"If the mangroves disappear, so will San Crisanto — that's how big the risk is": Wetlands of a Coastal Lagoon Ecosystem and Local Adaptation to Climate Change

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ABSTRACT

The Yucatan coast (Mexico) contains Ramsar sites of socioecological importance, but also faces problems, such as hurricanes, that increase its vulnerability. The frequency and magnitude of these threats increased, partly due to climate change, necessitating strengthened local adaptation strategies that incorporate the socioecological context and needs of wetland inhabitants. Thus, this study's objective was to analyze responses to climate change by members of the port town San Crisanto (Yucatan) to learn about their perceptions and the actions they take when faced with hurricanes and their impacts. The study used a qualitative phenomenological methodology, working with 23 participants who witnessed three intense hydrometeorological events. As an ejido (unit of communal land tenure) in possession of land and resources, its members maintain the mangroves and manage them as a strategy of Ecosystem-based Adaptation (EbA). They support their actions with local socioecological knowledge of their territory and place-based attachment to the lagoon ecosystem that provides their livelihoods, but there also persist several practices requiring attention, such as filling floodable areas with waste, which damages the local population and ecosystem. We conclude that the ejido collective is relevant to ecosystem protection and recommend that EbA strategies be documented and strengthened in order to tend to the human population and the wetlands themselves in the face of climate change.

RESUMEN

La costa de Yucatán (México) tiene sitios Ramsar de importancia socioecológica, pero también enfrenta problemas, como los huracanes, que incrementan su vulnerabilidad. La frecuencia y magnitud de estas amenazas aumentó, en parte por el cambio climático, siendo necesario fortalecer estrategias locales de adaptación que incorporen el contexto socioecológico y las necesidades de los habitantes que viven de los humedales. Por ello el objetivo del estudio fue analizar las respuestas de miembros del puerto de San Crisanto (Yucatán) ante el cambio climático, para conocer sus percepciones y acciones ante los huracanes y su impacto. En el estudio se usó una metodología cualitativa fenomenológica, trabajando con 23 participantes que vivieron tres eventos hidrometeorológicos intensos. Un ejido detenta la tierra y sus recursos, sus miembros manejan los manglares con una estrategia de Adaptación basada en Ecosistemas (AbE) y los conservan. Sustentan sus acciones en el conocimiento socioecológico de su territorio, apego al lugar y al ecosistema lagunar del cual obtienen sus medios de vida, pero persisten prácticas que deben atenderse; como el relleno con basura en zonas inundables, que vulnera a la población y el ecosistema. Concluimos que el colectivo ejidal es relevante para proteger los ecosistemas, siendo recomendable documentar y fortalecer las estrategias de AbE para atender a la población y humedales ante el cambio climático.

INTRODUCTION

The State of Yucatan lies in the northern part of Mexico's Yucatan Peninsula, and with a surface area of 39,540 km2, it constitutes, along with Campeche and Quintana Roo, a great flatland geologically composed of mainly limestone rock from the Tertiary Period (García and Graniel 2010). Water is a notably essential component of this region due to its unique presentation in spaces and landscapes. The territory's highly permeable karstic ground induces rapid filtration of rainwater into the subsoil, recharging the great interconnected subterranean aquifer that serves as the main water source for the region's population, given the absence of superficial sources of fresh running water (García and Graniel 2010).

These subterranean waters are connected to coastal lagoons, seagrasses, and coral reefs (Morales-Ojeda et al. 2021), making the coast another vital hydro-social space for residents' livelihoods. Extending approximately 378 km in length and bound by the Gulf of Mexico to the north, the peninsula's coastline primarily contains barrier beaches and flooding lagoons, as well as shallow bays with visible saltwater intrusion (García and Graniel 2010). This region's wetlands are composed of marine ecosystems, marshes, and estuaries where complex interactions exist between hydrological elements, soils, and organisms (Ramsar 2016). Included among its vegetation areas are "petenes" - islands of mangroves or tropical semideciduous forest, "tasistals" - seasonally inundated savannahs of tasiste palms (Guadarrama et al. 2018), coastal dune scrub thickets, and marine angiosperms - seagrass (Durán et al. 2014). There are also significant extensions of mangrove forests containing the four most predominant species in Mexico: Red Mangrove (*Rhizophora mangle*), Black Mangrove (*Avicennia germinans*), White Mangrove (*Laguncularia racemosa*), and

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Buttonwood (*Conocarpus erectus*). These environments are important due to their provision of different ecosystem services, such as coastal protection in the face of extreme hydrometeorological events and soil retention. Hence, three sites within this territory were declared as Wetlands of International Importance under the Ramsar Convention: Dzilam State Reserve (to the east; with 61,706.8 ha, declared in 2000); El Palmar State Reserve (to the west; with 50,177.4 ha, declared in 2003); and the Marsh and Mangroves of the North Coast of Yucatan State Reserve (MMNCYSR) (covering an area of 54,776.7 ha, declared in 2022).

The relevance of these wetlands is also related to the historical development of regional socioeconomic activities, because before 1950, the coast was sparsely inhabited, and its residents lived primarily off of subsistence fishing and inland activities such as agriculture and hunting (Fraga 2004). Another activity carried out since pre-Hispanic times is salt extraction in spaces locally referred to as ponds, located within estuaries. Salt is naturally produced when the level of seawater introduced into the ponds increases during the rainy season. The dissolved salt settles to the bottom, forming a layer called brine. In the dry season, direct sun evaporates the excess water, decanting salt to accumulate at the bottom of the pond in crystallized form (Guzmán-Noh and Gurrí 2021). These situations changed from the mid-20th Century until the 1970s, since the region's economic and social conditions propelled more settlement along the coast and led to further productive activities such as fishery of scaly fish (Salas et al. 2006) and sun and beach tourism, which incorporated the recreational use of sites such as natural springs, like those in El Corchito (Progreso, Yucatan), which forms part of the MMNCYSR (Paredes and Castillo 2018).

By settling in Yucatan's coastal lagoon ecosystem and modifying its environment, human populations are exposed to the frequent impacts of extreme hydrometeorological phenomena. This region has the highest national landfall rates of Category 4 and 5 hurricanes (Appendini et al. 2019), which cause intense rain and flooding, cyclonic ocean swells, and strong winds. The impact of these natural events on the region are further magnified by human activities (e.g., accelerated and disorganized urban development, coastal erosion, and land use change), devastating large extensions of mangroves and increasing pollution of bodies of water (Herrera-Silveira et al. 2005). Inadequate residential and roadway infrastructure further limit local capacity to withstand these climate contingencies.

The Special Action Program Against Climate Change in Yucatan (PEACC in Spanish; 2018) reports that coast's vulnerability might increase as of 2040, given predictions of more intense and frequent hydrometeorological phenomena. But already in 2020, the Atlantic Basin was the site of unprecedented events, namely the formation of 30 tropical storms, a record number of registered phenomena in a single season that surpassed the 28 events recorded in 2005 (NOAA 2022). Tropical storm Amanda/Cristobal and Hurricanes Gamma, Delta, and Zeta produced flooding that was connected to 74% of the disaster declarations that year, with Veracruz, Chiapas, Tabasco, and the Yucatan Peninsula being the most affected areas in all of Mexico (CENAPRED 2021). This situation emphasizes the need to strengthen and construct adaptive measures that allow inhabitants to address the challenges stemming from climate change, taking into consideration the most vulnerable societies and ecosystems.

Mangrove ecosystems are allies in our efforts to mitigate the current and future effects of climate change, given that one of their primary ecosystem services is acting as a natural protective barrier, absorbing the impact of hurricanes normally experienced by human settlements (Herrera-Silveira et al. 2022). Similarly, research about adaptive measures in Mexican coastal localities indicate that their effective implementation is hindered by the prevalence of institutional and social difficulties. There exist several examples of strategies that demonstrate the historical importance of a culture of prevention, as characteristic of some societies, and of best practices based on local management and conservation projects in coastal wetlands (Escudero and Mendoza 2021). Hence, it is crucial to know the perceptions of and actions taken by local communities to tackle problems, given that the effects of global environmental change, including climate change, are particularly felt and perceived at the local level, and it is relevant to consider local experiences and their relationships with ecosystems (down-up approach) (Reid et al. 2009; Nash et al. 2019).

Given the significance of coastal wetlands for the livelihoods of local populations, and accounting for the socio-environmental issues that increase the vulnerability of these coastal ecosystems and societies, our general objective was to analyze the development of local responses of adaptation to climate change undertaken by members of San Crisanto, in Yucatan, Mexico, by understanding their perceptions and actions when confronting the impacts of one of the region's primary natural threats - hurricanes - and taking into consideration the particular characteristics of their coastal lagoon ecosystem.

STUDY AREA

San Crisanto (Figure 1) (21°21′08″N 89°10′18″W) is a port town belonging to the municipality of Sinanché, located in the Central Waterfront of Yucatan and within the Marsh and Mangroves of the North Coast of Yucatan State Reserve. According to the Index of Hydrometeorological Risks of the Coast of Yucatan (Orellana et al. 2014), this locality has a high probability of hurricane impact. Some of the strongest ones, measured on the Saffir-Simpson scale, have included Gilbert in 1988 (Category 5, which fractured the coastal highway and caused an inlet to open, joining the

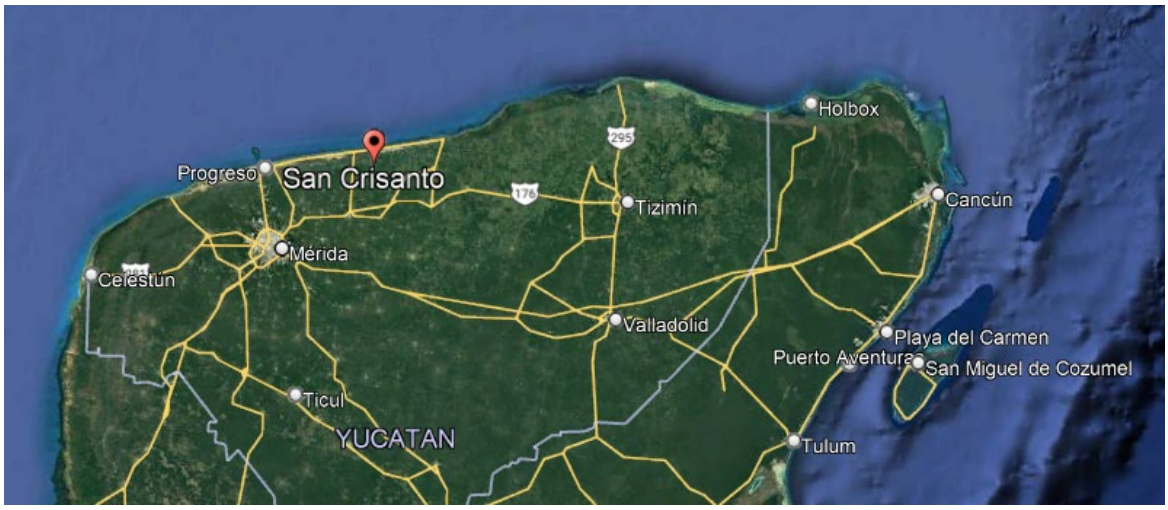

Figure 1. Location of the port town of San Crisanto on the northern part of the Yucatan Peninsula. (Source: Google Earth)

Figure 2. Land tracts managed by the ejido. (Source: Google Earth)

sea and marshes in the near municipality of Yobain), and Isidore in 2002 (Category 3, which led to significant socio-economic impacts across the region).

This town is home to 605 inhabitants (Inegi 2020). Included among their primary socioeconomic activities are fishing and tourism. San Crisanto also contains a homonymous ejido (unit of collective land tenure) because in 1956, 20 residents fought to obtain land as an ejido collective (1,472 ha), then securing these properties in 1992 due to reforms to Article 27 of the Mexican Constitution via the Program of Certification of Ejidal Agrarian Rights (Procede in Spanish) (Castillo-Burguete 2001). Currently, the ejido's 35 members (ejidatarios) manage land tracts (Figure 2) of relevance to the community, such as salt ponds (20 ha), 850 hectares of mangrove forest with the four most predominant species in Mexico (Pérez 2012), and coconut palm groves (Cocus nucifera) (150 ha) where the Malayan dwarf, tall Pacific, and hybrid varieties are cultivated and which are managed through volunteer work by ejido partners and payment of daily wages to their relatives and other community members. Regarding the management of ejido lands and the decision-making process involved, Pech (2010) described that every ejido member owns individual property titles and together manage common areas such as mangroves, salt ponds, and coconut groves, the bases for developing ejidatarios' and community livelihoods. Ejidatarios elect representatives who serve as president for three years, analyzing and collectively deciding in assemblies about changes to and administration, management, or sale of ejido lands by voting on land management options. Ejidatarios monitor, care for, and manage the spaces that belong to them in an organized fashion and with a crew dedicated to cleaning and pruning plants in the coconut groves and cleaning the mangrove canals used for ecotour-

Figure 3. Swamp area of the lagoon where inhabitants tend to fill marshes with rubble, debris, and waste in order to build up land and situate their houses on higher ground. (Photo by Casares)

Figure 4. San Crisanto's salt ponds flooded from the impact of tropical storms and hurricanes in 2020. (Photo by Casares)

ism. They also manage resources and collaborate with international organizations and research centers through the creation of the San Crisanto Foundation civil association in 2000 (PNUD 2012).

The main challenges detected in relation to the management and care of these spaces are described by the history of the community and of the ejido itself. It is worth noting that before the creation of the ejido, inhabitants of San Crisanto freely used provision services such as mangrove wood in order to make charcoal, obtain firewood, and build houses. Ejidatarios mention that when they first began managing the lands, there was very little mangrove to speak of because of the inadequacy of management until then, so in the 1990s, they applied for permission from the Secretariat of Environment and Natural Resources to regulate their mangrove resource management (Pech 2010). The ecosystems weren't in good condition; they noticed a paltry presence of birds and fish and poor hydrological flow through the mangroves. Flooding caused by the periodic impact of hurricanes and storms is another problem that damages homes, streets, and natural resources in the port. The most vulnerable areas are those closest to the swamp (Figure 3), where inhabitants of these dwellings fill the lagoon with debris and waste to get their houses on higher ground.

Another area recurrently affected by hydrometeorological phenomena is that of the salt ponds. Salt is not regularly extracted because the ponds (Figure 4) are not in an optimal state for production. Given the constant flooding derived from the impact of hydrometeorological events (Pech 2010), the ponds are consistently muddied and their maintenance is costly. In addition to extracted salt being stored in warehouses, ejidatarios haven't sold it because of competition from other vendors.

METHOD

This study was approached qualitatively, following the guidelines for phenomenological methodology based on the philosophy of Edmund Husserl to understand subjects' perspectives, their topics of interest, and the problems that surround them (Fuster 2019). The use of a non-probabilistic convenience sample informed a wider panorama of the experiences of San Crisanto's inhabitants, and participants were selected with the criteria of being members of households that had lived through the impact of hurricanes Gilbert (1988), Isidore (2002), and the hydrometeorological events of 2020, and/or people who had occupied a government position or a leadership role in local ejidal organizations during the aforementioned events, in order to have more extensive points of reference for individuals' history in the community. We conducted semi-structured interviews with 23 people (43% women and 57% men), asking what actions they take to handle the impact of hurricanes in their locality, about their perceptions regarding the risks posed by and changes to hydrometeorological events over the years, and their observations about the sites most vulnerable to the impacts of hurricanes where the primary actions of adaptation to climate change take place.

RESULTS AND DISCUSSION

Community perceptions and experiences in the face of hurricane impacts

Participants in this study have significant experiences that have shaped their perceptions and actions when facing hurricanes, a finding that coincides with observations by Chavez-Rodriguez (2016), reflecting on the construction of a collective memory with regards to taking on risks and disasters, comparable to Wilson (2013). These authors reported Gilbert (1988), Roxanne and Opal (1995), and Isidore (2002) as the most impactful hurricanes.

Since the impact of Hurricane Gilbert, participants identified flooding as one of the primary problems. Since 1995 when Hurricanes Opal and Roxanne flooded the port, ejidatarios decided to autonomously begin restoring mangroves' hydrological flow, the first stage of which consisted

Figure 5. Mangrove canal in San Crisanto, used primarily for tourism. (Photo by Casares)

Figure 6. Natural springs in San Crisanto's mangroves. (Photo by Casares)

of opening drainage canals between the swamp and the salt ponds to keep houses from flooding. Constructing canals within the mangrove forest helped fresh water from existing springs move to other areas and improve flow. Another project was the creation of Units of Environmental Management (UMA in Spanish, a place for alternative development compatible with conservation interests) for Morelet's crocodiles (*Crocodylus moreletii*) and mangroves.

Nevertheless, in 2002, the path of Hurricane Isidore felled 90% of San Crisanto's mangrove forest, and ejidatarios decided to communally clean and restore this space. The open canals were useful for having access to places where they could reforest with mangrove plants. Participants mentioned that the hurricane dispersed seeds, and mangrove varieties grew where there once were none. Maintenance in this context was grounded in local ecological knowledge transmitted by their families: they know how to clean, prune, and select the plants they extract without affecting the growth of other trees. This type of ecological knowledge is also reported in other cases, such as Savo et al. (2016).

Stemming from the ejido's work to restore the mangroves, since 2002, they created and strengthened ecotourism projects to take advantage and make use of this space, as well as the coconut groves. In the mangrove forest, canals (Figure 5) were utilized as a means of transporting visitors on tours and being able to access natural springs (Figure 6) for recreational purposes. This activity is regulated, and ejidatarios base the number of tourists that can visit the mangrove on their prior experience: upon observing the initial ecotourism site, if they see any negative changes, they reduce the number of occupants, thus regulating the ecosystem's carrying capacity (Castillo-Burguete et al. 2019).

Intergenerational community management and care of the mangroves, collaborative work with international organizations and educational institutions, and ejidal organization led to members developing a "blue carbon" credit certification project in 650 ha of the mangrove forest beginning in 2011, through which they seek to obtain resources that will benefit the ejido and the community at large, allowing for long-term conservation of this ecosystem (Casares 2023). The Blue Carbon Project was initiated collaboratively between research centers, international associations like Climate Seeds, and the San Crisanto ejido, the first ejidal organization in Mexico to undertake a project of its type in coastal wetlands.

Given the uniqueness of the Blue Carbon Project, many challenges were presented. Participants from the ejido felt the biggest problems with this project were the lack of awareness and clarity with regards to Mexican laws dealing with wetlands and blue carbon. Likewise, there were no similar projects created by ejidal organizations in Mexico to serve as models, highlighting the need to consider the group's own organizational structure. Data from technical studies and specialized techniques were needed to measure the mangroves' capacity for carbon capture. Therefore, collaboration with research centers was essential to achieving blue carbon certification. In 2022, the certification was made official and agreements began in order to secure initial buyers, profiled only as "European companies" at the time this study was completed.

Even though participants had all experienced catastrophic hurricanes, they express that they haven't considered emigrating from their locality because of the tranquility and safety they perceive there, as well as the proximity to their places of work out at sea and in mangrove forests. In the literature, this is defined as the relevance of place-based attachment, referring to the affective bond associated to the meaning that residents assign to their place of inhabitance, manifested through cognitions and emotions that facilitate closeness, as demonstrated in the case of Bukvic et al. (2022), also foreseen as topophilia by Tuan (1974) decades earlier. These aspects are important for studying

risk perception and actions taken to handle those risks and for understanding people's motivations and willingness to protect their environments or surrounding ecosystems (Pucker et al. 2022). Participants' experiences have generated vast knowledge about how to face hurricanes from within households, given that the local population also acts in order to protect their houses and belongings, and to follow directions to opportunely evacuate the area when a hurricane is about to arrive, which coincides with other studies that draw attention to the fortification of this social and cultural capital of risk prevention (Audefroy et al. 2018; Malak et al. 2020).

Based on traditional ecological knowledge that ejidatarios have developed through their work in these spaces, and on the sense of belonging they have, given their place-based attachment, local people's clarity on this subject is such that they express, "If the mangroves disappear, so will San Crisanto. That's how big the risk is." Their mangrove forests are not only unique because of their provision of services that are basic to their livelihood, but also because of their management under the ejidal communal land tenure system, one of the few like it in the country; this also allows ejidatarios to decide collectively and locally about how to protect and conserve this ecosystem.

Local measures of adaptation to climate change based in the area's wetlands

Since flooding is one of the primary problems for the port town, inhabitants of the lands surrounding the marshes fill them with debris and waste so that their houses stand taller, thus diminishing the risk of flooding during the rainy hurricane season. This area is primarily inhabited by people of lower income in physically unstable houses; building up the ground with debris is a recurrent measure taken in various areas of the Yucatan coast where lower income folks see the marshes as "affordable" places to live. This measure reveals both the problem of inadequate access to housing and a lack of compliance with laws designed to protect the marshes. The aforementioned coincides with Muñoz-Salazar et al. (2017), who point out that in some dynamics of spatial transformation in coastal areas, the state has not generated any processes that are truly inclusive of all people and that address adequate territorial regulations, which is one of the causes of the persistence of informal settlements and continued deterioration of wetlands. Additionally, we observed a contrasting action in the community: the construction of palafitte stilt-houses (Figure 7) to keep inhabitants safe from flooding. These prototypes are rectangular homes elevated above the ground with pilings, covering certain durability criteria to aptly withstand the effects of hydrometeorological events. These stilt-houses were constructed during participatory action research projects (Castillo-Burguete et al. 2008) initiated in the mid-1990s with community facilitators, accompanied by researchers from Cinvestav, Mérida Branch.

In relation to the measures carried out by the San Crisanto ejido, their actions can be included within the framework of strategies based on the use and management of natural resources, known as Ecosystem-based Adaptation (EbA) (UICN 2020). EbA actions within the ejido are conducted through ecosystem management, conservation, and recovery, primarily in the mangrove forest, with, for example, the Blue Carbon Project, the UMA for Morelet's crocodiles (Crocodylus moreletii), and ecotourism activities. In this regard, Doswald et al. (2014) mentioned that one of the characteristics that strengthen the development of this type of strategy based on management, conservation, and recovery at a local level is the diversification of ecosystem-based practices like nature-based tourism, species conservation strategies, and blue carbon credit promotion that allow for a reduction in the local population's environmental, social, and economic vulnerability, attending a variety of needs in addition to conserving biodiversity.

Another characteristic of the measures carried out by the ejido is related to community participation and relationships, which are indispensable for any project that promotes

Figure 7. Palafitte (Photo: Castillo 2002) after the impact of Hurricane Isidore and palafitte located in San Crisanto. (Photo by Casares)

Figure 8. American flamingo (*Phoenicopterus ruber*) in the salt ponds of San Crisanto. (Photo by Casares)

Figure 9. Reddish egrets (*Egretta rufescens*) in the salt ponds of San Crisanto. (Photo by Casares)

the development of just and sustainable means for tackling socioenvironmental problems. This was visible in our study by way of participants' knowledge of the socioenvironmental history of the ejido, which has consolidated community organizations that manage natural resources, also reported in part by Pech (2010).

With regards to the salt ponds, ejido members decided it wasn't worth the effort to drain and clean them, due in part to the constant impact of hurricanes, but mainly to the fact that they were no longer competitively situated in that market. This coincides with findings by Guzmán-Noh and Gurrí (2021) who mention the recurrent impact of hurricanes as the primary cause of productive abandonment of these ponds in other areas along the coast.

Another important finding of our study is that there is little recognition of the other ecosystem services provided by these areas, such as protection and habitat for local and migratory bird life (Figures 8 and 9), a component that should be considered in comprehensive proposals of adaptive measures to climate change in this region.

CONCLUSION

In the process of fulfilling our general objective, it became clear that the wetlands located in San Crisanto are of vital importance for developing local means of adaptation to climate change and inhabitants' livelihoods, primarily due to their relationship with the local economy and the use of the mangroves managed by the ejido. Place-based attachment to, understandings of, and local ecological knowledge about these ecosystems are important for their management, conservation, and protection. Ejidal organization has also been a relevant element for collective decision-making and follow-through of established agreements.

Strategic actions based in ecosystem management demonstrate the generation of collaborative processes for managing natural spaces, such as mangroves and the diversity of activities derived from them. Strengthening this type of strategy reveals itself as a means of protecting ecosystems such as wetlands and carrying out actions sustainably. In the case of Mexico, lands managed under ejidal organization have been the most important and well-conserved.

Nevertheless, a critical analysis of other persistent actions in the locality, such as filling floodable land around the marsh with debris, is necessary, given that these actions perpetuate increased vulnerability of these spaces and their inhabitants. Similarly necessary is a land use ordinance that considers the relevance of these wetlands and the use and maintenance of salt ponds.

The experience shared is useful to fuel an explanation for the similarities and differences between adaptive actions and processes in response to climate change in other areas of the Yucatan coast, in places managed by ejidal organizations across the country, and spaces that demonstrate the relevance of coastal wetlands of the world for developing local livelihoods and wetland conservation. Likewise, we highlight the usefulness of phenomenological studies as an appropriate approach for identifying psychosocial aspects that influence adaptative measures and wetland conservation.

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