productivity of the system	A resource system productivity refers has a curvilinear effect on self-organization across all sectors. If water sources are already exhausted or apparently very abundant, users will not see the need to manage for the future. Users need to observe scarcity before they invest in self-organization (Wade 1994). Groundwater is a non-renewable finite resource
RS6	Equilibrium properties	In CPR some resources perform near the Nash equilibrium over time. For higher levels of stress, the systems may be pushed away from equilibrium and reinforcing loops begin to dominate the system's dynamics. Lower intensities of stress, balancing loops tend to lead the system to an equilibrium state.

RS7	Predictability of system dynamics	System dynamics need to be predictable that users can estimate what would happen if they were to establish particular harvesting rules or no-entry territories. Yucatan possesses characteristics of high porosity and permeability causing rapid rainwater evaporation and infiltration of water and pollutants. Combining this with high warmer temperatures during the year makes storage poor. High unpredictability resource flows affects the ability of users to allocate available resources or undertake activities that would augment supply (Agrawal, p:1655)
RS8	Storage characteristics	Land coastal interactions are currently affected for changes in fluxes of groundwater due to well constructions. Salinization problems of the aquifer are degrading important ecosystems.
RS9	Location	

Table 3. Users (U) and main attributes as proposed in the SES framework (Ostrom 2007).

Variable		Description
U1	Number of users	Large, medium or small number of users. The impact of group size on collective action is usually mediated by other variables
U2	Socio economic attributes	This includes age, marital status, levels of wealth or income, heterogeneity, etc. This is influenced by the heterogeneity on the group
U3	History of use	Successors, traditional ecological knowledge passed by generations, changes in water management strategies Rules and norms are likely to have been in place during earlier times. Local communities might have had greater control over resource management
U4	Location	Spatial location of the cenote e.g. cenotes located in NPA's or protected zones is expected to have less pollution problems. Cenotes are important sites on the communities, they represent spots of biodiversity and are rooted in the communities
U5	Leadership, entrepreneurship	Referred to communitarian members which are seen as influential in the decision making process, young, familiar with changing external environments, connected to local traditional elite. Low leadership
U6	Norms/social capital	Thrust among users in reaching agreements and monitoring. Lack of trustworthiness and reciprocity, locals do not developed their own norms (only one exception in one community)
U7	Knowledge of SES's/Mental models	User's knowledge of the resource and their attributes. Lack of knowledge about the resource units and resource system they are using (including experts)

U8	Importance/dependence of the resource	This is the value of the resource reflected in the dependence on the resource for a substantial portion of their livelihoods
U9	Technology used	Technological means available to exploit the resource can transform the cost-benefit ratios of harvesting products and this may undermine the sustainability of institutions. Change in power relations since locals dependent on common pool resources loss certain levels of access. The privatization in some commons involves state officials and selling products that were earlier under common property rights. Enough time is needed before users are able to adapt to the new technologies.

Table 3. Governance system (GS) and main attributes as proposed in the SES framework (Ostrom 2007).

Governance System		Description	Category
GS1	Government organizations	The government systems that control the rules of use of the resource in question (generally top-down or bottom-up)	Local (SEDUMA, JAPAY) National (Conagua) International (GEF, UNESCO)
GS2	Non-government organizations	Further institutions that control, develop rules of use of the resource in question	NGO's Cooperatives Ejidos
GS3	Network	Networking with government agencies or	No solidarity among users, lack of networking with government,

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	structure	external aid	in some cases successful networking with NGO's
GS4	Property rights system	Common property institutions specify the rights of a community to a resource	Private property, Ejido property, Open access, State property Agrawal 2010
GS5	Operational rules	Operational community norms for managing the resource and the different activities permitted	
GS5	Collective-choice rules	It refers to collective actions performed by users	Collective choice arrangements are notable absent. Some efforts have made by local groups to protect and restore the resource by cleanups. Locals do not protest (or have been unable to do this effectively) against the pollution of the resource (they protect the wells located on their own houses)
GS7	Constitutional rules	Institutional regimes and arrangements concerning monitoring, sanctions, adjudication and accountability	
GS8	Monitoring and sanctioning processes	Formal or informal norms for monitoring within the community	Supernatural sanctions on some cenotes were identified but population does not follow them up