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Responding to disturbances: lessons from a Mayan social-ecological system

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Abstract: The Mayans of the Yucatán Peninsula, together with their environment, conform social-ecological systems with adaptation and resilience to natural, political and economic disturbances. In this study, we use the framework of social-ecological systems for describing a mechanism that allows a Mayan community and its natural environment to respond to disturbances over time. We describe (1) the activities that members of the community develop as part of their strategy for managing natural resource management, and (2) the history of the social-ecological system focusing on meaningful events: changes in their institutional body, landscape and/or practices for exploiting natural resources, and interactions between these changes. Through both semi-structured and in-depth interviews, historical narratives and participant observation, we found that managers use the environmental heterogeneity to diversify the exploitation of species, manage the secondary vegetation and protect mature vegetation. Formal and informal institutions of access, regulation and administration of natural resources regulate

productive activities and management practices. These institutions operate differentially at the levels of environmental units (prohibition of the exploitation of the natural resources of mature tropical forests) and species (protection of the jaguar and cougar). Diversification of productive activities, management of environmental heterogeneity and the presence of flexible institutions enable responses in the social-ecological systems that have the potential to contribute to its long-term maintenance. Comprehensive studies like this might help to understand adaptive capacity and social-ecological resilience.

Keywords: Appropriation of nature, local institutions, natural resources management, landscape heterogeneity

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1. Introduction

Conservation of tropical forests in Latin America involves unprecedented challenges (Castillo and Toledo 2000). The mismatch between conservational and development policies is leading to higher rates of land-use change and degradation (Gómez-Pompa and Kaus 1999; Ramírez-Delgado et al. 2014). Climate change is affecting ecological processes and the way people manage their natural resources, on which they depend as the primary source of food and income (Manuel-Navarrete et al. 2011). Besides, concerns about globalization through policies for commodifying nature point out the risk of weakening ecological and social systems if policy makers ignore local processes for governing forests (Arsel and Büscher 2012). Leichenko and O'Brien (2008, 9) argue that there is a double exposure when a particular region, social group or ecological area is simultaneously confronted by exposure to both global environmental change and globalization. Facing these challenges require analyzing social and ecological systems in an integrated approach, as well as building responses based on local realities, knowledge and technical experiences (Ramírez-Delgado et al. 2014).

The Yucatán Peninsula is a region where the analysis of the interplay of social and ecological systems in response to double exposure may contribute to its understanding. First, because the Mayan people have inhabited the region and managed their natural resources for over 3000 years (Barrera-Bassols and Toledo 2005). Second, because hurricanes and fires, historically intense and frequent in the region, represent two of the most severe impacts on forest ecosystems (Boose et al. 2003), affecting its resilience. Third, constant pressures

for high-yield productive activities are leading to social-ecological vulnerability while diminishing sustainable practices for managing resources (Ayala 2001; Martínez-Ballesté et al. 2006). Finally, public conservation policies, like payment for environmental services (PES) or protected areas (PA), are being questioned about their real capacity for maintaining long-term effects on forest conservation (Ellis and Porter-Bolland 2008; Kosoy et al. 2008). Nevertheless, some Mayan communities in the region have responded to these challenges relying on cultural values and not only on improvised responses, making relevant the understanding of the social-ecological systems they conform (Gómez-Pompa and Kaus 1999; Smardon and Faust 2006).

Throughout history, the Yucatec Mayan culture has faced recurrent disturbances of different nature and magnitude while their populations fluctuated (Faust 2001; Gunn et al. 2002), including its population collapse in the Classic and Postclassic periods (Folan et al. 2000). Recent survival and recovery of Yucatec Mayan communities after such disturbances are associated with their ability for managing vegetation mosaics, maintaining the multi-crop systems called milpas, and exploiting different species (200–300 plant species) from various environmental units (Barrera-Bassols and Toledo 2005). In conjunction, these activities conform a diversified strategy for managing resources and ecosystems; that have direct effects on social and ecological processes. From the social perspective, this approach allowed the Maya to develop activities destined to either satisfy their subsistence needs or to carry products to the market. These have been complementary strategies for satisfying needs of food, energy, materials and health of households. In ecological terms, while domestic gardens and milpas promote successional dynamics of the forest, activities (such as apiculture and hunting) contribute to ecological interactions with forest ecosystems. Within social-ecological systems with low human population and land-use pressure, the diversified strategy for managing resources in the Yucatán Peninsula allows stable populations of local fauna (Escamilla et al. 2000), and conservation of forests, including undomesticated and semi-domesticated plant species.

Developing the Mayan diversified strategy for managing resources and ecosystems requires institutions and social rules that work as supporting agents. Members of the communities developed these strategies and include rights for accessing and regulating the use of forestland, and plant and animal species (Brown 1996). In some rural communities of Mexico, the central institutions for managing forest lie on communitarian committees that regulate the provision of land for agriculture ("tierra agrícola"). Head of families are given land permits that are subject to kinship organizational principles (Barnes 2009).

For our analysis of communitarian resilience and adaptive capacity of two communities in the Yucatán Peninsula, we used the social-ecological system approach (Holling 1973; Berkes and Folke 1998; Resilience Alliance 2015). The social-ecological systems concept considers these as complex and integrated systems in which humans are part of nature and nature is integrated into societies. The concept implies that local communities and their institutions interact and

evolve in conjunction with the ecosystems that support them (Berkes and Folke 1998; Berkes et al. 2000; Anderies et al. 2004). The ecological elements comprise aspects such as the components and processes occurring in biotic communities and organisms. The social factors relate to issues such as land property rights, access to resources and different systems of knowledge (Gunderson 2000; Neudoerffer et al. 2005). Resilience will be referred as the degree to which members of these communities are capable of self-organizing in response to disturbances (Resilience Alliance 2015). Adaptive capacity will be referred to as the ability of the community for shaping change within the social-ecological system. We use the term institutions for referring to the set of rules, regulations, and processes that guide decision-making among members of the communities. These institutions are classified for their analysis as formal (rules and constitutional laws) and informal (behavioral norms and codes of conduct) (Berkes and Folke 1998).

In this study, we analyzed the strategy of natural resources management and the institutions that support them in two communities in the Yucatán Peninsula. We particularly examined how these strategies and institutions have adapted and remained resilient to natural and social disturbances through time. By combining ethnographic methods, we used historical narratives with registers of current activities and institutions, as well as site-placed mapping of land-use units to document how adaptive capacity in these Mayan social-ecological systems go beyond short-term responses. We looked for identifying responses emerged from cultural characteristics that belong to long-term processes. The Mayan social-ecological systems from this research have created adaptive responses to events that threaten their livelihood by making use of their landscape heterogeneity, flexible body of institutions and diversified strategy for managing natural resources.

Questions leading this research were: (1) What activities have the members of these communities developed as part of their strategy for managing natural resources? (2) How are these activities relevant to defining the social-ecological system landscape? (3) Which are the local institutions associated with natural resources' management; and (4) Which relationships emerge from local institutions and strategies for managing natural resources as responses to disturbances?

2. Methods

2.1. Study site

Nuevo Tesoco is a community located in the northeast of the Yucatán Peninsula, in the municipality of Tizimín, Yucatán. It adjoins the Ría Lagartos Biosphere Reserve, and El Zapotal, a private protected area managed by the non-governmental organization Pronatura-Península de Yucatán (PPY) (Figure 1). The social-ecological system of Nuevo Tesoco is formed by two *ejidos*, which is a collective form of land ownership in Mexico: Nuevo Tesoco (29 households) and Santa María Pixoy (11 households). Each *ejido* is spatially defined, with distinct

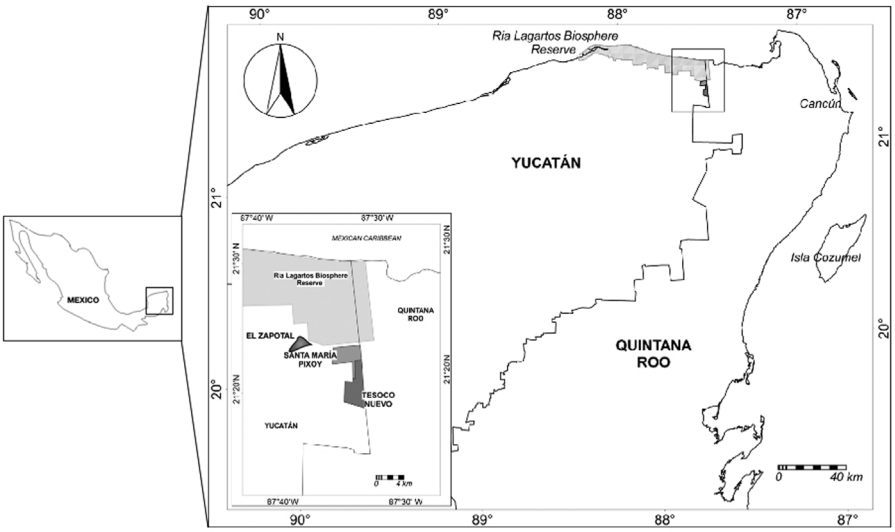

Figure 1: Location of the ejidos of Nuevo Tesoco and Santa María Pixoy, Yucatan, Mexico.

authorities, and holds its separate assembly. The families of both *ejidos* (40 households with around 180 inhabitants in total) live in the community of Nuevo Tesoco and carry out most of their productive activities in the *ejido* of Nuevo Tesoco. All of the households are formed by Yucatec Mayan families who arrived at the study site in October of 1995. They migrated because of social problems from the *ejido* of Yokdzonot Presentados, located 50 km South of Nuevo Tesoco. As with many rural communities of the Yucatán Peninsula, the inhabitants of this community maintain the characteristics of their culture such as language and religious ceremonies related to their productive practices.

The dry season lasts from December to May and the rainy season from June to November. The average annual rainfall is around 1000 mm. The vegetation is semi-deciduous tropical forest (Challenger 1998) and provides habitat for important species for conservation, including the jaguar (*Pantera onca*).

2.2. Research methods

We conducted the study during the years 2011–2012. The main aspects researched during fieldwork and the qualitative tools implemented are shown in Table 1. We made three visits to both *ejidos*, Nuevo Tesoco, and Santa María Pixoy. In the first visit, we presented the project to the General Assembly of both ejidos. We carried out informal talks, and the members of the *ejidos* provided consent for the study.

During 2011, we conducted semi-structured interviews with heads of families of the *ejidos* (n=40). The aim was to characterize management practices and productive activities performed by the households of the community within the

Table 1: Main themes registered during field work. Qualitative tools included: semi-structured and in-depth interviews, historical timelines, participative mapping, and walks through land-use units.

Topics	Subtopics
Productive activities	Environmental unit where is developed
	Characteristics of the environmental unit
	Destiny of obtained products
	People involved
Landscape units	Size
	Animals and plants associated
	Movement of animals
	Ecological interactions
	Institutions for managing landscape units
History	History of events affecting the socio-ecological system
	History of organization
	History of local institutions
	History of land-use change
Drivers and change	Environmental units affected by an event
	Effects of events within the socio-ecological system
	Responses generated after an event
	Land-use change at *ejido* level

social-ecological system. Questions included topics about number of environmental units under management, their size, biodiversity associated, ecological processes associated (for example, movement of animals), natural resources extracted, productive activities developed and destiny of the products. We produced two historical timelines: one with members of the *ejido* of Santa María Pixoy (n=9) and another with members of the *ejido* of Nuevo Tesoco (n=13). Participants ordered the events that had affected the strategy for managing resources and the landscape since the foundation of the social-ecological system. Establishment and evolution of local institutions related to natural resources were also registered, and the events were noted on paper. Themes leading the discussion included: natural phenomena, social events that happened within the *ejidos*, public policies, and the arrival of external institutions that might had affected internal dynamics associated with institutions and management of natural resources. In the final stage involving the historical timelines, we asked participants to make reflections about the impacts of each event on the management strategy and the environment within the social-ecological system.

We developed participative mapping exercises by using large-scale Google Earth satellite images with the landscapes of both *ejidos*. We registered four variables: (1) environmental units, including transformed environment, secondary vegetation, old-growth vegetation, water zones; (2) on-going productive activities such as forestry activities, apiculture, hunting, extraction of non-timber goods; (3) institutions related to exploitation of natural resources, for example, common or

private use of natural resources; and (4) events recorded on the historical timeline. When a discussion took place, the corresponding mark was made after consensus among participants were reached. The participants were members of the *ejido* that belonged or had been part of the local authorities since the foundation of the *ejidos*. Eight members of the *ejido* of Santa María Pixoy and six from the *ejido* of Nuevo Tesoco participated.

Also, we conducted in-depth interviews with the heads of each participant family. Interviewees were individuals that had expressed explicit interest in contributing to the research (n=20). We also developed walks through different land-use units and carried out participant observation. Themes for in-depth interviews included: (1) relevant characteristics and benefits (material or immaterial) of environmental units; (2) effects (in the ecological and the social system), and lessons learned after the occurrence of the disturbances registered); and (3) problems related to changing institutions or management practices in order to build responses. All methodologies used were interlinked, allowing constant verification.

The analysis of the information was progressive. The initial set of questions regarding the social-ecological system produced general responses on the topic that, following the analysis, allowed the generation of more specific responses. In this way, we addressed themes with increasing specificity and depth after each workshop. Thus, a cyclic process of question-response-analysis-question was generated. We recorded information in audio recordings, photographs and field notes. In order to validate the information and its interpretation, at the end of each workshop (or soon afterward) diagrams summarizing the information were shown to the participants. In this way, the *ejido* members were kept informed of the research progress. At the same time, this dynamic favored dialog and feedback with all the participants.

We captured and analyzed information initially on word processors, then ordered on Microsoft Excel spreadsheets according to the characterization in general dominions and themes. Finally, we refined the characterization into particular themes: management practices, institutions (formal and informal) associated with management, interactions between practices, and institutions and changes in these interactions over time. The environmental units identified in the participative mapping were digitalized using the software ArcGIS 9.2.

3. Results

3.1. Strategy of natural resources management and configuration of Nuevo Tesoco and Santa Maria Pixoy landscapes

Three factors characterized the strategy for managing natural resources within the social-ecological system: The exploitation of more than 150 species of animals and plants, the use of secondary vegetation areas and protection of the old-growth forest. This strategy enables the Mayan social-ecological system and the implementation of productive activities documented previously by García-Frapolli et al. (2013). The result of this approach has been the formation of a

heterogeneous landscape, in which the inhabitants of the community recognized 16 different environmental units (Figure 2). We explain these environmental units by their primary ecological characteristics, together with the productive activities that define their structure (Table 2).

3.1.1. Transformed environment

Following Toledo et al. (2008), by transformed environment we imply those artificial ecosystems which are a production system and have been subjected to modification by human action. *Milpas*, homegardens and a nursery conform the transformed environment of the social-ecological system:

Milpas. A total of 18 crop species are cultivated by people of Nuevo Tesoco and Santa María Pixoy (on average, of six species grown per *milpa*). *Milpas* ranged in size from 1.3 to 6 ha, with a mean size of 2 ha per *milpa* plot and an average distance of 2 km from the household. Apart from the species cultivated, *milpa*s also provide firewood and timber, as well as game for hunting. Hunting

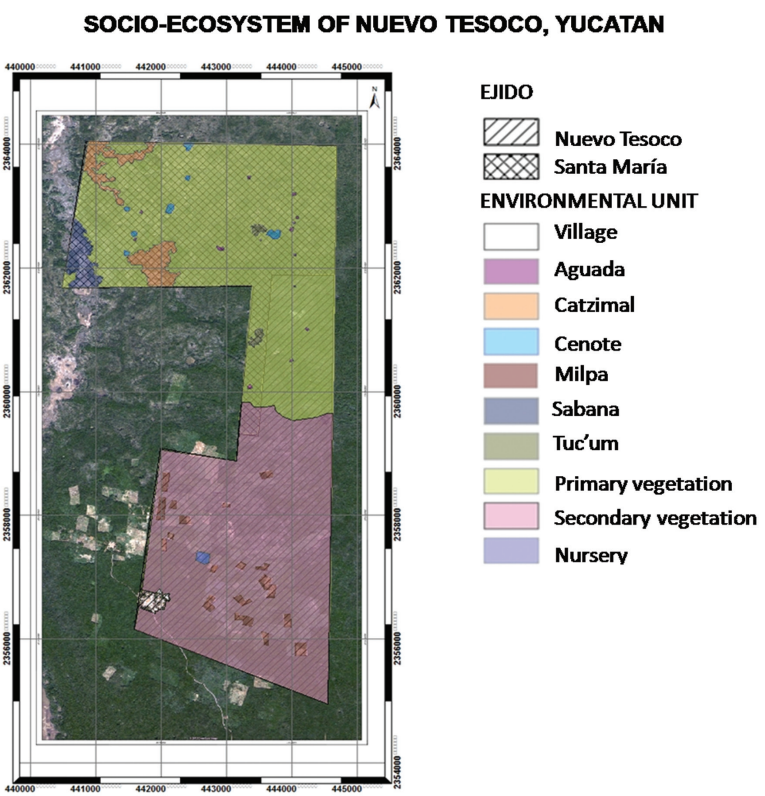

Figure 2: Environmental heterogeneity in the ejidos of Nuevo Tesoco and Santa María Pixoy, Yucatán.

Table 2: Productive activities developed in different land use units of the socio-ecological system. Activities are developed for the market for auto-consumption.

Land use unit	Destiny of productive activities	
	Market	Self-consumption
Polycultures	Nursery Vegetable gardens Livestock production Forestry species	Milpa Homegardens
Successional forest	Apiculture Reforestation	Extraction of guano Firewood Hunting Timber Extraction of plant species
Mature forest	PES: Monitoring and Clearing	

takes place in the *milpa*s mainly from October to April, when *milpas* are visited by boars that feed primarily on the maize (*Zea mays* L.), squash (*Cucurbita pepo* and *C. moschata*) and sweet potato (*Ipomoea batatas*).

Homegardens. These are systems located around each house; homegardens are managed mainly by the women of the household. At least 55 plant species and eight animal species are maintained in this system. The natural resources provided by the homegardens are mainly consumed at home, but a small fraction is sold or exchanged within or outside of the social-ecological system.

Community nursery. Area of 4800 m^2 located in the Northeast of the community. The nursery produces 18 native species of trees and shrubs of ecological and economic importance for the region, such as cedar (*Cedrella odorata*) and *pich* (*Enterolobium cyclocarpum*) (Pronatura-México 2010). Maize for consumption within the social-ecological system and chili peppers (*Capsicum* spp.) and tomato (*Solanum lycopersicum*) for sale are also cultivated. A small area of the nursery is dedicated to rearing goats.

3.1.2. Secondary vegetation

Secondary vegetation growth begins once areas dedicated to *milpa* are left in fallow (three to 4 years after being used). Secondary vegetation sustains a successional process composed of six environmental units, according to the local knowledge (Figure 3). Secondary vegetation is also considered as a buffer zone for extracting resources and occupies 39% of the territory. Seven different activities are conducted in this area: collection of firewood (100% of households), timber (100%), and other plant species (33%), cutting of guano (*Sabal yapa*) (40%), apiculture (5%), reforestation (100%) and hunting (18%). Six environmental units were described by the interviewees as conforming secondary vegetation and stages of the forest succession: *Sak'aab, Sak'aabhubche, Hubche', Ka'analhubche', Kelenche'*, and *Ka'analkaax* (Table 3).

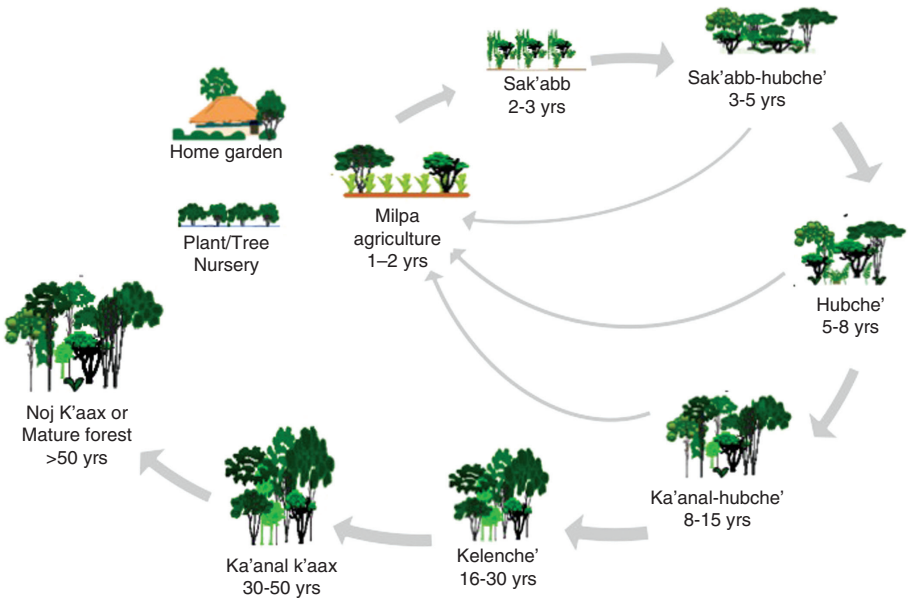

Figure 3: Successional dynamic of the secondary vegetation of Nuevo Tesoco, Yucatán. The tropical forest of 3–15 years may return to use as the milpa agricultural system, mainly during the hubche' stage (5 and 8 years).

Table 3: Characteristics of secondary vegetation mentioned by interviewees describing the successional dynamics of the forest within the socio-ecological system.

Environmental unit	High (m)	Age (years)	Key plant species	
			Scientific name	Common name
Sak'aab	<1	2–3	*Viguiera dentata*	Tajonal
Sak'aab hubche'	1	3–5	*Bejucos*	Bejucos
Hubche'	4–5	5–8	*Sabal mexicana*	Guano
			Brosimum alicastrum	Ramón
Ka'anal hubche'	5	8–15	*Lysiloma latisiliquum*	Tsalam
			Bursera simaruba	Cha'ka
Kelenche	10	15–30	*Manilkara zapota*	Zapote
			Enterolobium ciclocarpum	Pich
Ka'anal k'aax	15	30–50	*Cordia sp.*	Bojón
			Thrinax radiata	Chit
Suhuy k'aax	>15	>50	*Simaruba glauca*	Pa'sak

3.1.3. Old-growth vegetation

Despite the fact that the forest provides important resources (i.e. sapodilla and bread nut), exploitation of natural resources has been prohibited for more than 16 years in the old-growth forest vegetation of the social-ecological system of

Nuevo Tesoco. This environmental unit is the primary habitat of species such as the cougar and jaguar. In this environment, the only authorized activities are surveillance and monitoring, both of which are remunerated by the federal program of Payment for Environmental Services (PES). No extractive activities are allowed. In addition to the environmental unit of old-growth vegetation, the *ejido* members recognized two environments with the dominance of one plant species (*catzimales* and *zapotales*), one with few tree species and a rocky soil (*tuc'um*), two environments that are seasonally flooded (*sabanas* and *aguadas*), and water bodies (*cenotes*). These units are shown in Figure 2.

3.2. Building formal and informal institutions. Historical narrative

The social-ecological systems studied were founded on the 15th of October 1995. The head of families were responsible for building the village: houses, roads, one elementary school, one forum for communal meetings, one doctor's office, and one church. First property titles were given for the *ejido* Nuevo Tesoco, 29 families were included; the rest, acquired property titles for the neighboring landscape, naming the *ejido* Santa María Pixoy. Thus, the social-ecological system was created by two *ejidos*: Nuevo Tesoco and Santa María Pixoy. Members of both *ejidos* lived together in one village, sharing responsibilities and authority. In 1997, because of the long distance between the village and the lands made *milpa*s in Santa María Pixoy, it was agreed among all head family members that the *ejido* would be designated exclusively for conservation. For this, the *ejido* of Nuevo Tesoco was divided according to informal agreements, and it was dedicated mainly to agriculture were members of both *ejidos* could develop their respective *milpa*s (Table 4).

The first productive activity to be established in the social-ecological system was apiculture as beehives arrived with the first goods of each family. By 1996, all families were established, and the first *milpa* cycle took place. The assistance of the public program PROCAMPO was then sought, and chemical fertilizers were introduced; a remaining practice in *milpa*s within the social-ecological system at present times. In 2002, the Program of Certification of *Ejido* Rights and Titling of Urban Commons (PROCEDE, by its acronym in Spanish) carried out the regularization of the social property of both *ejidos* and provided individual plot certificates and titles of common use rights. The arrival of PROCEDE had a secondary effect: it helped to certify different institutions that already existed informally among the members of the *ejidos* concerning limits, and representation for particular issues (for example, municipality reunions, negotiation of governmental initiatives). An *ejido* committee for Nuevo Tesoco, another for Santa María Pixoy and a third for the village were created.

Although management of the land continued in a collective manner, territorial division of Nuevo Tesoco gave rise to changes in institutions involved in accessing to resources. Specifically, members of Nuevo Tesoco could make use of the

Table 4: Formal and informal institutions that structure the management strategy of natural resources in the transformed environment (TE), secondary vegetation (SV) and in the old-growth tropical forest (OGF) of Nuevo Tesoco, Yucatán.

Formal and informal institutions	Environment		
	TE	SV	OGF
Access to natural resources			
Division of the socio-ecosystem in two *ejidos*	x	x	x
Plots under informal agreements	x		x
Individual exploitation of the space	x	x	
Milpas in plots which do not belong to the individuals (SMP community members with no land title)	x		
Regulation of natural resources			
Extraction of resources	x	x	
Fines for overexploitation of natural resources		x	
Prohibition of cutting large trees	x	x	x
Protection of jaguar and puma	x	x	x
Subsistence hunting	x	x	
Prohibition to sell guano	x	x	x
Taxes for cutting valuable wood		x	
Management of natural resources			
Creation of two *ejido* committees: NT and SMP	x	x	x
Community management of space		x	x
Individual management of space	x	x	
Community monitoring and surveillance	x	x	x
Maintenance and clearing of roads and firebreaks		x	x
Chac-chac (Religious ceremony)	x		
Joint hunting (*Clamoreo*)	x	x	
Municipal committee		x	

natural resources found only within the plot assigned to them by the authority. At the same time, members of Nuevo Tesoco and Santa María Pixoy reached an agreement: members of the *ejido* Santa María Pixoy could develop *milpa*s located within the territory of the Nuevo Tesoco *ejido* as long as they had the approval of one or more members of the *ejido* of Nuevo Tesoco.

In 2005, Hurricane Wilma (category 5 on the Saffir-Simpson scale) flooded many areas of the territory, reaching a depth of four meters in the low zones and completely ruining the crops. The immediate response of the *ejido* members was the organization of brigades to monitor the state of the territory and to carry out clearings to reduce the subsequent risk of fire. A Surveillance Committee against fires was formed, which is still in operation at present. While the inhabitants received institutional support, the amounts of maize, beans and other articles received were insufficient. Many *ejido* members had to leave in search of work in order to satisfy the basic needs of their families, as well as selling the majority of their domestic animals. It was not until 2008 that production began to re-establish, when the majority of *ejido* members started to obtain yields once again from their *milpa*s and recover part of their apicultural activity.

During 2008, the *ejido* of Santa María Pixoy decided to inscribe almost all of its territory in the PES program. During the 5-year period of the program, all activities involving land use changes were prohibited, along with the extraction of natural resources. Before this program entered into force in Santa María Pixoy, the old-growth vegetation was still dedicated to conservation; however, activities such as subsistence hunting, extraction of guano and certain timber species for house construction were permitted. Monitoring was an activity that was also conducted before the PES; however, it was not done as systematically as is the case at present.

The decision of having a PES program in Santa María Pixoy was consequence of a process of conservation that the *ejido* had already begun with the environmental organization PPY. Aware of this decision, and of the responses of this *ejido* to Hurricane Wilma, PPY proposed to the members of Santa María Pixoy the development of a project for the long-term monitoring of jaguar in the conserved zones of the *ejido*, and the adjacent area to the private reserve "El Zapotal"(see Faller-Menéndez et al. 2005). As part of this project, members of both *ejidos*, as well as some from neighboring *ejidos* and a number of youths, received training in the use of cameras and data collection in the field. As part of the agreements that arose from both the jaguar conservation project and the establishment of the PES, important conservation actions were carried out on the social-ecological system, such as the creation of firebreaks in strategic zones of the old-growth vegetation. One aspect of note in terms of the influence of the PES program is that the work of creating firebreaks is now remunerated with the funds provided by the PES, and any *ejido* member can participate. In the same way, the formation of these committees and the firebreak work helped to strengthen community work and raise awareness of the need to map the limits of the *ejido* and the different environmental units within the social-ecological system.

In 2010, Nuevo Tesoco initiated a project for sustainable exploitation of guano. The project was authorized by the National Forestry Commission (CONAFOR, by its acronym in Spanish), and allowed an annual extraction of 33 tons of leaves for commercialization. All of the Nuevo Tesoco *ejido* members had the right to extract and sell guano leaves in quantities authorized by the *ejido* assemblies while extraction for self-consumption did not require authorization. Nevertheless, difficulties for taking the guano leaves outside the village and selling (due to road access and gas prices), the *ejido* of Nuevo Tesoco decided to introduce PES in 416 ha of the original area designated for extracting guano. At the beginning of PES negotiations, authorities of Nuevo Tesoco tried to develop this program at the same time that maintain the permission for sustainable exploitation of guano. The argument was that cutting guano leaves is a necessary activity for the ecosystem as they become extremely dangerous as fuel material during the dry season. Nevertheless, because PES guidelines prohibit the exploitation of any activity, Nuevo Tesoco members decided to renounce to the permit for sustainable exploitation of guano and deal with dry guano leaves as fuel material during monitoring activities within the area.

In 2009, PPY together with the Forestry National Committee (CONAFOR) and the Coca-Cola Foundation funded the creation of the community nursery, which is now run by several families and relatives in the *ejido* of Nuevo Tesoco. The project began with the production of 12,000 plants over an area of approximately 4800 m^2. At present, the nursery is in the process of enlargement and the *ejido* members hope to reach an area of 2 ha, pending the authorization of the other members of the community. Eighteen native species of trees and shrubs, of ecological and economic importance to the region, are produced in the nursery.

This project, together with the PES, has given rise to an important process of delimitation of areas for reforestation, which are supplied by the plants produced in the nursery. Similarly, the nursery is providing plants to other *ejidos* in the zone that have ongoing reforestation projects. Prior to this program, the *ejido* members reforested areas in early succession and transplanted useful or valuable species. The program modified the management practices in the secondary vegetation. Reforestation was conducted in the *sak'aab*, *sak'aab hubche'* and *hubche*'. The area for reforestation was geo-referenced and precise limits between successional states were established. Exploitation of plant resources was prohibited for a period of 5 years. CONAFOR technicians had responsibility for decisions regarding the species and number of individuals that were used for planting.

In this way, it is possible to say that the social-ecological system of Nuevo Tesoco used three different strategies to address the previously described disturbances (see Table 5): (a) Modification of the diversity of productive activities

Table 5: Main institutions associated with the response of the socio-ecological system of Nuevo Tesoco to: Hurricane Wilma, Payment for Environmental Services program, and Creation of the community nursery.

EVENT	EXISTING INSTITUTIONS	
	BEFORE THE EVENT	AFTER THE EVENT
Hurricane Wilma	Provision of temporary labor for remuneration Monitoring	Clearing of combustible material Clearing of combustible material Monitoring Provision of temporary labor for remuneration
Payment for Environmental Services	Community management Establishment of areas for conservation Extraction of plant resources Hunting Land use change Monitoring Protection of jaguar and puma	Clear boundaries of the ejido Community management Establishment of areas for conservation Monitoring Protection of jaguar and puma
Community nursery	Reforestation Seed collection	Clear delimitation of reforested areas Reforestation Production of plant species for sale Prohibition of extractive activities Seed collection

that make up its management strategy; (b) alteration of its institutional body in order to generate institutions that regulate the use of natural resources, and (c) the reconfiguration of the space of the territory.

4. Discussion

There are three main consequences for Nuevo Tesoco and Santa María Pixoy concerning the responses to disturbances: local people increased the implementation of remunerated practices, the reconfiguration of their environmental heterogeneity and the strengthening of local institutions, directed towards monitoring and protecting their natural environment. These consequences are relevant as they articulated a mechanism or a process that defines the ability of the social-ecological system for its long-term stability.

Ability to respond to disturbances is not unique for this Yucatec Mayan social-ecological system. Authors like Toledo et al. (2003, 2008) gave empirical evidence of adaptive management among different indigenous communities living in the Tropical areas of Mexico. This adaptive management was associated with the maintenance of a multiple strategy for using natural resources. Also, it has been shown that diversification of productive activities might contribute to food security (García-Frapolli et al. 2008), as well as to the maintenance of stable populations of flora and fauna within the Yucatán Peninsula (Escamilla et al. 2000). Also, diversified landscape units created by this strategy could function as reservoirs of germplasm to fulfill critical ecosystem functions (Alayón-Gamboa and Gurri-García 2008).

Within the social-ecological system, the strategy for managing natural resources was based on a diversified use of species, the management of agroforestry systems (milpa and homegardens), the management of the secondary vegetation and the protection of the old-growth forest. After a disturbance, people modified the natural resource management strategy in Nuevo Tesoco by diversifying their productive activities or changing their practices. As a result, 13 productive activities developed. Homegardens and milpas of Nuevo Tesoco constituted central elements of the subsistence production of the social-ecological system. These systems play a role in the maintenance of the biodiversity and depend directly upon it; we recorded more than 150 species of plants and animals used for direct consumption by households and commercialization. Similarly, the maintenance of homegardens allowed the social-ecological system to respond to Hurricane Wilma in 2005 by selling domestic animals to raise funds for buying essential products, as a solution to the lack of food security.

In the case of other Yucatan Mayan social-ecological systems, practices associated with this traditional strategy have favored resilience (Barrera-Bassols and Toledo 2005). Environmental heterogeneity has allowed a higher presence of small mammals from the forest (Medellín and Equihua 1998). At the same time, others have demonstrated that domestic gardens in Yucatec Mayan social-ecological systems might contribute to conserving wild species, as well as to complement family diet (Martínez-Ballesté et al. 2006).

People of Nuevo Tesoco and Santa María Pixoy altered the configuration of their space, as happened with the establishment of PES. They managed the environmental heterogeneity while diversifying their productive activities. With PES, previous activities in the old-growth vegetation, focused on the protection of flora and fauna, were economically supported by this regional and national program of conservation. In contrast, activities in the secondary vegetation were directed towards the remunerated use of natural resources (for example, cutting of guano and assisted reforestation), or to generating products for direct consumption by households (hunting, collecting of wood). It is worth noting that the environmental heterogeneity has also been fundamental in the connection with regional and national levels of management.

Nuevo Tesoco and Santa Maria Pixoy also restructured or created local institutions through the ejido assemblies. The local institutions maintained a feedback process with the ecological system and with the strategy for managing natural resources. Reforestation and PES were articulated successfully in the dynamics of Nuevo Tesoco; remuneration of the practices associated with these governmental programs implied the recognition of traditional conservation practices. Furthermore, it formalized and strengthened local institutions that had existed prior to the implementation of the programs referred to above. As a result, these institutions have modified the configuration of the social-ecological system landscape.

In turn, the flexible nature of the institutions within the social-ecological system facilitated the feedback process. These institutions changed under context-dependent conditions and have had considerable influence at the levels of environmental units. Also, in relation to species of flora and fauna, creating multi-scale relationships among the social-ecological system, organisms and conservation programs. The links generated show two important aspects. Firstly, institutions have succeeded in the social-ecological system by enabling members to participate and build change (Ostrom 1990; 2009). Secondly, institutions are relevant when discussing and acting upon conservation from a multifactorial perspective (Castillo and Toledo, 2000; Dietz et al. 2003). It also gives some information when considering local communities as an essential component for forest conservation (Smardon and Faust 2006; Agrawal 2007; Ellis and Porter-Bolland 2008). Multi-level programs focused on conservation can promote the learning and adaptation of the social-ecological system by opening communication in the context of management (Armitage et al. 2009).

Disturbances experienced by the social-ecological system and analyzed in this research belong to different origins and affected various elements of the system, but changes were within the ability of the social-ecological system to respond. Institutions regulated the strategy for managing natural resources; this interaction was dynamic and allowed responses in the context of change. Once again, three key elements supported this dynamism: diversification of productive activities, management of environmental heterogeneity and the flexibility of the formal and informal institutions.

It has been argued that, to contribute to the resilience of vulnerable social-ecological systems such as Nuevo Tesoco, it is necessary to generate effective strategies of communication among local managers, scientists, and politicians. Clear and flexible management policies that guarantee support and the permanence of the different lifestyles in the region are also necessary. In this way, the maintenance of cultural and biological diversity is ensured (Eakin and Lynd 2006). However, we require more case studies in the Yucatan Peninsula that analyze how new institutions are configured, identify the long-term lessons of their modification, and determine the role played in these processes by local entities of collective choice.

5. Conclusions

The adaptive capacity of the social-ecological system to manage change will depend in part on their ability to re-organize and in part on cultural alternatives. Our results provide evidence that traditional strategies remain and that they are still currently viable. The events recorded demonstrate three types of responses to disturbances. The inhabitants of Nuevo Tesoco: (a) modified the natural resource management strategy, diversifying their productive activities or modifying their management practices; (b) altered the configuration of their space; and (c) restructured or created local institutions through the *ejido* assemblies. The consequences of these responses were an increased number of remunerated practices, reconfiguration of the environmental heterogeneity and strengthening of local institutions directed towards monitoring and protecting their natural environment. That is to say, Nuevo Tesoco uses elements of the traditional Yucatec Mayan strategy of appropriation of nature in order to create responses to disturbances that facilitate their permanence in the Yucatán Peninsula, a region with high indices of biodiversity and of great interest for conservation.

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