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"HYDROLOGICAL RESTORATION OF THE MANGROVES OF THE SAN CRISANTO EJIDO"

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Abstract: Mangroves are important from ecological and social perspectives. Mangrove restoration projects are increasingly recognized as allies to achieve sustainable development efforts and mitigation and adaptation to climate change. Forest owners at the community level can establish cost-effective initiatives to comply with Mexican legislation for the registration of forest carbon projects and the certification of the increase in the aerial carbon stock over time. However, mangrove restoration projects do not produce positive results from technological bases alone, but require community participation, appropriate government structures, and alignment of objectives and goals of local and external actors. This study illustrates the socio-environmental bases behind the hydrological restoration and community management of a mangrove in the Yucatan Peninsula, Mexico, as well as the socio-environmental benefits obtained. The results and discussion advance knowledge on ecological restoration by detailing the hydrological restoration approach in mangroves associated with meteorological disturbances.
Keywords: wetlands, nature-based solutions, social safeguards, environmental safeguards

INTRODUCTION

Mangroves are important wetlands from ecological and social perspectives (Sasmito et al., 2023). These forests provide resources (nutrients, habitat, nursery, refuge, etc.) to numerous species of adjacent ecosystems: terrestrial forests, reefs, seagrasses, etc. (Walker et al., 2022). Mangroves are increasingly recognized for their importance as allies in achieving sustainable development efforts and mitigation and adaptation to climate change (Friess et al., 2020), which is why their conservation and restoration are proliferating (Grimm et al., 2022).).

Restored and rehabilitated mangroves have recognized economic, social and ecological value for coastal communities (Ellison et al., 2020). The Millennium Ecosystem Assessment (MEA) categorizes the benefits that society obtains from ecosystems (ecosystem services) into four categories: *supply, regulation, support and cultural*(MEA, 2005). Mangroves provide important ecosystem services in all four categories: provisioning services, for example, wood, firewood, charcoal and medicines (Lee et al., 2014; Friess et al., 2020, Alongi, 2022); regulating services, for example, CO2 sequestration and capture, flood, storm and erosion control, and saltwater intrusion prevention (Donato et al., 2011, Alongi, 2012); supporting services, for example, breeding, spawning and rearing habitat for commercial fish species (Blaber, 2007; Barbier et al., 2011); and cultural services, for example, recreation, as well as aesthetic values and other non-use values (Sarhan & Tawfik, 2018; Treviño, 2022).

The types and methods of mangrove restoration and rehabilitation are numerous including: 1) incorporation of mangroves in engineering structures for coastal defense, 2) monocultures, 3) ecological restoration of mangroves, in which the flood level is manipulated (channelization, drained, etc.) so that physicochemical variables (flood level, salinity, nutrients) reach adequate levels for establishment, growth and reproduction, and 4) mangrove design, which puts people and their needs in the foreground, and then uses those needs must define the set of ecosystem services that will be included in the project and must be satisfied with the restoration or rehabilitation (Ellison et al., 2020). Carbon sequestration in restored mangroves can exceed natural carbon reserves and thus play a significant role in combating climate change (Osland et al., 2020). Because carbon is traded on the market, the sale of carbon credits provides financial incentives for sustainable mangrove management (Climate

Action Reserve, 2022; Ellison et al., 2020). Forest owners at the community level have the potential to participate in cost-effective initiatives to comply with Mexican legislation for the registration of forest carbon projects and the certification of the increase in the carbon stock in trees over time. However, mangrove restoration projects do not produce positive results from technological bases alone, but require community participation, appropriate government structures, and alignment of objectives and goals of local and external actors (Lovelock and Brown, 2019). There are not many case studies on the hydrological restoration of mangroves associated with meteorological disturbances as a nature-based solution to generate long-term climate benefits, as well as other social and environmental benefits. The objective of this study is to illustrate the socio-environmental bases behind the hydrological restoration and community management of a mangrove associated with meteorological disturbances in the Yucatan Peninsula of Mexico, as well as the socio-environmental benefits obtained.

METHODS

STUDY AREA

This study presents the ecological and social bases of the ecological restoration of 691.5 hectares of mangrove in the Ejido San Crisanto, Yucatán. Mexico (Figure 1). Four species of mangrove (*Laguncularia racemosa, Rhizophora mangle, Avicennia germinans and Conocarpus erectus*) They have been recorded in the area, presenting themselves in different configurations depending on the hydrology of the site (Pech, 2017). The dominant species in the area is L. *racemosa*, due to the low salinity influenced by specific freshwater discharges (~40 water holes) (Pech, 2017; Fundación San Crisanto, 2022). The mangrove area borders other land uses, for example, thorny lowland forest, coconut plantations and savanna (San Crisanto Foundation, 2022).

The climate in the study area is dry, warm with rain in summer. As an effect of the geographical position of the Yucatan Peninsula, the mangroves in the study area (as in the entire Peninsula) have historically been affected by hurricanes (Table 1).

Year	Hurricane Name	Category	Wind speed
1955	"Hilda"	3	(185 km/h)
1961	"Carla"	4	280 km/h
1988	"Gilberto"	4	324 km/h
2002	"Isidoro"	3	225 km/h
2020	"Cristobal"	1	45-55 km/h

Table 1. History of hurricanes in the Ejido San Crisanto

The Ejido de San Crisanto was created by presidential resolution based on an Agrarian Law of the seventies, providing the community with autonomy on its land. The productive activities that have been carried out since the formation of the ejido are: coconut cultivation and production, production of common salt and ecotourism (Fundación San Crisanto, 2022). In 1996, the San Crisanto Foundation was established with the commitment to advise and execute mangrove conservation and restoration actions to promote social development and use resources in a sustainable manner. Since then, the ejido has invested resources (>2 million Mexican pesos) in the preservation of the mangrove, environmental education in the community, and in obtaining alternative financing to restore the mangrove after natural disturbances that occur naturally in area.

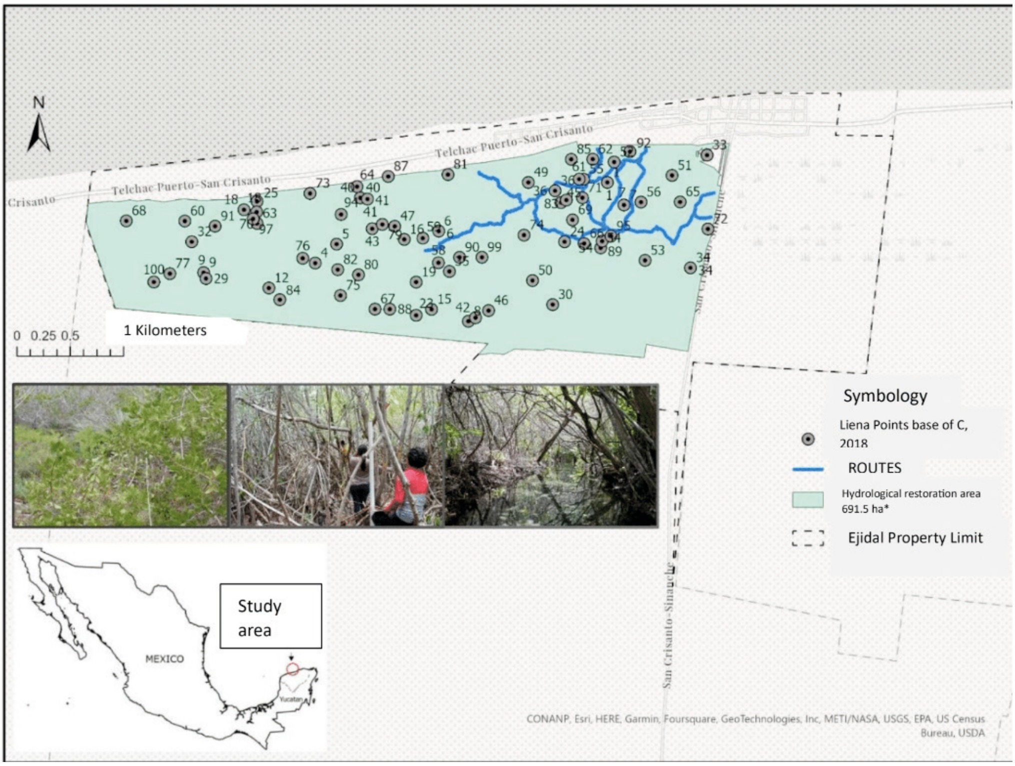

Figure 1. Location of the mangrove, canal network and monitoring plots (since 2018) in the Ejido San Crisanto.

Year	Species composition	Average diameter (cm)	Density (ind/ha)	Sample size (n)	Reference
2001	White mangrove (*L. racemosa*) Red mangrove (R. mangle) Buttonmangrove (C. erectus) Black mangrove (A. germinans)	ND	5,000	5 Transects	Informe actividades UMA San Crisanto, 2011
2010	White mangrove (L. racemosa) Red mangrove (R. mangle) Buttonmangrove (C. erectus) Poplar (Ficus cotinifolia)	2.1 ± 1.17	1,600	8 Transects	Informe actividades UMA San Crisanto, 2011
2016	White mangrove (L. racemosa) Red mangrove (R. mangle) Buttonmangrove (C. erectus) Black mangrove (A. germinans) Poplar (Ficus cotinifolia)	3.8 ± 2	3,600	13 plots ($400m^{2)}$	``Fundacion San Crisanto``, 2018
2018	White mangrove (L. racemosa) Red mangrove (R. mangle) Buttonmangrove (C. erectus) Black mangrove (A. germinans) Poplar (Ficus cotinifolia)	4.9 ± 2	5,100	75 plots 500 m2	``Fundacion San Crisanto``, 2022

Table 2. Summary of historical forest structure of the Ejido San Crisanto.

MANGROVE HYDROLOGICAL RESTORATION

The hydrological restoration had been planned since 1995. After the passage of Hurricane Gilberto (1998), the restoration of freshwater flows (from springs) within the mangrove area and the monitoring of the recovery of the vegetation began. with support from government programs. However, in 2002 Hurricane Isidoro negatively affected forest cover by 90% after its passage. The community responded by increasing efforts to clean and clear 12,000 m of canals and 40 water sources within the 691.5 hectares of mangrove. The project generated nearly 60 jobs and substantial economic benefits for the members of the ejido (through ecotourism). Hydrological flow is important for the maintenance of the ecological functions of mangroves such as carbon capture, coastal protection, soil retention, water purification, provision of habitat for marine and terrestrial species, etc. (San Crisanto Foundation, 2022). By restoring channels that connect waterholes, we sought to enable forest succession.

Figure 2. Left: effects of Hurricane Isidoro (2002) on the mangrove swamp of Ejido San Crisanto. Right: Cleaning and desilting activities of waterholes and channels to facilitate hydrological flow.

RESULTS

In 2001, the 4 main species of mangrove were recorded: white (Laguncularia racemosa), red (Rhizophora mangle), black (Avicennia germinans), buttonwood (Conocarpus erectus), according to the environmental impact analysis for the registration of the San Crisanto Natural Resources Management Unit in 2011. After the passage of Hurricane Isidoro, no presence of live individuals of black mangrove (A. germinans) was recorded, but the presence of individuals of Poplar (Ficus cotinifolia) was observed. In 2016, as a result of a forest inventory co-sponsored by the National Forestry Commission and with the exchange of knowledge and training of human resources with the Technological Institute of Mérida, live individuals of black mangrove (A. germinans) were again recorded. In 2017, an evaluation of forest carbon stores by researchers from the IPN Research and Advanced Studies Center in Mérida (Pech et al., in press) represented the scientific basis for the community to later vote during an Assembly in 2018. Please develop a forestry emission reduction certification project under the Climate Action Reserve (CAR) standard, which is based in California, USA. Later in 2021, the international organization ClimateSeed became a strategic ally in obtaining funds to continue reporting, monitoring and verifying CO2 emissions reductions from mangrove growth. This project complements the mangrove conservation and restoration work that has been carried out by the Ejido since 1995 (Fundación San Crisanto, 2022). The inventory was co-developed with the community and the presence of the four mangrove species plus the associated species Ficus sp is reported. Table 2 presents the species composition, diameter and average density of the forest in the mangrove of the San Crisanto ejido before and after Hurricane Isidoro.

Since 2018, the ejido has monitored forest carbon capture in living and dead trees and the reduction of emissions is verified. By May 2022, the project has already registered 10,368 emissions reduction credits which have been sold to the international carbon market. Table 2 summarizes the aerial carbon store over time and the amount of credits (1ton CO2 reduced = 1 credit) obtained.

Year	Reporting Period	Aerial carbon in the mangrove (691.5 ha) (CO_2)	Credits Issued
2018	Base line	64,119.43	1,372
2019	Period 1	76546.05	3,242
2020	Period 2	90765.92	1,319
2021	Period 3	106711.11	2,924
2022	Period 4	112895.61	1,511

Table 2. Historic air carbon stocks and emissions reduction credits issued under the California emissions offset program.

DISCUSSION AND FINAL CONSIDERATIONS

The management and governance of mangroves is a complex task because this ecosystem intersects with different land uses and values assigned by stakeholders and agencies with diverse perspectives and priorities (for example, conservation, tourism, agriculture, climate change mitigation, among others).) at different jurisdictional levels (Thompson, 2018). The success of San Crisanto shows the potential of incorporating the commercialization of blue carbon (carbon stored in the mangrove) to finance the conservation and restoration of mangroves, and to produce income that contributes to the sustainable development of the community. Mangrove restoration projects are aligned with international principles and national commitments of ethics and social and environmental integrity, it is possible to contribute with ways to improve the quality of life and the quality of the environment. Furthermore, various activities associated with forest management (e.g. afforestation, restoration, agroforestry, improved forest management, etc.) can be used as nature-based solutions to mitigate climate change (Seddon, et al., 2020).

This study advances the science of mangrove restoration by illustrating an example of hydrological mangrove restoration associated with natural disturbances in which the social part was considered fundamentally to guide institutional and group agreements. This study aligns and contributes to the 2030 Agenda for Sustainable Development, the post-2020 global biodiversity framework and the United Nations Decade for Ecosystem Restoration (IUCN, 2021).

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