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Carolina Rojas Quezada *Editor*

# Urban Wetlands in Latin America

## Protection, Conservation, Innovation, Restoration, and Community for Sustainable and Water Sensitive Cities

Springer

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# Urban Wetlands for Sustainable Cities in Mexico

Ina Falfán and Luis Zambrano

## Contents



**Abstract**

As a hydrologically diverse country, Mexico has thousands of natural and artificial wetlands throughout its territory. Of this large number of wetlands, 144 are included in the Ramsar List, and four of them correspond to wetlands embedded in urban areas. For centuries, there has been a severe depletion of aquatic systems in Mexico; however, there are still many relevant wetlands in urban areas, some of which are currently protected by Mexican laws. Here we focused on continental and coastal lacustrine and estuarine systems for the sustainability of cities. We outlined the importance as cases of conservation in Mexico of two Ramsar sites, the 'Xochimilco and San Gregorio' wetland in Mexico City and the 'Interdunary Lagoons System in the city of Veracruz', and four non-Ramsar sites, 'La Laguna de las Ilusiones' in Villahermosa; 'Laguna La Escondida' in Reynosa; 'El Estero El Salado' in Puerto Vallarta; and the artificial wetland 'El Palote' dam, in León. These urban wetlands support populations of endemic, vulnerable, endangered, and/or critically endangered species of flora and fauna, and, at the same time, they are essential spaces for leisure and recreational activities. However, even with their conservation status, these systems are under intense urban pressure, being necessary to develop better restoration and management strategies for land and biodiversity. The long-term conservation of urban wetlands in Mexico and the ecosystem services they provide to citizens, as well as improving the resilience and sustainability of cities, still require the combined efforts of people and government.

**Keywords**

Aquatic ecosystems · Urban lakes · Urban lagoons · Urban water bodies · Wetlands benefits · Natural protected areas

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## 1 Introduction

Worldwide, wetlands are part of urban systems mainly due to two different processes. On the one hand, for centuries, humans have settled near or around wetlands and water bodies to survive and thrive, as these provided food, water, and other raw materials (e.g., fuel, fiber) and a way to dispose of people's waste. Over time, wetlands were embedded by the growing urban centers and often modified so that people could continue to use them for washing clothes, as rainwater storage, as garbage pits and sewers, and as communication and transportation routes (Ghermandi et al. 2010; Molina-Prieto and Rubio 2016; Stefanakis et al. 2014). On the other hand, once the city was/is fully established, the creation of wetlands to provide a wide range of services to people has become a relatively common practice (Stefanakis et al. 2014; White et al. 2020).

Urban wetlands include a wide range of permanent and temporary natural and artificial systems within cities, such as coastal zones, lakes, lagoons, rivers, streams, ponds, estuaries, marshes, tidal flats, peatlands, mangroves, canals, drains, reservoirs, ponds, and stormwater treatment areas (Alikhani et al. 2021; Forman 2014; Haase 2015). However, while natural wetlands are declining globally, artificial ones (generally smaller in size) have increased at the same scale (MEA 2005; Davidson 2014; Darrah et al. 2019; Birch et al. 2022), a trend that is replicated in Latin America (Darrah et al. 2019). Approximately 62% of 6,968,452 ha of natural wetlands in Mexico have been lost for several reasons (Landgrave and Moreno 2012; Moreno 2008). However, within a particular historical logic of desiccating natural wetlands and constructing artificial ones is that, for example, more than 50% of 1834 lakes, lagoons, and other confined water bodies in the 145 most populated Mexican cities are of artificial origin nationwide (Falfán and Zambrano 2023).

Wetlands in urban areas are valuable because of the benefits they provide to people, wildlife, and cities. These benefits, derived from their structure and functions, include fish and fiber supply, water supply, water purification, climate regulation, flood regulation, coastal protection, recreation, and tourism (Alikhani et al. 2021; Ampatzidis and Kershaw 2020; Haase 2015; MEA 2005). Through interaction with natural and artificial wetlands, people benefit their physical, mental, and emotional health and quality of life (Johansson et al. 2019; White et al. 2020). Urban wetlands provide habitat and refuge for aquatic, semiaquatic, and terrestrial wildlife groups (native and exotic) such as birds (including migratory), amphibians, reptiles, fishes, and mammals (Almazán-Núñez and Hinterholzer-Rodríguez 2010; Ramírez-Jiménez et al. 2017; Rueda et al. 2017). Within an appropriate management and planning framework, urban wetlands can help maintain the connectivity of ecosystems fragmented by urbanization, thus providing wildlife corridors (Dallimer et al. 2012). Through urban wetlands system, the individuals of the different species can move from one place to another in search of suitable conditions for their survival, thus contributing to the conservation of species diversity in the fragments and the wetlands themselves (Lee et al. 2022; Yang et al. 2022).

While urban wetlands can contribute to the resilience and sustainability of cities by providing services, they are also vulnerable spaces. Namely, when they cause annoyances or disservices, such as the presence of mosquitoes, bad smells, or flooding, and are therefore perceived as wastelands, the tendency is to disappear/desiccate them to convert them to other urban land uses (Forman 2014; Ibrahim et al. 2012; Poó 2012). Furthermore, they are the first that receive the negative effects of urbanization, urban lifestyle, and urban metabolism, such as polluted discharge water from industries and households, loss of area due to garbage, and the presence of exotic and invasive species (Birch and McCaskie 1999; Mancini et al. 2012; Schueler and Simpson 2001). However, in the current global climate change, urban wetlands, along with green spaces, can be considered part of nature-based solutions aiming to mitigate its adverse effects on cities (Cui et al. 2021; Haase 2017; MEA 2005).

Mexico is ecologically, climatically, geomorphologically, and hydrologically diverse, which has favored the presence of thousands of natural and artificial wetlands throughout its territory,

including those in urban areas (Falfán and Zambrano 2023; Ortiz-Arrona et al. 2022; Thornhill et al. 2022). Of these thousands, 144 are Ramsar-listed (CW 2023a), and only four correspond to urban wetlands, namely, Ramsar-listed wetlands in urban areas (CW 2023b). However, no Mexican city is accredited as a Ramsar Wetland City, which is an accreditation, different from the Ramsar List, granted in 2018 and 2022 to cities located near and dependent on wetlands of international importance to highlight and strengthen their conservation, wise use, and sustainable socioeconomic benefits for local people (CW 2023c). Mexican public policies and legal frameworks have favored the establishment of some urban wetlands as natural protected areas (NPAs), mainly of state attribution, recognizing them for their ecological, ecosystem, and conservation value, as well as places for tourism and recreation (GEJ 2020; Palacios and Castillón 2013). NPAs constitute an environmental policy instrument with a broader legal definition for the conservation of biodiversity (CONANP 2023). Here we describe some study cases of protection and conservation of urban wetlands, outlining their processes, why they are essential for conservation, and how these different types of Mexican wetlands favor the sustainability and resilience of the cities where they are located.

## 2 Methods

We focused on continental and coastal lacustrine and estuarine systems for the sustainability of cities. We reviewed and outlined the importance, as cases of conservation in Mexico, of two Ramsar sites, the 'Xochimilco and San Gregorio' wetland in Mexico City and the 'Interdunary Lagoons System in the city of Veracruz', and four non-Ramsar sites, two lagoons; 'Las Ilusiones' in Villahermosa and 'La Escondida' in Reynosa, one estuary; 'El Salado' in Puerto Vallarta, and the artificial wetland; 'El Palote' dam in León (Figs. 1 and 2). All these urban wetlands are declared NPAs with management plans (Table 1).


**Fig. 1** Location of described Mexican urban wetlands

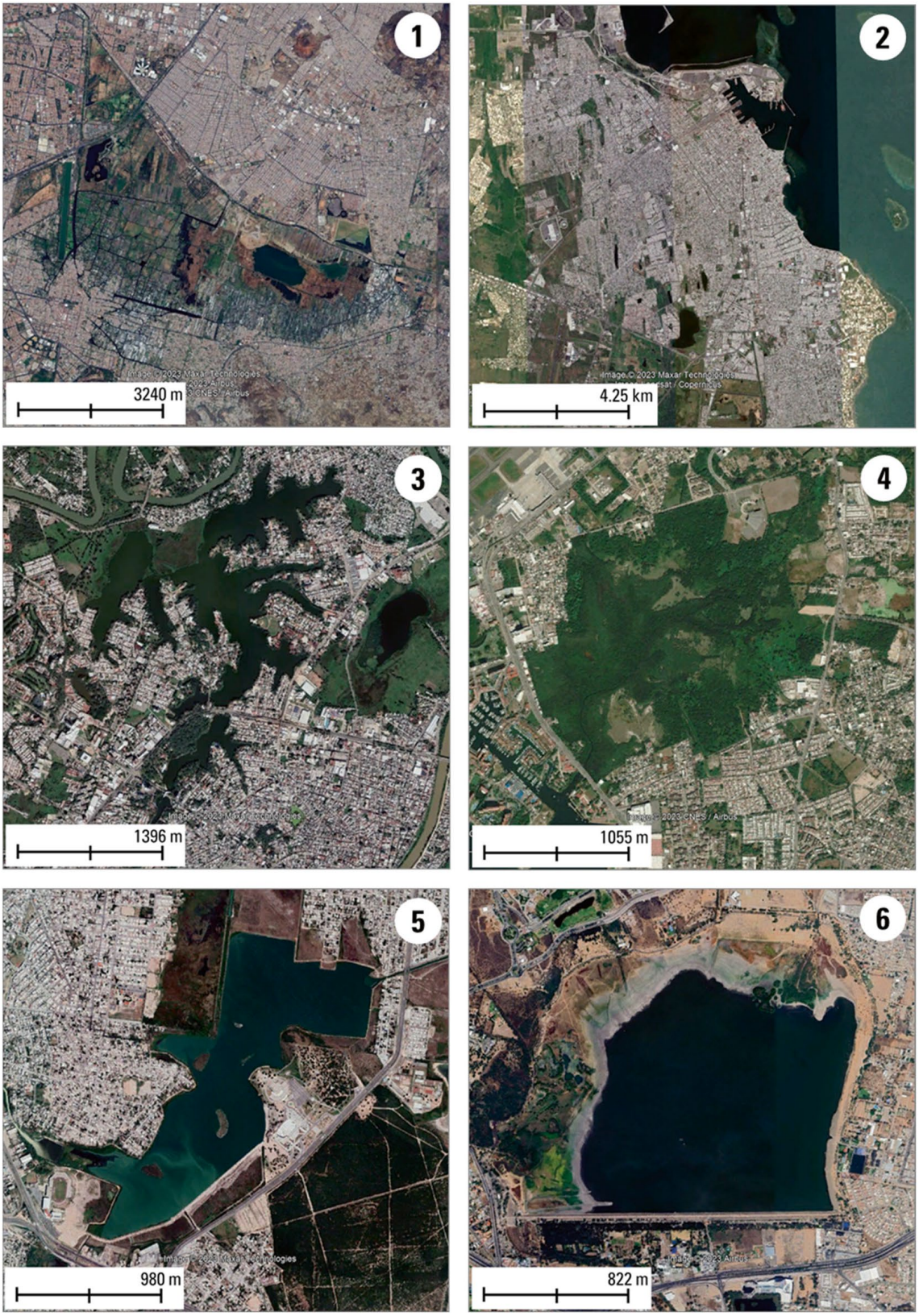


**Fig. 2** Views in Google Earth of described Mexican urban wetlands. **1**: Xochimilco and San Gregorio wetland, date: 04/2023, @ 2023 Maxar Technologies, @ 2023 Airbus, @ 2023 CNES/Airbus. **2**: Interdunary Lagoons System of Veracruz, date: 02/2021, @ 2023 Maxar Technologies, Landsat/Copernicus. **3**: Las Ilusiones lagoon, date 04/2022, @ 2023 Maxar Technologies. **4**: El Salado estuary, date: 11/2020, @ 2023 CNES/Airbus. **5**: La Escondida lagoon, date 05/2022, @ Maxar Technologies. **6**: El Palote dam, date: 04/2023, @ 2023 Airbus

**Table 1** Mexican urban wetlands information related to their condition as NPAs

| Urban wetland (Year declared as state NPA) | NPA category | NPA conservation subprograms | Services provided by the urban wetland |
|---|---|---|---|
| 1. Xochimilco and San Gregorio wetland (1992) | Zone subject to ecological conservation | Protection<br>Hydraulic management<br>Ecological restoration<br>Productive use<br>Regulation of recreational, sports, and government activities<br>Research, monitoring, and evaluation<br>Community participation<br>Institutional coordination<br>Administration | Habitat for endemic, native, and endangered species<br>Preservation of remnant ecosystems and wetlands<br>Preservation of an ancient system of production and cultural heritage<br>Water storage and filtration, aquifer recharge and discharge, flood prevention<br>Water for agricultural and urban use<br>Carbon sequestration, biomass export, and climate regulation<br>Tourism, recreation, sports |
| 2. Interdunary Lagoons System in the city of Veracruz (2016) | Multifunctional biological corridor | Protection<br>Management<br>Restoration<br>Knowledge<br>Culture<br>Administration | Preservation of remnant ecosystems<br>Habitat for endemic, native, and endangered species<br>Groundwater recharge<br>Sediment retention, microclimate regulation<br>Water filtration and storage, flood protection<br>Recreation, educational values, and social interaction<br>Aesthetic values and higher capital gain of neighborhoods |
| 3. Las Ilusiones lagoon (1995) | Ecological reserve | Protection<br>Management<br>Restoration<br>Knowledge<br>Culture<br>Administration | Habitat for endemic, native, and endangered species<br>Carbon sequestration, water flow regulation, and microclimate regulation<br>City's identity<br>Aesthetic values<br>Tourism, culture, and recreation<br>Educational values |
| 4. El Salado estuary (2000) | Ecological conservation zone | Protection and surveillance<br>Interpretation and environmental education<br>Research, monitoring, and scientific cooperation<br>Institutional cooperation, extension, and collaboration<br>Natural resources management<br>Construction and maintenance | Preservation of remnant and critical ecosystems<br>Habitat for endemic, native, and endangered species<br>Water storage and filtration, flood prevention<br>Protection against natural hazards and infrastructure failures<br>Carbon sequestration<br>Educational values and recreation<br>Tourism |
| 5. La Escondida lagoon (1997) | Urban Park | Protection<br>Knowledge<br>Management<br>Restoration<br>Culture<br>Administration | Preservation of remnant ecosystems<br>Habitat for endemic, native, and endangered species<br>Water flow regulation and water storage<br>Water for urban use<br>Recreation, sports, and tourism<br>Educational values |
| 6. El Palote dam (2000) | Ecological park | Natural resources management<br>Environmental education and public use<br>Research and monitoring<br>Administration and surveillance | Habitat for endemic, native, and endangered species<br>Water flow regulation and water retention<br>Water for urban use<br>Recreation<br>Educational values |

A general panorama of the paths and ways of conservation of urban wetlands in Mexico and how these spaces contribute to sustainable Mexican cities in this descriptive study is based on a literature review and synthesis of the information found. We use information from publicly available sources such as hemerographical, institutional, and tourism websites, NPA decrees, and management programs.

## 3 Results

### 3.1 Ramsar Sites

Of the thousands of natural and artificial wetlands in Mexico, to 2023, 144 are included in the Ramsar List (CW 2023a). We address two of the four Ramsar-listed urban wetlands: The Xochimilco and San Gregorio Atlapulco Ejidos Lake System in Mexico City and the Interdunary Lagoons System in the city of Veracruz (CW 2023b).

#### 3.1.1 Xochimilco and San Gregorio Wetland in Mexico City

The Xochimilco and San Gregorio wetland in Mexico City has been a Ramsar site since 2004 covering 2657 ha (CW 2023a). It has been a UNESCO Cultural and Natural World Heritage since 1987 (UNESCO 2023) and an FAO Globally Important Agricultural Heritage System since 2017 (FAO 2017). It is also an NPA by the local government since 1992 with the category of Zone Subject to Ecological Conservation (GDF 2006). All these recognitions for this unique wetland are because of its natural and social history. The broadest objective of the wetland as an NPA is to conserve the natural resources of the ecosystem and the cultural landscape through the integral management of these same resources and the revaluation of pre-Hispanic production techniques (GDF 2006).

Xochimilco and San Gregorio represent a 2% remnant of the system of five ancient lakes over which Mexico City and other settlements are established (Zambrano et al. 2020). Present-day Mexico City was founded centuries ago by indigenous people who settled on a peninsula in the central part of the lakes, using the southern part for food production in the chinampas (Poó 2012; Zambrano et al. 2020). Chinampas is a production system that is still practiced in this wetland nowadays. Producers cultivate ornate flowers and vegetables for subsistence and local sale (González 2019). Some of them are transitioning to more agroecological forms of production that include the rehabilitation of native fauna and flora in Xochimilco and San Gregorio (Figueroa et al. 2022; LRE-UNAM 2023).

The chinampas system increased the number of habitats and biodiversity in Xochimilco, being home to native and endemic, terrestrial, riparian, aquatic, and subaquatic species of flora (halophytic vegetation, tulars) and fauna (fishes, reptiles, amphibians, birds, mammals), several of which are in some category of risk according to official Mexican standards (GDF 2006; Ramsar 2004a; Zambrano et al. 2020). The most emblematic and charismatic species in this system is the axolotl salamander *Ambystoma mexicanum*, a species threatened with extinction due to the loss and degradation of its habitat, as well as the introduction of invasive non-native species that pose a direct threat to the axolotl population (Zambrano and Rojas 2021; Zambrano et al. 2020). Because of its biological, ecological, and conservation values, the axolotl is used as a flagship species for the restoration of the site (Zambrano et al. 2020).

This NPA is also an important tourist place for sports, recreation, and leisure activities, visited annually mainly by local tourists, with the positive and negative impacts of this productive activity in the wetland system. One of the proposals for tourism in this area is the transition to conservation tourism and gastronomic tourism, aiming to act with ecological awareness and conserve the integrity of the wetland (Vázquez-Medina et al. 2023). At the same time, Xochimilco and San Gregorio, a complex water system of ~40 km$^2$ of artificial channels, small lagoons, and temporary wetlands transitioning between rural and urban areas (Contreras et al. 2009), provides ecosystem services such as carbon sequestration, flood prevention, aquifer recharge and discharge, biomass

export, and climate regulation (Castelán et al. 2015; GDF 2006; Zambrano and Rojas 2021).

However, the system is far from ideal, being polluted and eutrophicated because of anthropic activities such as domestic wastewater, agrochemicals use, and solid waste (GDF 2006), so it is necessary to understand this aquatic environment as a socioecological system (Zambrano and Rojas 2021). People live in and actively participate in this natural yet highly transformed system, the reason why are essential for the protection, restoration, and long-term conservation of Xochimilco and its biological and cultural diversity for their own benefit and that of Mexico City in general (Zambrano and Rojas 2021; Zambrano et al. 2020).

### 3.1.2 The Interdunary Lagoons System in the City of Veracruz

The Interdunary Lagoons System in the city of Veracruz was designated as a Ramsar site on 2 February 2005, with 141 ha (CW 2023a). It is part of a larger NPA: The Multifunctional Biological Corridor Archipelago of Interdunary Lagoons in the Urban Area of the Municipalities of Veracruz and La Antigua, Ver., of state attribution, decreed in November 2016 (GEV 2016). While the Archipelago is composed of 33 urban, semiurban, and rural lagoons, only eighteen correspond to the Ramsar site and are embedded and distributed in the urban matrix of the city (GEV 2018; Ramsar 2004b).

The system consists of lagoons from 0.52 up to 60.21 ha, corresponding to the coastal dune ecosystem of Veracruz, rare in the rest of the country and therefore of exceptional regional value (GEV 2016; Peralta-Peláez et al. 2019). These lagoons are a remnant of possibly more than 200 that existed in the region, many of which disappeared with urban and population growth (Cruz 2005). They provide nesting and resting habitats for species of shorebirds and waterfowl, local and migratory, and are on the route of the world's largest migratory corridor of raptors (Cruz 2005; Ramsar 2004b). The vegetation in the lagoons is composed of floating and hydrophyte species, tulars, typhals, and popals (GEV 2016; Ramsar 2004b).

These lagoons provide ecosystem services such as groundwater recharge, sediment retention, water quality maintenance, microclimate regulation, water storage, and flood protection for urban areas. Located in low to high-density habitational areas, they are used for recreational activities, environmental education, and meeting places for social interaction between neighbors and for the interaction of the people with nature. As places with a high aesthetic value, for some lagoons, the land in nearby neighborhoods has a higher capital gain (GEV 2016; Ramsar 2004b). In some lagoons, tilapia was introduced for subsistence fishing (Peralta-Peláez et al. 2019; Ramsar 2004b). However, after becoming an NPA, fishing is not allowed in the lagoons corresponding to the restoration zone (GEV 2018). Nevertheless, fishing occurs, causing irregular settlements and damage to wildlife (Ruiz 2023; Serrano 2022).

Because of pressures such as illegal human settlements, domestic water, and waste discharges, urban lagoons are also at constant risk of reduction and total desiccation (GEV 2016; Ramsar 2004b), are deteriorated, and all of them have some degree of pollution, eutrophication, clogging, and general degradation (GEV 2016; Peralta-Peláez et al. 2019). The leading causes of the deterioration of the Interdunary Lagoons System include the lack of knowledge about their functions and services, the lack of environmental education, and the lack of surveillance of these water bodies by decision-makers and the general population (GEV 2016; Ramsar 2004b).

However, part of the population, especially those living near the lagoons, recognizes their benefits and services, is interested in their conservation, and is even willing to pay for the conservation of the lagoons and their integrity as a system (Torres 2022). Furthermore, desilting, construction of walkways on the banks for recreational purposes, drainage construction to prevent sewage discharges, reforestation with native species, and maintenance and cleaning in general, have been carried out (GEV 2016; Ramsar 2004b). Such efforts must be continuous and include monitoring the evolution of each lagoon and the system as a whole (Torres 2022).

## 3.2 Non-Ramsar Sites

In Mexico, there are still many relevant urban wetlands that could meet some of the Ramsar criteria as they support vulnerable, endangered, or critically endangered species, or threatened ecological communities, support plant and/or animal species when they are in a critical stage of their biological cycle and provide them with a refuge when they are in adverse conditions (CW 2023d). These wetlands also provide benefits and services to the people and the cities they are located (Table 1).

### 3.2.1 'Laguna de las Ilusiones' in Villahermosa, Tabasco

The Laguna de las Ilusiones has been an NPA since February 1995, with the category of state Ecological Reserve (GET 1995). Extended over 259 ha, it is part of a more extensive system of urban lagoons. However, it is the city's most important and largest natural one (GET 2019; Rodríguez et al. 1997). Its constitution as an NPA is to protect, conserve, and restore the natural ecosystems of Tabasco, as well as to provide spaces for recreation, environmental education, use of natural resources, and ecological research (GET 2019).

The protected vegetation, including a 10 m buffer from the lagoon, is hydrophyte, riparian vegetation, secondary vegetation, grasslands, and palm groves (GET 2019), which provide refuge and food for aquatic, semiaquatic, and terrestrial species that thrive in the city. The two most emblematic species inhabiting the natural lagoon are the manatee (*Trichechus manatus*—at risk of extinction), with an isolated wild population, and the Morelet's crocodile (*Crocodylus moreletii*—special protection), with possible reproductive problems (Pérez-Garduza et al. 2023; Rueda et al. 2017). Other no less important wildlife groups are fishes, turtles, birds, and mammals such as bats and otters, including species with some conservation status (GET 2019; Hidalgo et al. 2019).

Recognized as an element of the city's identity (Ricárdez et al. 2016), it is linked to its beauty and scenic value, as well as to tourism, cultural, and recreational activities, for which parks, museums, docks, walkways, and other facilities are located on its edges, in the southern part. Among the recognized ecosystem services that the lagoon provides are carbon sequestration, regulation of the water flow, and contribution to regulating the city's microclimate (GET 2019).

Two water regulation vessels are part of Las Ilusiones. They are the first to receive the water entering the lagoon, along with sediment and pollutant inputs from runoff and wastewater from the hotel zone and adjacent residential areas, which is why the vessels and the lagoon are hypereutrophic, polluted, and in the continuous process of clogging. The lagoon has lost all its flow from tributaries, so it depends on rainfall and the volume of water provided by drains and sewers in the urban area (Flores et al. 2018; GET 2019; Hansen et al. 2007).

Actions of recovery of the lagoon have been carried out over the years aiming to maximize the resilience of the lagoon in coping with natural phenomena and anthropogenic activities (GET 2019, 2022; van Afferden et al. 2008). However, to prevent the complete deterioration of the lagoon, promote and achieve its restoration, and conservation of the flora and fauna that find a habitat in this system, it is necessary to count on the compromise and participation of the population and the corresponding authorities and stakeholders, and the effective implementation of the management plan and regulations that protect the lagoon. To achieve these goals, it is necessary to raise public awareness of the ecological, biological, environmental, economic, and social importance of Las Ilusiones (GET 2019).

### 3.2.2 'El Estero El Salado' in Puerto Vallarta, Jalisco

The estuary El Salado has been a state NPA since July 2000 in the category of Ecological Conservation Zone (GEJ 2000). When first established, its area was 168 ha; however, in 2020, 40 ha were added to 208 ha (GEJ 2020). The NPA protects and conserves a mangrove ecosystem, marsh vegetation, remnants of semideciduous forest, thorny forest, secondary vegetation, and aquatic and subaquatic vegeta-

tion, as well as wildlife groups such as birds, including migratory, mammals, reptiles including crocodiles (*Crocodylus acutus*), and amphibians; some of the species in these groups are in some level of vulnerability in official Mexican standards (GEJ 2020; Molina et al. 2012; Rubio 2018).

According to the objective of environmental education on the lagoon systems and coastal estuaries, tourism, and recreational activities are allowed in El Salado. The mangroves and the channel that permanently flows into the Pacific Ocean are used for interpretive trails and nature observation areas with guided visits (GEJ 2020; Ortiz et al. 2015). El Salado seeks to strengthen the integrity of the water body and protect species of fishing importance that complete some part of their life cycle in the estuary, aiming finally to benefit the fishers' quality of life. To achieve the objectives, activities of restoration and reforestation have been carried out since its decree as NPA (GEJ 2020).

The estuary, 80% of its basin perennial and intermittent runoff, 20% floodable areas, is an essential regulating vessel that allows runoff from upstream to be integrated, filtered, and diverted to the estuary, especially during the rainy season. Likewise, under extreme conditions, both the permeable soil system and the mangrove canopy serve as a natural barrier against the onslaught of tropical storms and hurricanes (GEJ 2020). In addition, the mangroves of the El Salado estuary are undeniable carbon sequestration reservoirs, a benefit that escalates to the municipal and national levels (Kumagai et al. 2020).

In 2019, a residential residual water collector collapsed, and the sewage was discharged into the estuary, affecting the estuary, the channel, the port dock, and the beaches adjacent to the estuary entrance, helping, however, to minimize the risk of flooding with sewage waters, especially for the most vulnerable population in Puerto Vallarta (CA 2019; GEJ 2020). According to the monitoring and due to the recuperation measures implemented, recovery of the estuary from the discharge would be in the short and medium term (CA 2019). However, according to El Salado's management program, education and information about all the benefits that this wetland provides to the population, as well as a 'great social conscience', are essential to achieve its conservation along with its contribution to the sustainability of Puerto Vallarta (GEJ 2020).

### 3.2.3 'Laguna La Escondida' in Reynosa, Tamaulipas

La Escondida, a natural lagoon and its surroundings, constitute a state NPA of 320 ha since 1997 in the category of Urban Park (GET 1997). La Escondida has been protected thanks to the concern of the population, ecologist groups, and the scientific community due to the high pressure that the accelerated urban expansion and the oil industry were exerting on this water body (Camacho et al. 2009; GET 1997).

The NPA represents a relic of the region's original vegetation harboring important biodiversity (GET 1997) since it is located in a coastal plain in the xerophytic region of Mexico, initially dominated by Tamaulipan thorn scrub. The potential distribution of the different vegetation types that are characteristic of this area in the north of the state and that may be present in La Escondida are halophytic vegetation and grassland, tular, mezquital, cultivated grassland, and riparian vegetation (GET 2015).

This park is home to amphibians, reptiles, mammals, fishes, and birds (breeding residents and winter migrants) (GET 2015). La Escondida is located on the route of migratory birds from Canada and Alaska, constituting a resting and nesting area for this taxonomic group (Camacho et al. 2009; Sánchez and Batres 2007). Seventeen of the species in the lagoon are under a conservation category according to official Mexican standards and international regulations (GET 2015).

La Escondida aims to promote the ecological recovery of the aquatic environment that allows its use for the improvement of the urban environment, recreation, and scientific research; to maintain ecological integrity and facilitate the development of environmental education and recreation, minimizing the impact on natural resources; and to allow the opening of a protected natural area for the exercise of an environmental interpretation and knowledge of natural pro-

cesses and their equilibrium (GET 1997). It also aims to be transformed into a regulating basin to avoid flooding during the rainy season, thus protecting the people living in the peripheral neighborhoods (Arcos 2009). However, hydraulic infrastructure and the continuous maintenance of the drains and canals are still needed to avoid the risk of flooding during the rainy season (GET 2015; Jiménez 2020; Rivera 2011).

It is a place for recreational, sports, and tourist activities, linked to the development of environmental education and awareness (GET 2015). However, the NPA status of La Escondida has not been enough to stop the continuous deterioration of the lagoon. The different municipal administrations have attempted to restore the lagoon's ecosystem. However, they have not succeeded due to the lack of continuity and coordination between governmental areas (Camacho et al. 2009). The general situation of the lagoon represents challenges and priority lines of action for the scientific, environmental, and political community at the regional level, as well as the agreement between different governmental entities so that the recovery of La Escondida can be carried out (GET 2015).

### 3.2.4 The Artificial Wetland 'El Palote' Dam, in León, Guanajuato

El Palote dam is the main element of the 'Metropolitan Park from the Municipality of Leon, Gto.' a state NPA in the category of Ecological Park, decreed in September 2000 at the request of the Technical Committee of the León Metropolitan Park Trust (GEG 2000). The objectives of the Metropolitan Park are to preserve the water body of the dam (IEEG 2001), to provide recreational and leisure opportunities that contribute to the formation of an environmental culture that allows people to participate in the protection and conservation of the NPA, to stop the degradation of the natural resources of the area and to maintain the quality of the landscape (GEG 2000).

The dam was built to solve the water problems of León, both droughts and floods, with contributions from the people and the government (Córdova 2022; Navarro 2012). The main intention was to supply the stored water for the use of the population and industry (Córdova 2022; Navarro 2012). Today, the El Palote dam regulates rainwater runoff from the three original catchment micro-basins in the mountains to the north, northwest, and northeast, helping to prevent flooding in León (IEEG 2001; Navarro 2012). However, although the dam is part of the intermediate recharge zones (IEEG 2001) and is one of the largest dimensions in the municipality of León (GEG 2000; IEEG 2001), supplies water to only 3% of the urban population. The water from the dam is mainly used to maintain the Metropolitan Park (GEG 2000). However, in March 2023, the dam was at 34% of its capacity, resulting in a water shortage for 97 neighborhoods in León (SAPAL 2023). Faced with such a situation before, the management program of the NPA proposes the suspension of the extraction of water for public supply (IEEG 2001).

The Metropolitan Park, inaugurated in 1993, has an area of 337 ha, of which ~ 85% corresponds to the water body of the dam (Córdova 2022). Its flora is composed of native and introduced species (DRN 2016) and provides a habitat for species of wildlife groups: birds, fishes, amphibians, reptiles, and mammals. Twenty of these fauna species are endemic or in some status of protection in the Mexican official standards (SMAOT 2021). It is also located on the migratory route of the center of the country and provides a habitat for migratory birds (GEG 2000).

In this NPA, the economic activities allowed are mainly those related to recreation, education, culture, and tourism. Recreational and subsistence fishing are allowed, the latter only for a few family groups; fish re-stocking, if necessary, is allowed during periods of maximum dam flooding. Soil extraction (with the aim of de-silting the dam) is also allowed as long as it does not breach the impermeable layers, respects the total storage capacity of the dam, and does not disturb or increase the depth of the (shallow) feeding areas of the birds (GEG 2000; IEEG 2001).

To preserve the El Palote dam, it is necessary to implement a comprehensive management strategy that includes the micro-basins that feed it as they have various degrees of erosion problems,

as well as the sanitation and cleaning of the streams that feed the dam, as problems with garbage and pollutants persist (IEEG 2001). Such a management strategy, together with the controlled activities of the visiting population, aims to reduce as much as possible the negative impacts on the NPA and to maintain its ecological integrity and functionality for the benefit of the people, the wildlife, and the city of León. In addition, there is a proposal to expand the NPA to maintain ecological quality, preserve connectivity between ecosystems (i.e., with a non-urban NPA), and limit productive activities, land use changes, and urban growth trends in the area (IMPLAN 2016).

## 4 Conclusions

Mexico's natural conditions have favored the presence of wetlands across a significant portion of its territory resulting in different types of urban wetlands. These spaces contribute to the sustainability of Mexican cities in different ways, depending on their origin (i.e., natural, artificial), location within the different regions (e.g., climatic, vegetation), protection category, conservation status, level of pollution and eutrophication, hydrology, and intermittency, among other factors. Mexican urban wetlands are home to populations of native, endemic, vulnerable, endangered, and/or critically endangered species of flora and fauna, constitute conservation areas that contribute to flood control, water storage, and filtration, and are important spaces for leisure and recreational activities that also promote tourism in the cities.

The urban wetlands described here are NPAs, mainly of state attribution, and represent the different types of Mexican ecosystems they protect. They are a sample of the categories and statuses of conservation and protection resulting from the application of Mexican laws on protecting natural areas. All of them are, to a greater or lesser extent, public spaces in which environmental education is considered, and in all of them, tourist and recreational activities are carried out. As a result, all of them have been modified to accommodate infrastructure and equipment, in most cases at the expense of the extent of the wetlands themselves.

Except for Xochimilco and San Gregorio, in which people are an integral part of the wetland, and the Interdunary Lagoons in Veracruz, scattered throughout the city and in direct contact with people since they are parts of residential areas; in the rest of the wetlands human settlements are not allowed, yet parts of their borders limit with residential areas or are subject to illegal settlements in their margins or zones of influence. Regarding tourism in these protected natural wetlands, it is an ambivalent factor since nature-based tourism, along with recreational and leisure activities, brings economic benefits and is an essential tool for environmental education and awareness; however, poor planning and execution of these activities can lead to the depletion of the same protected resources and areas designated as tourist sites (Mora-Olivo et al. 2009). This represents a critical situation and high vulnerability for these systems, as they are the first to receive the impacts of anthropic activities and the urbanization process. As a result, the systems are polluted, eutrophic, and in different stages of degradation, even though, they continue to provide services to the population, biodiversity, and cities.

The management programs of these protected wetlands include knowledge, monitoring, restoration, and research, yet such activities are carried out with different intensities or not at all, depending on the NPA. For some, there are no complete or updated data on the species that live and visit these wetlands, nor on their pollution and eutrophication dynamics. For successful management, conservation, and sustainable use for the benefit of the population, monitoring and periodic studies are needed. For some, restoration activities have been carried out depending on the interest of the authorities in turn and their available funds. However, they have been intermittent, sometimes insufficient, or carried out only in case of emergency. It is common in the news sites to find reports on the deterioration of the wetlands, death of fauna, or damage to flora.

Despite their protection status and importance to people for all the benefits they provide,

Mexico's urban wetlands are still vulnerable and under constant threat of disappearance. Non-protected wetlands are at even greater risk. The conservation status is not the last step as one might hope, but the continuation of a process to progressively achieve effective restoration and conservation of urban wetlands to benefit the population and the city environment.

Monitoring and restoration in and of protected wetlands can be expensive and not an easy task, yet necessary. To achieve adequate management and effective protection and conservation of these essential environments are necessary operational urban planning around the wetlands, compliance with laws and regulations at the three levels of government related to NPAs, and coordination between institutions and areas of government to carry out the actual implementation of management plans, reevaluate the social and economic pressures on their land and biodiversity, generate better policies of restoration and management, involvement and cooperation of educational institutions, and civil societies (Camacho et al. 2009; GEJ 2000). All actions are important, but above all, we need to understand that environmental care and protection of spaces such as urban wetlands are for the benefit of all. In times of global warming and water scarcity, the protection and conservation of urban wetlands is not an option but a necessity for the sustainability of cities and the well-being of their populations.

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