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Landscape Metrics and Conservation Status of Five Mangrove Wetlands in the Eastern Gulf of California Margin

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ABSTRACT

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Ecological significance and relevance of mangrove wetlands has been widely highlighted worldwide. Nevertheless, human-derived impacts and climate variability are increasing threats to these ecosystems in the last decades. Mangroves from Sinaloa (Mexico) integrate a large wetland corridor and provide several ecosystem services; however, diverse stressors could be increasing their vulnerability and associated biodiversity. The conservation status of five mangrove wetlands in this region was assessed through remote sensing techniques, landscape metrics, official databases and *in situ* records. In general, a decrease on mangrove cover was observed, excepting Estero de Urías and Ceuta, while aquaculture increased in all sites, with a greatest coverage in Santa María-La Reforma (increased 2057 ha in 18 years). The largest annual rate of change was observed in Huizache-Caimanero (–0.99%). Although conservation programs exist, there are signs of deterioration of mangrove wetlands according to this study.

ADDITIONAL INDEX WORDS: *Remote sensing, aquaculture, human dimensions, hydrology*.

INTRODUCTION

The Gulf of California (GC; Figures 1 and 2) has a high ecological and socioeconomic relevance (Lluch-Cota *et al*., 2007). Wetlands along the eastern margin of the GC provide a myriad of habitats that offer several ecosystem functions and services (*e.g*., Aburto-Oropeza *et al*., 2008) for both resident and migratory species and are characterized as mangrove wetlands according to the dominance of these species. Sinaloa comprises the highest mangrove coverage of the four Mexican states bordering the GC (81,558 ha during 2015; Valderrama-Landeros *et al*., 2017; Figure 1) and fourth in all the Mexican states (10% at a national level). According to the ecological status, socioeconomic significance, and vulnerability, some wetlands in NW Mexico have been decreed federal protection status (*e.g*., Natural Protected Areas like Marismas Nacionales, a biosphere reserve in Nayarit) or intergovernmental environmental agreements and programs (*e.g*., Ramsar sites, Important Bird Area). Currently mangroves are legally protected according to Mexican laws (NOM-ECOL-059-2010); nevertheless, human impacts have caused a notorious signature of change in the past decades (*e.g*., landscape changes in Sonora [USGS, 2016] and Sinaloa) associated with increasing establishment of shrimp aquaculture infrastructure and a significant loss of mangrove coverage (Berlanga-Robles *et al*., 2011). Intensive livestock activity, tourism infrastructure, natural events like hurricanes, agriculture, wastewater discharges, plastic pollution (polyethylene terephthalate), felling for firewood or construction, medicine, and charcoal are additional stressors for mangroves in this region. Mangrove disturbance also has a social impact, because local communities depend strongly on these ecosystems (*e.g*., the artisanal penaeid shrimp fishery in Sinaloa provided 12,156 ton during 2013; CONAPESCA, 2013). Additionally, 11 main rivers flooding from Sierra Madre Occidental—a mountain range in the NW region—to these coastal ecosystems have provided a wetland corridor for several local and migratory species (Navedo *et al*., 2015). Although these hydrological resources provide several goods and services to ecosystems along their passage, many of these rivers have been dammed for several decades (*e.g*., the recent construction of the Picachos dam in 2009 controlling the Presidio river, which flows into the northern section of the Huizache-Caimanero lagoon system; Figure 3).

The main goal of this study is to assess the conservation status of five mangrove wetlands in the eastern margin of the GC (Sinaloa, Mexico) through landscape metrics analysis and ecological and social indicators. Hydrological changes and marginality conditions of human communities near coastal lagoons are discussed as additional threats to the study areas.

METHODS

Satellite-derived data (1990–2011), cartography, databases, and *in situ* records were analyzed to assess the conservation status of mangroves in five coastal lagoons from Sinaloa, Mexico.

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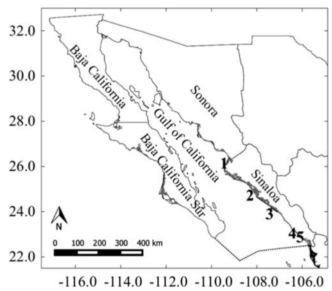

Figure 1. Mangrove coverage and distribution in the Gulf of California (red areas; Rodríguez-Zúñiga *et al*., 2013). Study wetlands in Sinaloa: (1) Agiabampo, (2) Santa María-La Reforma, (3) Ceuta, (4) Estero de Urías, and (5) Huizache-Caimanero. Dashed line shows the geographical limits for the Gulf of California Large Marine Ecosystem (NOAA, 2019).

Study Area

The study area comprises five coastal lagoons: Agiabampo, Santa María-La Reforma, Ceuta, Estero de Urías, and Huizache-Caimanero (Figures 1 and 2). Mangrove species *Avicennia germinans*, *Laguncularia racemosa*, *Rhizophora mangle*, and *Conocarpus erectus* are found in these wetlands. Currently, all study sites in this work are named Ramsar sites, except Estero de Urías (*i.e*. wetlands with ecological relevance, therefore singled out for implementation of conservation programs and sustainable use of their resources).

Agiabampo (centered at 26°16′47.41″ N, 109°11′30.83″ W) is characterized by a wide spatial extension of shrimp farms and agriculture influencing this ecosystem (González-Farías *et al*., 2002). Currently, freshwater inflows are mostly derived from nearby agriculture fields. These conditions, combined with a high rate of evaporation, lead to hypersaline coastal water-bodies (Álvarez and Jones, 2002). Santa María-La Reforma lagoon (centered at 25°1′21.14″ N, 108°6′22.04″ W) is located in central Sinaloa. It is surrounded by significant mangrove swamps, saltmarshes, and sandbars. Artisanal fisheries, agriculture, livestock breeding, and shrimp culture are the most important activities. Ceuta lagoon (centered at 24°6′27.19″ N, 107°10′1.32″ W) also has significant mangrove coverage; however, shrimp agriculture and aquaculture has forced landscape changes in the last decades (*e.g*., Alonso-Pérez *et al*., 2003; Monzalvo-Santos *et al*., 2006). Estero de Urías (centered at 23°10′24.79″ N, 106°21′7.70″ W) is surrounded by industrial and urban areas of Mazatlán—one of the most important tourist destination cities in Mexico—and comprises food processing plants, seafood packers, an electric power plant, and shrimp farms. Huizache-Caimanero (centered at 23°0′22.58″ N, 106°8′10.12″ W) is an important wetland that has provided several goods and services for local people dating to pre-Columbian times (Cruz-Torres, 2001). Table 1 shows the current protection status for each wetland.

Cartography and Image Processing

Landsat Thematic Mapper (TM) 5 images (one scene per year for 1990/1993, 1998, 2006, 2011, low cloud coverage, at 30-m resolution) for study areas were downloaded and processed (GloVis; USGS, 2019). Radiometric correction

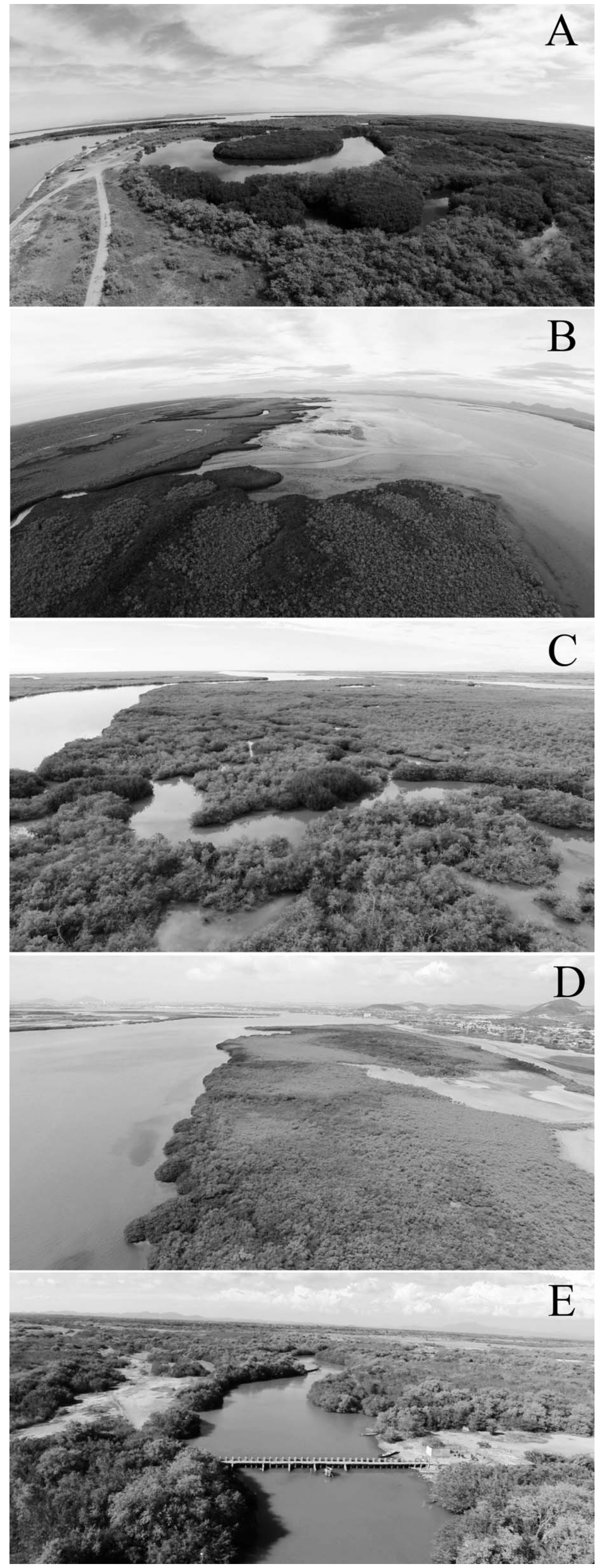

Figure 2. Aerial photographs for study mangroves in Sinaloa recorded with a DJI Phantom 2 drone and a GoPro 3+ camera. (A) Agiabampo; (B) Santa María-La Reforma; (C) Ceuta; (D) Estero de Urías; (E) Huizache-Caimanero.

Table 1. *Protection status of wetlands in Sinaloa.*

Coastal Lagoon	Protection Status and Ecological Relevance
Agiabampo	Ramsar site (ID 1797) Important Bird Area (MX 131). Priority wetland-DUMAC It is a resting site for many migratory bird species during the boreal winter. Four mangrove species are found, and it is an area of refuge, feeding, and growth for several species.
Santa María-La Reforma	Ramsar site (ID 1340) Important Bird Area (MX228) The lagoon supports important artisanal fisheries, such as shrimp, crabs.
Ceuta	Ramsar site (ID 1824) Important Bird Area (MX247) Site of Regional Importance by the Western Hemisphere Shorebird Reserve Network (WHSRN). The shore area was decreed as Sanctuary for sea turtles conservation.
Estero de Urías	No protection decreed It is a wetland surrounded by urban areas. Although it is an important habitat for several species, it is also affected by several anthropogenic factors.
Huizache-Caimanero	Ramsar site (ID 1689) Site of conservation importance in the Western Hemisphere Shorebird Reserve Network

was performed as mentioned by Flores-Cárdenas *et al*. (2018). Geographical limits and corresponding path/row for each lagoon system are shown in Table 2. Each image was delimited to the mangrove area for each lagoon system. Image processing was performed with Idrisi Taiga software by Clark Laboratories (Eastman, 2003). Details to calculate mangrove coverage, fragmentation analysis, and aquaculture coverage are described separately.

Mangrove and Aquaculture Area Coverage

Images were analyzed with the Idrisi Taiga software (Clark Laboratories; Eastman, 2003) to determine changes in mangrove and aquaculture areas in the past decades. To classify mangroves areas, a principal component analysis was applied to bands 3, 4, 5, and 7 to simplify pixel classification, followed by a supervised classification on three eigenvectors (maximum likelihood algorithm). Training fields were added according to diverse ancillary data (*e.g*., official cartography; CONABIO, 2013), high resolution imagery from Google Earth, and *in situ* records. Mangrove coverage (ha) was then calculated for each lagoon. The annual rate of change per year was calculated (q, expressed as percentage) according to the Food and Agriculture Organization of the United Nations (FAO, 1995):

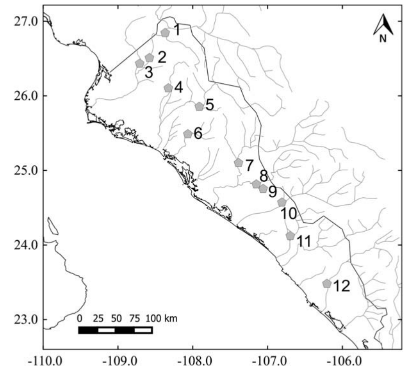

Figure 3. Main rivers (blue lines) and damps (⬟) in Sinaloa, México. Dams: (1) Luis Donaldo Colosio, (2) Miguel Hidalgo y Costilla, (3) Josefa Ortiz de Dominguez, (4) Ing. Guillermo Blake Aguilar, (5) Gustavo Díaz Ordaz, (6) Lic. Eustaquio Buelna, (7) Adolfo López Mateos, (8) Sanalona, (9) Ing. Juan Guerrero, (10) José López Portillo, (11) Aurelio Benassini Viscaíno, (12) Picachos. Cartography source: CONAGUA, (2019; dams: 1:1,000,000) and CONABIO (2019; hydrography: 1:4,000,000).

$$q = 100\left[\left(\frac{A_2}{A_1}\right)^{1/t} - 1\right]$$

where, A_1 and A_2 correspond to mangrove areas during the initial and final years, respectively, and t is total years for the study period. Aquaculture coverage was determined by false color composition (RGB) with bands 7, 4, 2 (mid-infrared, near-infrared, and green, respectively) of Landsat TM 5. Imagery and panchromatic band 8 of Landsat 7 Enhanced TM Plus (ETM+) was used to improve spatial resolution. Identified areas were also supervised with high-resolution imagery from Google Earth.

Fragmentation Analysis

Fragmentation is separation of the coverage of an ecosystem, which causes the formation of patches or fragments. One of the main consequences is the loss of connectivity and therefore biodiversity and is driven by natural or anthropogenic causes. The number of patches (NP) corresponding to the mangrove class was calculated for each image with FRAGSTATS software (McGarigal and Marks, 1995) as an indicator of fragmentation processes.

Human Dimensions

To characterize the social component, official cartography was acquired and analyzed (CONABIO, 2012, 2014). Cartography corresponding to food insecurity (defined here as the percentage of people with insufficient diet quality to ensure a healthy life) and marginality index (calculated according to

Table 2. *Geographical location, spatial location, and date for Landsat TM 5 satellite images analyzed for each lagoon system.*

	Min *X*	Max *Y*	Max *X*	Min *Y*	Path/Row	Dates
Agiabampo	−109.57	26.55	−108.98	25.91	34/42	15 Dec 1993; 10 Oct 1998; 25 May 2006; 16 Feb 2011
Santa María-La Reforma	−108.51	25.36	−107.69	24.64	33/43	19 Sep 1993; 9 Nov 2000; 12 Dec 2006; 25 Feb 2011
Ceuta	−107.58	24.35	−106.67	23.82	32/43	6 Apr 1990; 18 Mar 1998; 29 Dec 2003; 1 Nov 2011
Estero de Urías	−106.47	23.09	−106.2	23.24	31/44	16 Nov 1993; 15 Nov 1998; 24 Oct 2005; 12 Nov 2011
Huizache-Caimanero	−106.29	23.18	−105.95	22.82	31/44	19 Nov 1993; 13 Jan 1998; 1 May 2005; 25 Oct 2011

Min X = minimum longitude; Max Y = maximum latitude; Max X = maximum longitude; Min Y = minimum latitude

Table 3. *Landscape metrics for five mangrove wetlands in Sinaloa.*

		Landscape Metrics		
Lagoon	Year	Aquaculture (ha)	Mangrove (ha)	No. of Patches
Agiabampo	1993	1550	1352	675
	1998	1642	1589	759
	2006	1896	935	720
	2011	1992	1173	676
Santa María-La Reforma	1993	16,168	18,052	2255
	2000	17,075	16,790	2699
	2006	17,256	16,076	2239
	2011	18,225	17,525	2353
Ceuta	1990	4166	4935	1529
	1998	4588	5024	1607
	2003	4615	5186	1245
	2011	4900	5116	1178
Estero de Urías	1993	691	724	152
	1998	725	669	165
	2005	725	758	140
	2011	725	784	218
Huizache-Caimanero	1993	1088	552	871
	1998	1088	569	989
	2005	1107	431.4	571
	2011	1128	461	486

lack of education and household goods and services and defined at five levels: very low, low, medium, high, very high) were analyzed for each lagoon. Cartography was elaborated at the scales of municipalities for the former (CONABIO, 2014) and at community scales for the latter (CONABIO, 2012; here, the grade of marginality of rural communities located at a maximum distance of 5 km from coastal lagoons was considered and the mode was used to define the overall classification for each case).

Hydrology

The situation of hydrological sources influencing coastal lagoons in Sinaloa was reviewed for two case studies in Sinaloa (*i.e.* Mocorito, influencing Santa María-La Reforma, and the San Lorenzo River, influencing Ceuta lagoon). Interannual variability and trends of water discharges of rivers were analyzed according to monthly records from the Banco Nacional de Datos de Aguas Superficiales (Bandas) database (1939–1999 and 1944–2011, respectively), provided by the National Water Commission, Mexico (CONAGUA, 2016). Significance of the linear trends was assessed with the Sen slope estimator (Sen, 1968).

RESULTS

Landscape metrics derived from Landsat TM 5 imagery are summarized in Table 3 for the studied wetlands. The results for each topic are described separately.

Mangrove Coverage

A decrease in mangrove coverage was observed for all wetlands (Table 3), except Ceuta (+181 ha from 1990 to 2011) and Estero de Urías (+60 ha from 1993 to 2011). The greatest decrease was observed in Santa María-La Reforma (–527 ha during a period of 18 y). On the other hand, Huizache-Caimanero recorded an annual rate of change of –0.99%, followed by Agiabampo and Santa María-La Reforma with –0.78% and –0.16%, respectively (Table 4). Ceuta and Estero de Urías showed an annual rate of change of 0.17% and 0.44%, respectively.

Table 4. *Annual rate of change for mangrove wetlands in Sinaloa during 1990–2011.*

Wetland	Period	Deforestation Rate (%)
Agiabampo	1993–2011	–0.78
Santa María-La Reforma	1993–2011	–0.16
Ceuta	1990–2011	0.17
Estero de Urías	1993–2011	0.44
Huizache-Caimanero	1993–2011	–0.99

Aquaculture Coverage

Studied wetlands showed an expansion of aquaculture ponds with a higher growth in Santa María-La Reforma (increasing to 2057 ha from 1993 to 2011), while Estero de Urías showed the lowest value (34 ha from 1993 to 2011). Aquaculture development has been intermittent in most of the cases (*i.e.* a well-documented growth during the decade 1990–2000 and a continuous and smooth increase after the second half of the 2000s decade). Santa María-La Reforma and Ceuta showed a continuous increase in aquaculture area during the study period.

Fragmentation

The number of fragments or patches decreased for Ceuta (1529–1178 NP) and Huizache-Caimanero (871–486 NP), matching a decrease in mangrove cover for the latter, whereas Santa María-La Reforma (2255–2353 NP) and Estero de Urías (152–218 NP) showed an increase. The number of fragments for Agiabampo showed a decrease since 1998 (Table 3).

Human Dimensions

In general, rural communities are established near coastal lagoons, with the exception of Estero de Urías, an urban wetland in Mazatlán, Sinaloa, one of the most important tourist destination cities in Mexico. Food insecurity was higher for communities located around Huizache-Caimanero, whereas the marginality index ranged from medium to high for all lagoons, with the exception of Santa María-La Reforma, which reported a low index (Table 5; communities and additional data are shown in the Appendix).

Hydrological Changes

Water volume showed a decreasing trend for many of Sinaloa's rivers (not shown). Figure 4 showed that the Mocorito River (1939–1999; influencing Santa María-La Reforma lagoon) had a negative and significant trend ($p < 0.05$), whereas the San Lorenzo River (influencing Ceuta lagoon) showed no

Table 5. *Food insecurity (municipality scale), marginality index (corresponding to communities located in a 5-km radius from the study wetlands), and population.*

Lagoon	Food Insecurity (%)	Marginality Index	Population
Agiabampo	26	High	8469
Santa María-La Reforma	26	Low	12,775
Ceuta	21–32	High	6083
Estero de Urías	16	Medium	392,388
Huizache-Caimanero	32	Medium-high	12,302

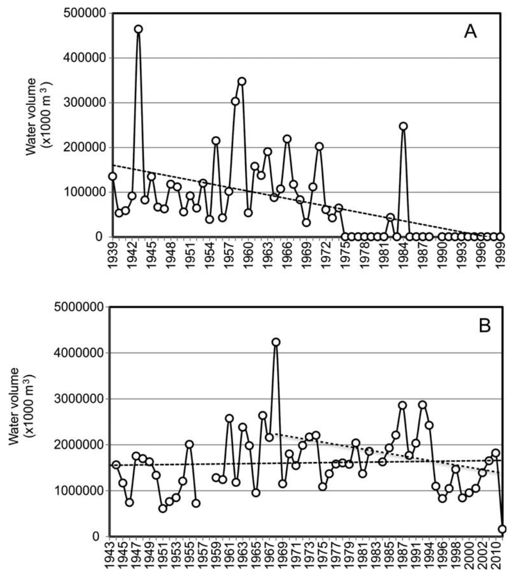

Figure 4. Interannual variability of water discharges of (A) Mocorito (Santa María-La Reforma lagoon) and (B) San Lorenzo River (Ceuta lagoon; dashed lines correspond to linear trends during 1943–2011 and 1968–2011). Data source: Bandas database, National Water Commission, México (CONAGUA, 2016). Trends were assessed with the Sen slope estimator (Sen, 1968).

significant trend for the full period (1943–2011); however, it was significant after 1968 ($p < 0.05$). As discussed later, such changes may be causing significant ecological disturbances in these lagoons.

DISCUSSION

Coastal wetlands in Sinaloa have been recognized by their high biological productivity (*e.g.*, Rodríguez-Zúñiga *et al.*, 2013); however, knowledge about these ecosystems is still poor in the Gulf of California (Brusca, Cudney-Bueno, and Moreno-Báez, 2006). The landscape of wetlands in this state has been changing in the last decades, which is likely related to the main driving forces of land use change in this region: aquaculture, livestock breeding, agriculture, fisheries, urban/tourist development, and climate variability. These stressors could be diminishing the overall conservation of these wetlands and associated biodiversity.

Mangrove forests in this state showed negative changes from 1970 to 2010 (Valderrama-Landeros *et al.*, 2017); that is, while coverage recorded a decrease (82,171–77,262 ha) disturbed mangrove increased (760–2257 ha). According to Valderrama-Landeros *et al.* (2017), a recovery was observed during 2015: the mangrove cover increased (81,558 ha) and the disturbed areas decreased (1851 ha). Results derived from this contribution and analyzed per coastal lagoon showed an overall loss in mangrove cover, with exception of Ceuta and Estero de Urías, which showed slight gains. There are not enough and not recent data about local deforestation rates in Mexico; however according to national surveys about extension, distribution, and monitoring of mangroves, the overall annual rate of change for Sinaloa has varied from –0.51% (Rodríguez-Zúñiga *et al.*, 2013, from 2005 to 2010) to 1.08% (Valderrama-Landeros *et al.*, 2017, from 2010 to 2015). According to the results, the deforestation rate varied from this report when analyzed separately for each lagoon (*e.g.*, Santa María-La Reforma, the largest lagoon in Sinaloa, recorded a –0.16 annual rate, whereas Huizache-Caimanero reported –0.99 (Table 4). Although the loss of mangroves is multifactorial and not easy to determine, the increase of shrimp aquaculture facilities in Sinaloa has been notable, especially during the 1990s, when changes in the Mexican Constitution related to land tenure in 1992 resulted in an increase of this activity and in conversion of coastal areas, including mangrove wetlands, into diverse urban developments (*e.g.*, tourism resorts; Morzaria-Luna *et al.*, 2014). The number of fragments or NP is a basic landscape metric frequently reported in the literature; here, the NP also varied per lagoon. For example, NP increased for Santa María-La Reforma and decreased significantly for Huizache-Caimanero, in addition to mangrove cover, suggesting that fragmentation processes are occurring more drastically for the latter. In particular cases like Ceuta, the decrease in fragmentation levels could be related to the increase in their size (*i.e*. the increase in mangrove area, mainly in the first stage during 1990–1998). This period coincides with a strong El Niño–Southern Oscillation event (1997–1998), which is related to positive sea-level anomalies in the GC and may facilitate the establishment of propagules and an increase of mangrove cover (López-Medellín *et al.*, 2011). Despite its geographical proximity, all lagoon systems in Sinaloa have a different dynamic and management and conservation plans.

Huizache-Caimanero showed the highest overall percentage of mangrove loss (16.4% in 18 y). The vulnerability of mangroves in this lagoon increases as multiple activities are performed (*e.g.*, artisanal fisheries, aquaculture, agriculture, and high marginality conditions), along with signs of inbreeding associated with a restriction on propagule dispersal because of the presence of seasonally fixed fishing structures known as *tapos* (Millán-Aguilar *et al.*, 2016; Figure 2E). Figure 5 shows three protection categories implemented in coastal wetlands in Sinaloa: Important Bird and Biodiversity Areas, Ramsar, and Natural Protected Areas. Although a high spatial extension in Sinaloa falls under one or more of these categories, high vulnerability prevails for these wetlands because just a few areas are protected by federal laws (*i.e*. Natural Protected Area category; see Morzaria-Luna *et al.*, 2014, for a wider discussion). Agiabampo, Santa María-La Reforma, and Ceuta are partially protected by federal laws, in that they possess inner islands under the Protected Areas for Flora and Fauna category, in addition to other islands along the Gulf of California. Estero de Urías and Huizache-Caimanero have no federal decrees under any of the Natural Protected Area categories (*i.e*. Biosphere Reserve, National Park, Natural Monument, Protected Areas for Natural Resources, Protected Areas for Flora and Fauna, Sanctuary), and only the latter has been recognized as a Ramsar site and site of conservation importance in the Western Hemisphere Shorebird Reserve Network (2019). Currently, objectives and the structure of conservation biology have changed, now taking a multidisciplinary approach, including politics, economics, and sociology, to seek interactions between people and nature and determine

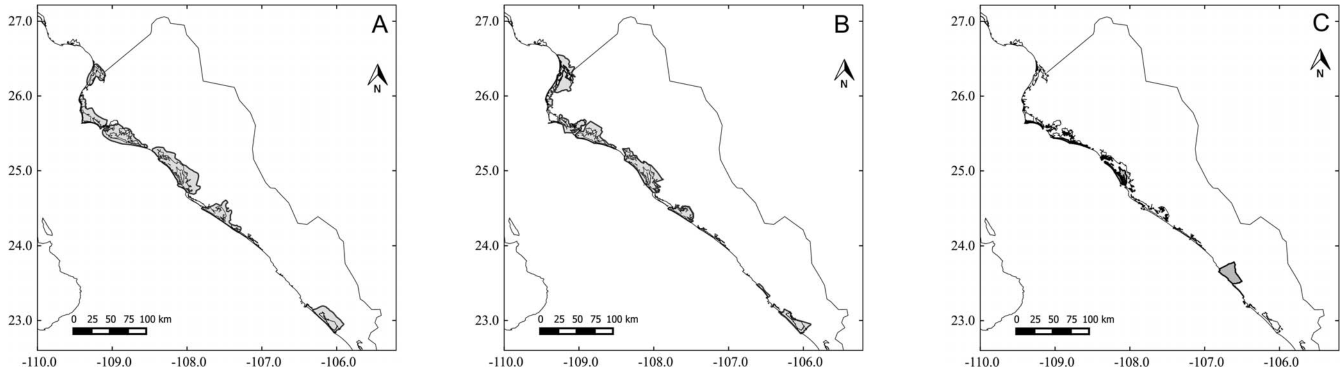

Figure 5. (A) Important Bird and Biodiversity Areas (IBAs), (B) Ramsar sites, (C) Natural Protected Areas. Cartography source: CIPAMEX (CONABIO), 2015; CONANP, 2016; SEMARNAT-CONANP, 2017.

how to manage this relationship to create better conditions for both (Groom, Meffe, and Carroll, 2005; Pomeroy, Parks, and Watson, 2004). Nowadays, a challenge for responsible authorities in Sinaloa (*e.g.*, Comisión Nacional de Áreas Naturales Protegidas [CONANP], Procuraduría Federal de Protección al Ambiente [PROFEPA], Comisión Nacional de Acuacultura y Pesca [CONAPESCA]) is not just to monitor compliance with current laws but also to work together with rural communities to establish local strategies for each case, to preserve the goods and services that mangroves offer; that is, coastal lagoons have different dynamics, not just from the environmental but from the social perspective.

On the other hand, Barrett, Travis, and Dasgupta (2011) discussed that persistence of extreme poverty conditions and continued rapid loss of biodiversity seem closely related, and such links have been widely discussed (*e.g.*, Camacho-Ibar and Rivera-Monroy, 2014; Dale and Connelly, 2012; Yoskowitz and Russell, 2015). With the exception of Estero de Urías, rural villages closest to wetlands from Sinaloa showed medium to high marginality conditions (Table 5; Appendix). Most of these rural villages strongly depend on the seasonal artisanal fisheries performed in these lagoons, which commonly include penaeid shrimp species (Rubio-Cisneros, Aburto-Oropeza, and Ezcurra, 2016). Although the conservation of these wetlands is relevant for fishermen, there is a general lack of knowledge about protection policies of these ecosystems. For example, the personal data of 54 fishermen in Huizache-Caimanero showed that only 41% had an elementary education only and that most of them ignored the meaning of conservation categories: none of the respondents knew the meaning of Ramsar sites; data not shown). In contrast, the social perception about these ecosystems might be different in other locations. According to López-Medellín, Castillo, and Ezcurra (2011), fishermen from other sites in the GC have shown a wider knowledge of the relevance of mangroves and related legislation because the approach of government authorities and the staff of non-governmental organizations and universities has occurred more often. Other marginality conditions, in addition to a low perception of the ecological significance of wetlands, may increase their vulnerability; however, as discussed by Ferraro, Hanauer, and Sims (2011), in other cases, such conditions are not necessarily associated with highly deforested areas. Hydrological changes in wetlands from Sinaloa have been occurring for decades, as main rivers have been dammed, forcing a lower freshwater inflow into coastal lagoons. Such conditions may be affecting both resident and migratory species, including mangroves and commercial species. Changes in freshwater inputs or frequent marine water intrusion into coastal lagoons may lead to significant ecological instabilities. Flores-Cárdenas *et al*. (2016) reported that salinity values during the annual cycle have changed in the last decades from dominant mixohaline to near euhaline conditions in Huizache-Caimanero, which derives from a more frequent communication with the adjacent sea. Such conditions may be affecting the early stages of salt-sensitive species like some penaeid shrimp species (*e.g.*, *Litopenaeus vannamei*), a species that predominates in artisanal shrimp captures in this lagoon. Coastal lagoons in Sinaloa are very vulnerable to salinization because of the dammed rivers, high evaporation rates, and more frequent communication with the sea. These conditions may cause significant damages to these ecosystems; for example, the construction of the Cuautla channel in 1971 in Marismas Nacionales (Nayarit) caused drastic hydrological changes that led to a large-scale mangrove mortality (Franco-Ochoa *et al*., 2012; Kovacs, Wang, and Blanco-Correa, 2001).

It is necessary to integrate all components of the ecosystem—in this case, for each coastal lagoon—including humans and their interests and needs to keep it healthy and productive (McLeod *et al*., 2005). As discussed in this contribution, mangroves in Sinaloa are highly vulnerable as multiple socioeconomic activities are performed within and along its boundaries, in addition to the impact of environmental stressors.

CONCLUSIONS

This study analyzed landscape metrics of mangrove ecosystems for five coastal lagoons from Sinaloa, Mexico. Mangrove cover did not improve in recent years in most cases; however, Ceuta showed an increase in recent years, and Huizache-Caimanero showed the lowest mangrove cover and highest deforestation rate. On the other hand, aquaculture farms increased in all lagoon systems during the $\sim$18 years, mainly in

Santa María-La Reforma. Additionally, marginality conditions of nearby established rural communities and a low perception of the relevance of ecosystem services of mangroves might be increasing their vulnerability. Nowadays, conservation of mangrove wetlands in Sinaloa involves a range of challenges, from governance frameworks, the urgent need to increase the staff of related institutions (*e.g*., CONANP) according to the spatial dimensions for each site, scientific research and monitoring, rehabilitation and restoration strategies, financing, and, particularly, the consideration of human dimensions in management programs.

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APPENDIX A

Marginality index and population for communities located in a 5-km radium from studied lagoons in Sinaloa, México.

Community	Lagoon	Marginality Index	Total Population
Agiabampo Uno[†]	Agiabampo	High	1929
Jitzámuri	Agiabampo	High	1259
El Hecho	Agiabampo	Medium	212
Bacorehuis	Agiabampo	High	1882
Poblado Número Cinco	Agiabampo	Low	2651
Agiabampo Número Dos (El Campito)[†]	Agiabampo	Medium	530
Navopatía[†]	Agiabampo	High	6
Costa Azul	Santa María-La Reforma	Low	1466
Valentín Gómez Farías (El Muerto)	Santa María-La Reforma	Low	368
Playa Colorada	Santa María-La Reforma	Low	878
La Reforma	Santa María-La Reforma	Low	6743
Santa María del Playón	Santa María-La Reforma	Medium	16
Doce de Octubre (La Sonrisa)	Santa María-La Reforma	Low	152
El Nuevo Ostional	Santa María-La Reforma	Medium	265
Los Algodones	Santa María-La Reforma	Very high	7
Dautillos	Santa María-La Reforma	Low	2109
Montelargo	Santa María-La Reforma	High	150
Yameto	Santa María-La Reforma	High	137
Casa Blanca (Ángeles Dos)	Santa María-La Reforma	Medium	417
Colonia Morelos (Pozole)	Santa María-La Reforma	High	67
El Conchal	Ceuta	High	507
Cospita	Ceuta	Medium	895
Heraclio Bernal	Ceuta	Medium	238
Laguna de Canachi	Ceuta	Medium	1081
Península de Villamoros	Ceuta	High	818
Soyatita (Cruz Segunda)	Ceuta	Low	309
La Espinita	Ceuta	Medium	88
Nicolás Bravo	Ceuta	Low	141
Pueblo Nuevo de Canachi (El Campito)	Ceuta	Medium	253
Colonia Loma Y Tecomate	Ceuta	High	98
El Tule	Ceuta	High	232
La Higuera	Ceuta	Medium	217
Soyatita	Ceuta	High	306
Ejido Culiacán (Culiacancito)	Ceuta	Medium	662
Campo Cachanilla	Ceuta	High	10
Campo la Paloma (Agrícola el Chaparral)	Ceuta	High	192
Campo Agrovo	Ceuta	High	36
Mazatlán	Estero de Urías	Very low	381,583
Barrón	Estero de Urías	Medium	1792
El Castillo	Estero de Urías	Low	2208
Los Gavilanes	Estero de Urías	Medium	43
El Zapote	Estero de Urías	Medium	181
La Guanera	Estero de Urías	High	23
Ampliación el Castillo	Estero de Urías	Medium	72
Ampliación el Zapote	Estero de Urías	Medium	204
Fraccionamiento los Ángeles	Estero de Urías	Low	6282
La Amapa	Huizache-Caimanero	Medium	255
La Amapa	Huizache-Caimanero	High	13
Ejido Gregorio Vázquez Moreno (San Joachín)	Huizache-Caimanero	Medium	874
La Guásima	Huizache-Caimanero	High	704
Los Pozos	Huizache-Caimanero	Medium	1110
Ejido Cajón Ojo de Agua Número Dos	Huizache-Caimanero	High	1750
Teodoro Beltrán (La Hacienda)	Huizache-Caimanero	Medium	676
Chametla	Huizache-Caimanero	Medium	1842
El Matadero	Huizache-Caimanero	Medium	718
Agua Verde	Huizache-Caimanero	High	4053
Ejido Francisco Villa (Las Garzas)	Huizache-Caimanero	High	172
Pozos Labrados	Huizache-Caimanero	High	135

[†]*These communities are located in Sonora state; however, they were counted as Agiabampo because they are located within a 5-km radius of the Agiabampo lagoon.*