Socio-environmental Value of Coastal Urban Wetlands in Veracruz, Mexico

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ABSTRACT

Coastal wetlands are among the most valuable ecosystems globally due to the ecosystem goods and services they provide to society. Cities are expanding, and the tendency is to encroach on wetlands filled in and built upon. When restored, urban wetlands produce many benefits for their inhabitants, but maintaining wetlands faces many challenges. However, to restore them, local people and their decision-makers must be involved. This paper focuses on the urban wetlands of the city of Veracruz: the dune lakes, Olmeca Lagoon, and Tembladeras, a freshwater marsh. A historical description of the area and its growth is given, as to how they became natural protected areas, and the state they are in now (social, biological, and water quality). This paper presents the socio-ecological interaction between human and ecological components, the values of its ecosystem services, and the actions and activities that can be developed to conserve these appreciated ecosystems.

RESUMEN

Los humedales costeros se encuentran entre los ecosistemas más importantes a nivel mundial debido a los bienes y servicios ecosistémicos que brindan a la sociedad. Las ciudades se están expandiendo y la tendencia es invadir los humedales, rellenándolos y edificar. Cuando se restauran, los humedales urbanos producen muchos beneficios para sus habitantes, pero su mantenimiento enfrenta diversos desafíos. Sin embargo, para restaurarlos, es necesario involucrar a la población local y a quienes toman las decisiones. Este artículo se centra en los humedales urbanos de la ciudad de Veracruz: los lagos interdunarios, la laguna Olmeca y Tembladeras, un pantano de agua dulce. Se proporciona una descripción histórica del área y su crecimiento, cómo se convirtieron en áreas naturales protegidas y el estado en el que se encuentran actualmente (social, biológico y de calidad del agua). Este artículo presenta la interacción socio-ecológica entre los componentes humanos y ecológicos, los valores de sus servicios ecosistémicos y las acciones y actividades que pueden desarrollarse para conservar estos valiosos ecosistemas.

INTRODUCTION

The Gulf of Mexico (GOM) is a geographic area with outstanding social, economic, and ecological importance due, among other things, to its influence on the three countries that share its border. There are five federal Mexican entities on its southern and western border. In the central part of the GOM —in the state of Veracruz, the mountain range called the Sierra Madre Oriental runs parallel to the coast. An extensive coastal plain is formed, along which rivers run down the extensive watersheds and drag a large amount of sediment, forming extensive dune fields (Tejeda-Martínez 2012). On the lower part of the watersheds, an intricate variety of coastal freshwater marshes, swamps, dune lakes, and mangroves are found (Moreno-Casasola 2016, Neri-Flores et al. 2019). The interaction of these ecosystems with human activities has given rise to both urban and rural coastal social-ecological systems. The city and port of Veracruz are an example of coastal social-ecological systems. The purpose of this paper is to emphasize the importance

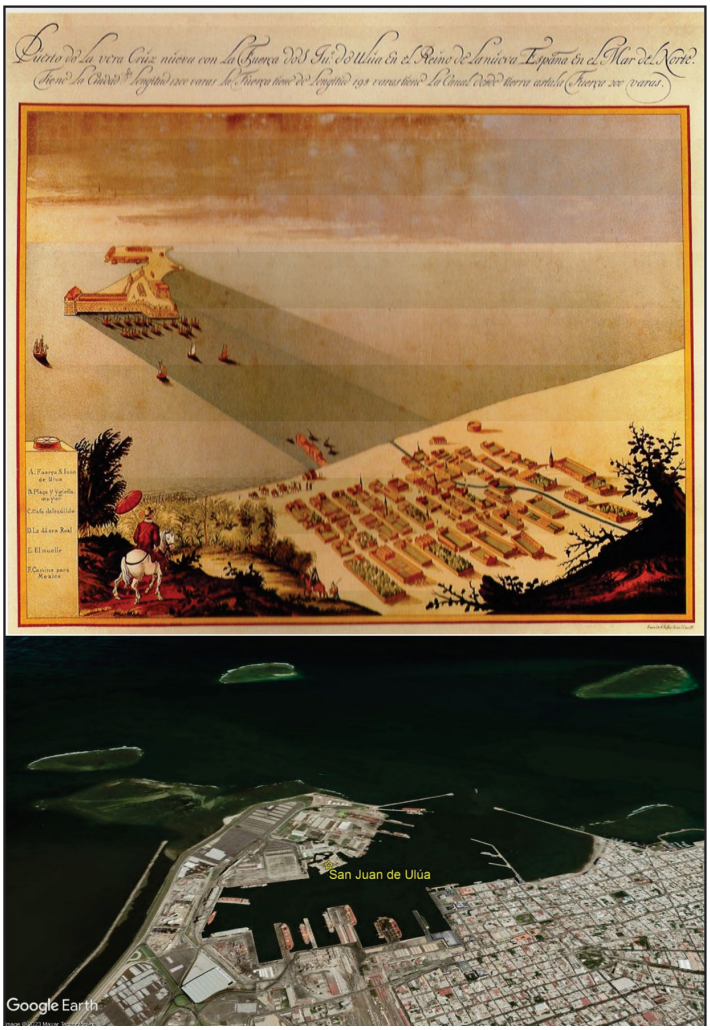

Figure 1. Image from the 16th Century showing the first constructions of the port of Veracruz. An island was used to build a fortress (San Juan de Ulúa) and served as a coastal protection together with the reef system (partly seen in the back in the Google image). Image Ruffoni (1907).

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of the Dune Lakes Natural Protected Area, which is made up of 33 urban dune lakes, to present the current situation of these freshwater coastal wetlands and its relation to Laguna Olmeca-Tembladeras Natural Protected Area, the socio-ecological interaction between human and ecological components, the values of its ecosystem services, as well as the actions and activities that can be developed as part of pilot projects that help to preserve them as urban wetlands.

HISTORICAL BACKGROUND

It was the first human settlement and port for the navigation route to Spain, founded by the arrival of the Spanish in the newly conquered territories (Cortés Hernández 2023). The final location of the city was determined mainly by the position of the island of San Juan de Ulúa, which generated a naturally protected bay and provided a security situation for the settlement, reinforced with the construction of a fortress (Aranda Sánchez 2015) (Figure 1). As a vital part of its defense system, a walled, fortified city was built to confront the pirates; this involved reproducing European models of military engineering and architecture (Aranda Sánchez 2015).

More importantly, because a small bay is formed in the area with a reef system in front —what is currently known as the Parque Nacional Sistema Arrecifal Veracruzano (PNSAV)—(Ortiz-Lozano et al. 2009), this still provides the ecosystem service of storm protection not only to the port and ship berth but also to the physical infrastructure such as homes and urban development against tropical storms and hurricanes (Burke et al. 2011). It also brings

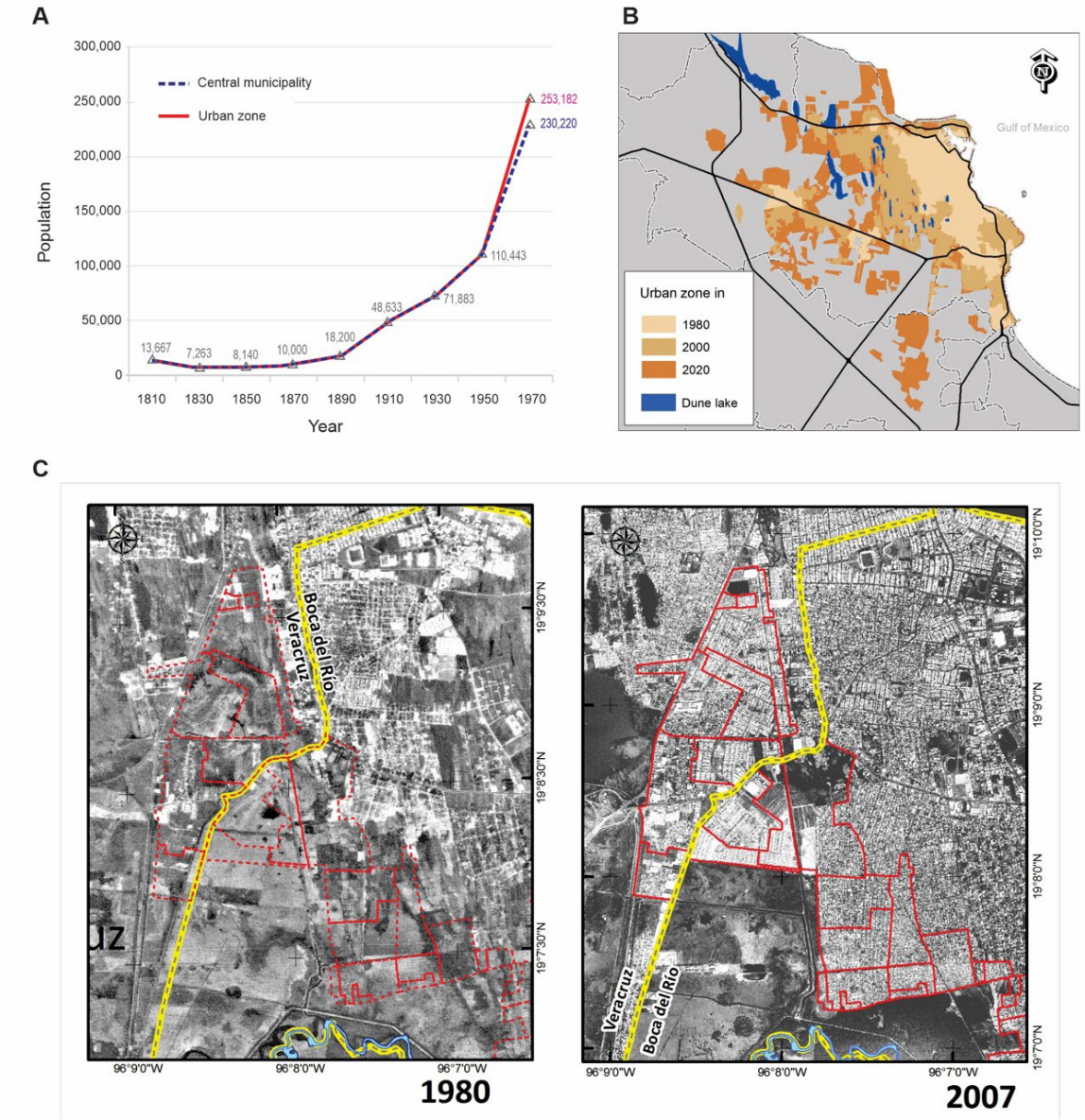


Figure 2. Information showing growth of Veracruz: A) Historical population growth in Veracruz and the metropolitan area 1810-1970 (Veracruz, Boca del Río-Medellín) (data from Padilla Galicia 2015). B) Expansion of the metropolitan area 1980, 2000 and 2010 (Own elaboration from Landsat images). C) Change in land use of coastal freshwater marshes (broadleaf marshes — popales, cattail marshes — tulares, and dune lakes) and mangroves. The map shows the digital orthophotos and the degree of urbanization (Basic Geostatistical Areas of the INEGI 2011). The red polygons represent the Basic Geostatistical Areas in 2010.

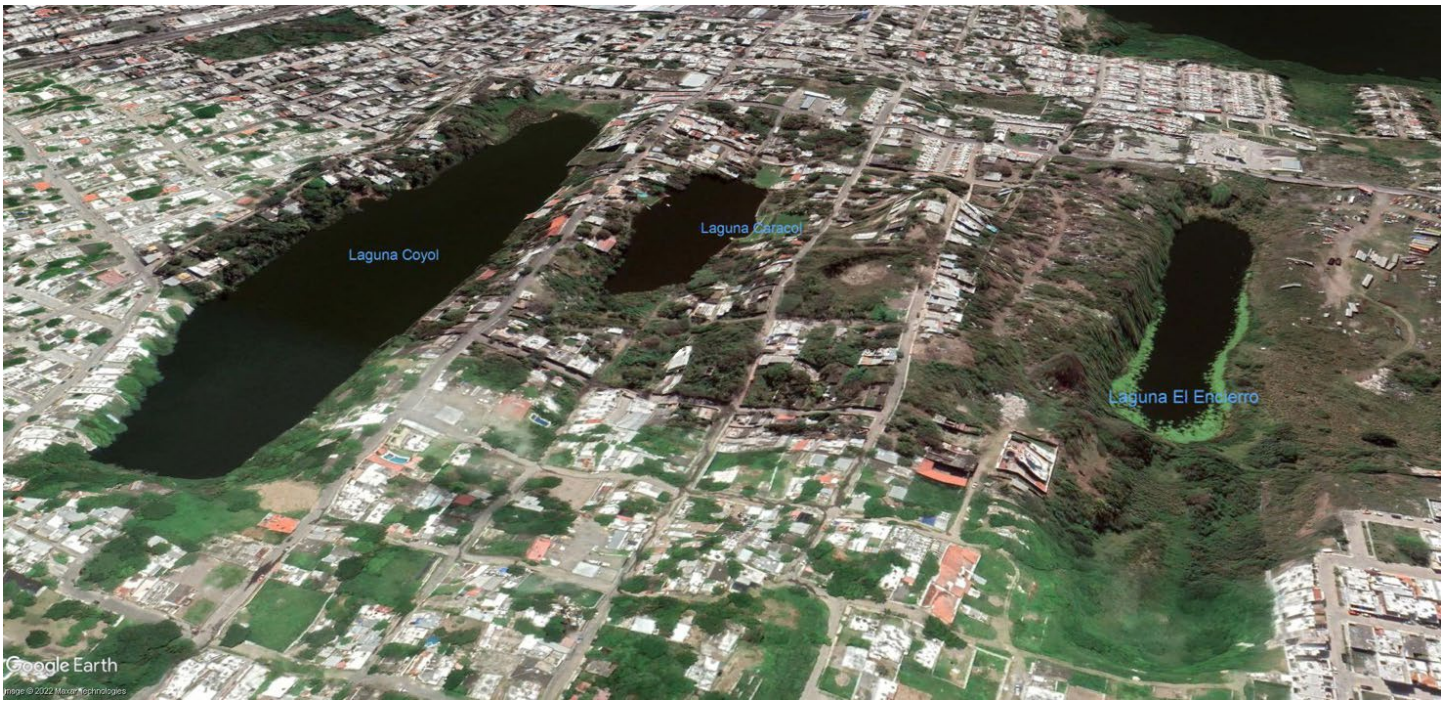


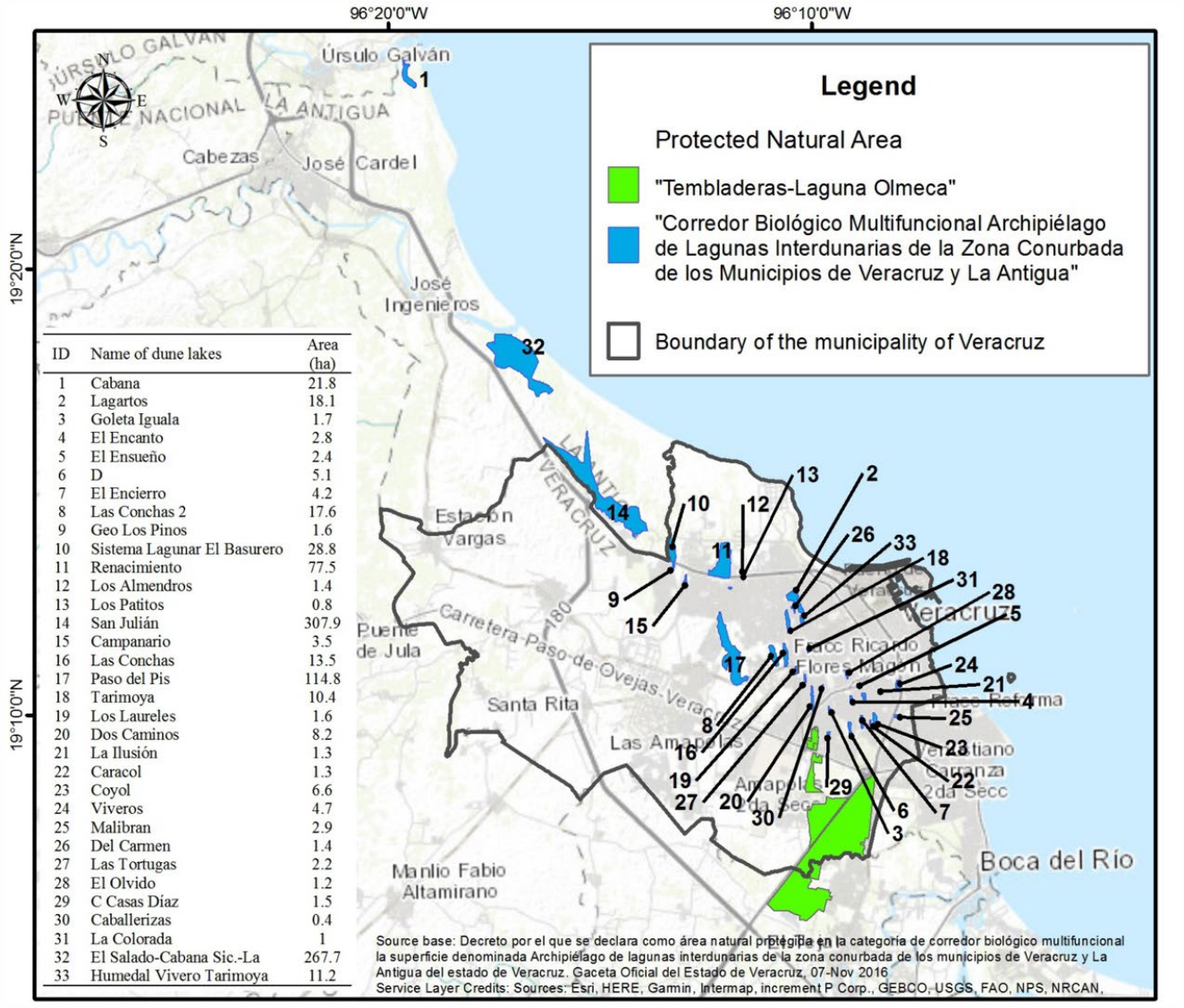
Figure 3. Dune lakes immersed in the city of Veracruz with much of the coastal dunes occupied by urban development. The lakes are present in the hollows at the base of the dunes. (Source: Google Earth). The Y axis is 3x.

protection from the strong winds produced by cold fronts, locally called "nortes", which consist of the movement of large masses of air whose speed ranges from 35 to 120 km/h. However, for the development of physical infrastructure, the dune system was not so favorable since it was an extension of mobile and semi-mobile parabolic and transverse dunes with dune depressions that flooded during the rainy season (Moreno-Casasola 2016), and some permanently surrounded by freshwater wetlands inland, as part of the Jamapa river floodplain (Neri-Flores et al. 2019).

Accelerated demographic growth began (5.0% annually) in the city and port of Veracruz in 1880, and in 1910-1930, it reached a population of 71,833 inhabitants (Padilla Galicia 2015) (Figure 2A). The linear urban growth towards the south of the city was due to the physiography of the coastline, which resulted in an elongated urban growth driven by the incipient development of the adjacent municipality of Boca del Río (Figure 2B). However, this growth occurred and continues (Figure 2C) on freshwater coastal dunes and wetlands, especially along the coastline, which modifies material and energy flow patterns and damages the dunes (Siemens et al. 2006), intending to create a flatter landscape. In this way, until the 1950s (Figure 2C), Veracruz was a traditional, compact city with low population density, an urban center corresponding to its historic center, and low demographic and economic growth. However, starting in the 1960s, there was accelerated demographic growth, which was reflected in the urbanization process until 1990 (Figure 2), especially in Boca del Río, which generated urban expansion on the dunes and interdune lakes between 1995-2010 (Vázquez-González et al. 2019).

Today, the port and city of Veracruz have spread over dunes and wetlands, constricting these natural environments (Figures 2C and 3). Jiménez-Orocio et al. (2015) estimated that the surface of coastal dunes in the municipality of Veracruz reached 13,000 ha. However, more than half of the dune surface is now urbanized land. Some stabilized transgressive dunes, parabolic dunes, and small frontal dunes remain. This model of urbanization has caused flooding from storm surges and rain from tropical storms. It is also caused by subsurface water from the Sierra Madre and can no longer emerge in many wetlands (Neri-Flores et al. 2019). Various events have occurred in the area that imply heavy losses for the population due to flooding. This was the case of Hurricane Karl in 2010, which caused flooding and economic losses due to household material assets of 150.85 million US$ (Vázquez-González et al. 2019).

Due to the socio-ecological importance of these urban wetlands, the government of the state of Veracruz decreed the Protected Natural Area "Reserva Ecológica -Laguna Olmeca Ecological Reserve" in 2011 (Gaceta-Oficial 2011) (hereafter called Laguna Olmeca and Tembladeras NPA), and in 2016 the Protected Natural Area "Corredor Biológico Multifuncional Archipiélago de Lagunas Interdunarias de la Zona Conurbada de los Municipios de Veracruz y La Antigua" five years later (Gaceta-Oficial 2016) including 33 lagoons (hereafter called Dune Lakes NPA). The latter comprises 33 dune lakes, of which 17 are part of the Ramsar 1450 site (Sistema de Lagunas Interdunarias de la Ciudad de Veracruz), which was decreed on February 2,



ID	Name of dune lakes	Area (ha)
1	Cabana	21.8
2	Lagartos	18.1
3	Goleta Iguala	1.7
4	El Encanto	2.8
5	El Ensueño	2.4
6	D	5.1
7	El Encierro	4.2
8	Las Conchas 2	17.6
9	Geo Los Pinos	1.6
10	Sistema Lagunar El Basurero	28.8
11	Renacimiento	77.5
12	Los Almendros	1.4
13	Los Patitos	0.8
14	San Julián	307.9
15	Campanario	3.5
16	Las Conchas	13.5
17	Paso del Pis	114.8
18	Tarimoya	10.4
19	Los Laureles	1.6
20	Dos Caminos	8.2
21	La Ilusión	1.3
22	Caracol	1.3
23	Coyol	6.6
24	Viveros	4.7
25	Malibran	2.9
26	Del Carmen	1.4
27	Las Tortugas	2.2
28	El Olvido	1.2
29	C Casas Díaz	1.5
30	Caballerizas	0.4
31	La Colorada	1
32	El Salado-Cabana Sic.-La	267.7
33	Humedal Vivero Tarimoya	11.2

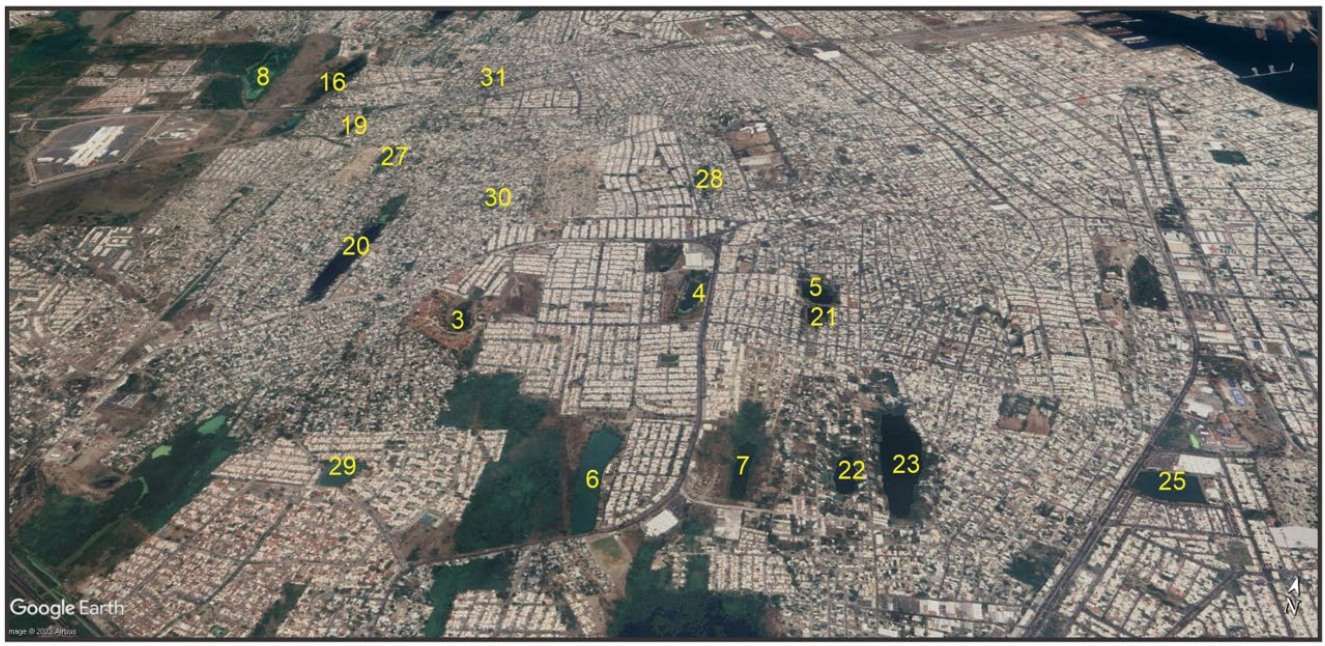


Figure 4. Map and view of Veracruz showing the Tembladeras-Laguna Olmeca Protected Natural Area and the location and name of the dune lakes that form part of the Dune Lakes Protected Natural Area (Corredor Biológico Multifuncional Archipiélago de Lagunas Interdunarias de la Zona Conurbada de los Municipios de Veracruz y La Antigua) and the Ramsar site. (Source: Google Earth).

2005, before the protected natural areas. Figure 4 shows a map of the area, a view of the city on a Google Earth image, and the names of the dune lakes. Its objective was to conserve the ecological state of the wetlands in order to maintain their functioning as interconnected hydrological vessels to reduce the impact of floods in the metropolitan area. Therefore, the ecosystem service of flood protection is vital in the area.

As can be seen in Figures 3 and 4, the dune lakes are immersed in the urban area and, in some cases, with a public space that separates them from the houses or private properties (i.e., Casas Díaz, El Encanto, El Ensueño, and Lagartos), and in others the urbanization reaches its shore (El Coyol, Tarimoya, and Dos Caminos). Despite the legal figure of the protected natural area and its management plan, there is little participation and collaboration between local governments (state and municipal governments), as well as incipient participation of citizens to maintain and improve the ecological conditions of lagoons to increase the quality of the environment and landscape.

There is also a published delimitation for each lake, that is, the perimeter of the water that is considered part of the protected natural area. However, the limit is at the water's edge in most cases, with very little space for developing recreation or environmental education infrastructure. Sometimes, there are spaces (a street or just a few meters) between the houses and the lake. These spaces allow floods to be cushioned in case of rising water and also allow recreational and/or educational use. However, these decisions must be made jointly with the inhabitants around them.

VERACRUZ URBAN WETLANDS TODAY

Assessment of the General State of the Dune Lakes and Laguna Olmeca

In 2004, the state of Veracruz and the municipality of Veracruz recognized their importance. The latter decided to incorporate them as part of the city's natural areas and worked with the neighbors to set limits to the growth and invasion of constructions on the lakes. They started formalizing streets in some of them to separate houses from the lakes, although at that time, the vision was more to convert them into parks and not urban natural lakes. Marlibran Lake still has a fountain with a water spout in the center. The state environmental authorities changed this perception and kept them as natural urban lakes.

Due to the recognized ecological and social importance of the dune lakes in the city, they were finally decreed a Natural Protected Area by the Government of Veracruz State in 2016. However, the delimitation of the perimeter only included the water body, and a buffer zone needs to be incorporated to protect and include critical zones that contribute to the maintenance of the ecological functions of dune lakes. Even so, this institutional effort continued to include the neighbors to convince them of their social and ecological importance. A Google Earth comparison of the urbanization around them in 2005 and 2022 showed that there has been no invasion of the lake borders. Through field verifications, we have confirmed that there are no illegal discharges of sewage in the lakes. These have been significant achievements. On the other hand, stormwaters have no management; they all flow into the dune lakes and finally into Laguna Olmeca, causing pollution and garbage accumulation.

Vegetation

It is described that in the depressions of coastal dune systems, wetter areas can be found where the flooding time is variable from a few weeks (humid slack) to permanent water forming dune lakes, which remain permanently flooded for at least more than six months of the year or permanently (Peralta Pelaez et al. 2014). In these bodies of water, especially on the margins and in the shallowest areas, wetlands are established: freshwater broadleaved marshes (popales), cattails marshes (tulares), floating vegetation, and swamps. Historical records indicate that up to 200 dune lakes were formed (Sarabia-Bueno 2014). Today there are 33 lakes whose size varies between 0.4 ha and 115 ha; most are very close to sea level. They are all part of the Dune Lakes NPA, but not all are part of the Ramsar site. In 2022, it was detected that several of them dried up since this year represented a set of very dry years in the area, a period that strongly impacted several of the lakes. In September 2023, they all had water.

In the dune lake wetlands one can still find floating vegetation (*Nymphoides indica, Nymphaea ampla, Salvinia* sp., and *Ceratophylum* sp.), submerged and emergent vegetation (*Typha domingensis, Phragmites communis, Paspalum* spp., *Thalia geniculata, Pluchea odorata, Cyperus articulatus, Phyla nodiflora, Sagittaria lancifolia* subsp. media, *Pontederia sagittata, Hydrocotyle umbellata, H. bonariensis*). Numerous bird species frequent these wetlands, including shore and aquatic birds (*Aechmophorus occidentalis* and *Egretta thula*) and semi-aquatic birds (*Fulica americana, Dendrocygna autumnalis, Ceryle torquata*, and *Mycteria americana*) (CONANP 2005; RAMSAR 2014). The wetlands are located on the route of the world's most significant migratory corridor of birds of prey with frequent key species such as *Falco peregrinus*, *Accipiter cooperi*, *Buteo platypterus, Pandion haliaetus*, and *Falco sparverius*.

In the Protected Natural Area of Tembladeras-Laguna Olmeca (Figure 4), the central wetland communities are the popal formed by Thalia geniculata, Pontederia sagittata, and Sagittaria lancifolia. Extensive patches of Typha domingensis are also present, forming dense stands associated with species such as *Cyperus articulatus, Cladium jamaicensis*, and *Ludwigia octovalvis*. There is also floating vegetation, with *Spirodela polyrrhiza, Pistia stratiotes*, and *Eichhornia crassipes*. Palm groves dominated by *Attalea liebmannii, Roystonea dunlapiana*, and *Sabal mexicana* oc-

Table 1. Physicochemical characteristics of the water of some dune lakes based on Sarabia-Bueno (2004).

	Tarimoya	La Colorada	Las Conchas	Los Laureles	Dos Caminos	El Encanto	El Enseño	La Ilusión	Caracol	El Coyol	Laguna D
Depth	71.80	173.25	146.00	114.17	197.17	132.83				248.20	138.00
Transparency	37.25	22.88	132.33	22.83	44.17	37.83	36.67	153.67	76.75	23.40	19.60
Temperature (“C)	22.92	19.35	18.70	23.10	23.87	22.03	21.38	18.17	20.15	21.82	438.78
pH	*7.88*	8.68	7.77	8.49	9.29	8.41	9.16	7.69	7.80	8.27	8.68
Salinity (ppm)	*0.346*	0.456	0.644	0.212	0.288	0.171	0.244	0.388	0.693	0.272	0.287
Oxygen saturation %	*237.20*	250.00	208.83	235.50	250.00	235.33	250.00	217.33	229.83	169.67	231.20
NO3 (mg/l)	*0.82*	36.88	15.74	1.06	0.79	0.94	1.46	1.05	1.34	8.44	2.32
NO2 (mg/l)	*0.00*	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	2.25	0.24
NH4 (mg/l)	*1.26*	0.51	0.22	1.83	144	1.35	0.37	0.17	0.21	1.43	6.45
P-PO4 (mg/l)	*0.86*	2.17	0.66	5.81	1.19	3.42	2.00	0.97	1.18	11.30	244.69
P_total (mg/l)	*7.71*	22.16	12.96	9.73	11.78	13.29	18.28	10.17	13.17	0.01	149.34

cupy rare patches. Other trees include *Salix humboldtiana* and *Ficus insipida*. Also, there is flooded grassland promoted by anthropogenic activities such as cattle ranching, which introduced grass species *Cynodon plectostachyus* and *Brachiaria mutica* that tolerate flooding (UNAM 2011).

Water Quality

The salinity indicated that all the lakes are freshwater (oligohaline). The pH fluctuated between 7.7 and 9.2. The oxygen saturation values are above 160% (Table 1). Nutrient values are variable, and there is no clear trend, except in Lake D, where water from the treatment plant is discharged. There is no more recent published water quality data.

Vidal Álvarez et al. (2022) sampled the water in Laguna Olmeca to measure fecal coliforms, biochemical oxygen demand, chemical oxygen demand, total phosphorous, total nitrogen, pH, total dissolved solids, temperature, and turbidity for producing a Water Quality Index (Brown y McCleland 1973). The value obtained was 35.02 (excessively polluted), which is a poor value, considering that the scale ranges from 0 to 100, with the latter indicating good quality. More critically, Sarabia-Bueno (2004) calculated this same index in 2004 and reported a 41.05 (heavily contaminated) value. A comparison of the two values shows a drop in water quality over two decades. There are several reasons to explain this. Over time, some dune lakes were connected through superficial channels to help drain the city during flooding, and these waters are discharged into Laguna Olmeca. The Lagoon has different discharge points for water with a high concentration of nutrients. The origin of the bacteriological contamination of the Olmeca Lagoon is mainly attributed to the irregular discharges of domestic wastewater from the human settlements around it, as well as the inefficient treatment of the wastewater treatment plant located northeast of the Lagoon, which discharges its effluents into it, the open dump on one side of the Lagoon (Vidal Álvarez et al. 2022); storm waters sweep many city areas, contaminate dune lakes and their channels, and end up in Laguna Olmeca. All these problems have not been resolved for more than fifteen years; on the contrary, they have worsened.

Perceptions of Ecosystem Services

Torres Juárez (2022) surveyed 125 persons living in the locality of four dune lakes and Laguna Olmeca. The answers showed that many people consider it a suitable place to live with values for social and family recreation. They also consider that their house increases in value by being in front of a lake or lagoon. As ecosystem services, they recognized beauty and landscape, biodiversity, the ability to provide habitat and protection to plant and animal species, and improved air quality and temperature. They consider them a source of activities (children’s playground, neighbors’ meetings, among others), relaxation, space for sports, flood control, and, to a lesser extent, fishing and obtaining products to market.

In the year 2020, the German Society for International Cooperation (GIZ) initiated the project titled “Sustainable Development in Urban Coastal Regions through the Integration of Ecosystem Services and Biodiversity (BIOCITIS).” This project identified the importance of conservation and restoration measures for coastal wetlands. One of the wetland systems selected for the start of this project was the Dune Lakes PNA. As a component of the proj-

Figure 5. Dune lakes — El Ensueño (right side) and La Ilusión (left side) — have small parks on both extremes and a small green public area surrounding them; these lakes are connected. Photography G. Sánchez Vigil.

Figure 6. Dune lake Tarimoya, has a lower urban density than other lakes; floating mat of Water Hyacinth (*Eichhornia crassipes*) in foreground. Photography G. Sánchez Vigil.

ect's activities, in 2022, interviews and workshops were conducted with key stakeholders (academics and decision-makers) from the municipal, state, and federal levels. The main strengths and threats to conserving these wetlands were identified in these workshops, and suggestions were generated to work together on conservation. During these workshops, it was recognized that wetlands' leading ecosystem service is protection against flooding. Some lakes are used as recreation spaces and food sources (hook fishing). Despite their protected status, these spaces need adequate surveillance, as debris, garbage, or dead animals are constantly deposited. Furthermore, the lakes are impacted by pollution from storm runoff. During the rainy season, stormwater carries solid waste, grease from mechanical workshops, and, in some cases, wastewater from irregular settlements near these lakes, which consist of building houses in places that are not permitted because of the risk of flooding (CENAPRED 2017, González-Terrazas et al. 2019) or because they are considered territorial reserves by both state and municipal legislation. There is a consensus that requires participatory strategic planning focused on the conservation of wetlands generated by the inhabitants of the lakes, along with other key actors, such as academics and decision-makers. Figures 5 and 6 show some pictures of the dune lakes.

Ecosystem Services

Ecosystem services (ES) are the benefits that the human population obtains directly or indirectly from the functions of an ecosystem (Costanza et al. 1997, Daily et al. 1997). They were classified and detailed according to their ecological, cultural, social, and economic value by de Groot et al. (2002). However, the MEA (2005) linked them to the different facets of human well-being depending on the culture, society, and the type of use (direct or indirect) of the goods and ES. In recent years, they have acquired great attention. For example, Costanza et al. (1997) conducted the first economic evaluation of ecosystems and biomes worldwide and by type of ecosystem service, and mangroves and freshwater wetlands had a total value of 2.3 and US$4.5 trillion/yr., respectively. Almost 20 years later, Costanza et al. (2014) carried out the same exercise to analyze the change in the value of ecosystems and biomes based on the ecosystem services offered and land use change; thus, mangroves and freshwater wetlands lost 0.5 and US$2.8 trillion/yr.

We evaluated and measured some ecosystem services in different types of wetlands (mangroves, swamps, marshes, and flooded grasslands, which formerly were freshwater wetlands). The services include carbon storage (Hernández and Moreno-Casasola 2018), plant and animal resources used by local communities (González-Marín et al. 2012, 2017), water storage in the soil (Campos et al. 2011), and fisheries dependent on different types of wetlands (Vázquez-Gonzalez et al. 2015). Likewise, a first economic valuation exercise was conducted on wetland ecosystem supply services based on the results obtained in these ecosystems, including dunes (Moreno-Casasola 2016, Vázquez-González et al. 2016). The highest monetary value of ecosystem services was the control and reduction of floods in urban areas, with 155,629 $US/ha for 2007 prices, while the lowest was the payment for the conservation of coastal wetlands, with 26 $US/ha for 2007 prices (Vázquez-González et al. 2016). In the case of Laguna Olmeca and Tembladeras, some of these values can be extrapolated, for example, flood control and reduction, estimating values around 100 and US$150 thousand/ha/ in 2007 prices (see Vázquez-González et al. 2019). This value can serve decision-makers to reinforce the importance of these urban wetlands.

WHAT WE'VE LEARNED AND WHAT'S NEXT

Through the years, we have developed a general view of the urban problems, better understand the different types of

wetlands, have worked on some of the causes of flooding to understand the subterranean water connectivity that links all the urban wetlands, and have set the scenario for getting involved with different stakeholders. We have developed relationships with the local government, the residents around some of the lakes, the schools in these areas, and the academic groups of various institutions.

This year, we began more intense social and environmental work in two dune lakes: El Coyol and Laguna D. These experiences and analysis on evaluation and economic valuation of ecosystem services are being adapted to these two lakes. We have finished 150 surveys with residents to understand and consider the neighbor´s perceptions and expectations. These results will be the basis for workshops with the local residents to ensure they form an essential part of the proposal of an environmental management plan for each lake. This information, coupled with the environmental services assessment, will help the county define strategies to build the bases of different payments for ecosystem services, environmental compensation, and the location of priority restoration areas for the recovery of ecosystem services. More importantly, the results can be incorporated into the programs and management plans of the Dune Lake Protected Natural Area to redirect the desired urban and peri-urban development. It should be based on the conception of a socio-ecological system, with strong participation in the residents' long-term involvement, stressing the importance of urban development with sound environmental planning.

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