Cost-Effective Wetland Risk Assessment for Ramsar Site Management in Southern Mexico

Tatiana Lobato-de Magalhães[1,2], Everardo Barba[3], and Dulce Infante Mata[4]

ABSTRACT

Despite wetlands are increasingly threatened by human land-use transformation and degradation, there is a lack of rapid, low-cost, and effective methods to assess and manage risks. Here we demonstrate and propose the use of ad-hoc consultation and directional surveys to assess the wetland risk severity, probability, and consequences for three Southern Mexico Ramsar sites. We compiled wetland functionalities and risks from the scientific literature and Ramsar Information Sheet for each of the 41 Southern Mexico Ramsar sites, then we create a list of relevant wetland functions and risks. To reduce variables (functions and risks) as well as to choose the focal sites, we used principal components analysis (PCAs). To prioritize risks based on the experts' opinions (96 regional wetland scientists) we applied Multi-Criteria Decision Making (MCDM) procedures. Our findings indicate climate change and drought as high risk for all studied wetlands. Agriculture and livestock were highly significant to the Pantanos de Centla coastal wetand area while María Eugenia highland wetlands have been more affected by urbanization and wastewater effluents. This methodology proved to be a cost-effective and timely approach to inform first-steps to decision-makers on risk identification, wetland management, and conservation planning at landscape-scale. This approach could mitigate the lack of funds designated to conservation and risk analysis for wetlands, which is a further issue in several developing countries, including Mexico.

Keywords Collaborative studies, ecosystem functions, Los Petenes, María Eugenia, multi-criteria decision making, Pantanos de Centla, risk prioritization

RESUMEN

A pesar de que los humedales están cada vez más amenazados por las acciones antrópicas, faltan métodos rápidos, de bajo costo y eficaces para evaluar y gestionar los riesgos a los ecosistemas de humedales. Este artículo demuestra y propone el uso de consultas ad hoc para evaluar la gravedad, probabilidad y consecuencias de riesgos para tres Sitios Ramsar del Sur de México. Se recopilaron las funcionalidades y riesgos de los humedales a partir de la literatura científica, incluyendo la 'Información Ramsar' para cada uno de los 41 Sitios Ramsar del Sur de México, así elaborar una lista de funciones y riesgos relevantes. Se utilizó un análisis de componentes principales para reducir el número de variables, para elegir los sitios focales. Para priorizar los riesgos con base en las opiniones de los expertos (96 científicos regionales de humedales), se aplicaron procedimientos de toma de decisiones multicriterio. Los hallazgos de este estudio indican que el cambio climático y la sequía son de alto riesgo para todos los humedales estudiados. La agricultura y la ganadería fueron muy importantes para el humedal costero Pantanos de Centla, mientras que el humedal de tierras altas María Eugenia ha sido más afectado por la urbanización y los efluentes de aguas residuales. Esta metodología demostró ser un enfoque rentable y oportuno para informar a los tomadores de decisiones los primeros pasos sobre la identificación de riesgos, el manejo de humedales y la planificación de la conservación a escala de paisaje. Este enfoque podría mitigar la falta de fondos destinados a la conservación y análisis de riesgos de los humedales, que es un problema recurrente en varios países en desarrollo, incluido México.

Palabras clave: Estudios colaborativos, funciones ecosistémicas, Los Petenes, María Eugenia, toma de decisiones multicriterio, Pantanos de Centla, priorización de riesgos.

INTRODUCTION

Wetlands are dynamic ecosystems that act as natural connectors between upland and aquatic systems, maintain biodiversity at regional and landscape scales, and are increasingly threatened by human land-use transformation and degradation (Calhoun et al. 2017; Schofield et al. 2018). In the last four decades, the estimated wetland losses are around 60% in Latin America and worldwide (Landgrave and Moreno-Casasola 2012). Moreover, wetlands are extremely susceptible to climate change, and losses will increase with rising temperatures and the decline of precipitation (Darrah et al. 2019). Consequently, there is need for a timely and cost-effective method to assess risks for wetlands for a wide use, particularly for developing countries where there is a lack of wetland professionals plus funds designated for environmental risk studies and long-term monitoring are usually scarce.

Wetland risk assessment and ecological indicators have been subjects of interest for the last few decades, especially for internationally important Ramsar sites. The first Wetland Risk Assessment Framework was developed by the Ramsar Convention during the 7th Meeting of the Conference of the Contracting Parties to the Convention on Wetlands based on van Dam et al. (1999). Their frame-

1 Faculty of Natural Sciences, Universidad Autónoma de Querétaro, Querétaro, QRO, Mexico. Corresponding author email address: tatilobato@gmail.com; tatiana.lobato@uaq.mx Instituto de Ecología AC., Carretera antigua a Coatepec 351, El Haya 91070, Xalapa, Veracruz, México
2 Biological Sciences Department, North Dakota State University, Fargo, USA
3 Sustainability Science Department, El Colegio de La Frontera Sur (ECOSUR), Villahermosa, Tabasco, Mexico
4 Sustainability Science Department, El Colegio de La Frontera Sur (ECOSUR), Tapachula, Chiapas, Mexico

work encompasses six steps: identification of the problem, identification of the adverse effects, identification of the extend of the problem, identification of the risk, risk management and reduction, and monitoring. Overall, research on wetland management and conservation is lacking in Latin America countries (e.g., Salazar-Navarro et al. 2020), where wetland ecosystems are under increased threat, particularly for the inland wetlands (Lobato-de Magalhães et al. 2020).

While Mexico has the second-highest number of Ramsar sites worldwide (144 sites designated as Wetlands of International Importance, surface area of 8,721,911 ha), behind the United Kingdom (175 sites) (Mauerhofer et al. 2015), its wetlands are severely threatened (Landgrave and Moreno-Casasola 2012; Gortari-Ludlow et al. 2015). A third of Mexico's Ramsar sites are in the Southern territory (41 sites) (Ramsar 2020). This region has some of the highest levels of aquatic plant species richness and endemism worldwide (Murphy et al. 2019). Additionally, Southern Mexico wetlands are valuable heritage places that provide several ecosystem services and substantially contribute to maintaining biodiversity at local and landscape levels (Smardon 2006; Gortari-Ludlow et al. 2015; Alcocer and Aguilar-Sierra 2019; Davidson et al. 2019). Surprisingly only 25 Southern Mexico Ramsar sites have management plans (13 implemented) while four sites have plans in preparation and the rest lack any planning. This suggests a low level of concern for wetland conservation in the country as well as emphasizes the need for a meta-analysis about risks and state of conservation of Mexican Ramsar sites (Lobato-de Magalhães et al. 2020).

The 41 Southern Mexico Ramsar sites are highly diverse ecosystems that cover 34,232 km^2 (2% of the total country surface) in seven Mexican states (lat. 14.68º and 22.47º North, long. -98.63º and -86.78º West), Campeche State (3 Ramsar sites), Chiapas (12), Guerrero (1), Oaxaca (4), Quintana Roo (12), Tabasco (1), and Yucatan (8). Eighty-five percent of those Ramsar sites occurs at low elevations (< 300 m a.s.l.), with the highest elevation Ramsar sites being highland wetlands located in Chiapas State (La Kisst and María Eugenia; 2,120 m a.s.l.). Most Southern Mexico Ramsar sites are classified as coastal and marine (64%), followed by inland wetlands (36%) ranging in size from 0.2 km^2 to 7,050 km^2 (Lobato-de Magalhães et al. 2020; Ramsar 2020).

Here, we propose the use of a cost-effective tool to wetland risk assessment using a collaborative approach (ad-hoc consulting) and multi criterion decision-making (MCDM). The principal objectives of this study are to determine the main ecosystem functions provided by wetlands, identify the major wetland risks, and analyze the effectiveness of the use of ad-hoc groups for cost-effective analysis for risks in three representative Ramsar sites: 1) Pantanos de Centla Biosphere Reserve (Tabasco State), 2) Los Petenes Biosphere Reserve (Campeche State), and 3) María Eugenia Highland Wetlands (Chiapas State). Our findings can contribute to understanding risk analysis for wetlands in general and specifically for Ramsar sites. This methodology is a potentially useful tool for decision-making and conservation strategies for Southern Mexico wetlands at local and landscape scales.

MATERIALS AND METHODS

Study Area and Data Source

The study was focused on three Ramsar Sites: Pantanos de Centla Biosphere Reserve (Lat. 18°18' N, Long. 92°27' W; Tabasco State), Los Petenes Biosphere Reserve (Lat. 20°11′ N, Long. 90°32′ W; Campeche State), and María Eugenia

Figure 1. Views of habitats at the study's Ramsar sites: a) Pantanos de Centla Biosphere Reserve, a mosaic of swamps, marshes, and mangroves which harbor several species (Tabasco State), b) Los Petenes Biosphere Reserve, a peculiar wetland landscape with natural fragment of forests (Campeche State), and c) María Eugenia Highland Wetlands, a highly threatened urban mountain wetland comprised of woody plants (*Salix*) and herbs like *Typha* and *Schoenoplectus* (Chiapas State). (Photos by Dulce I. Mata)

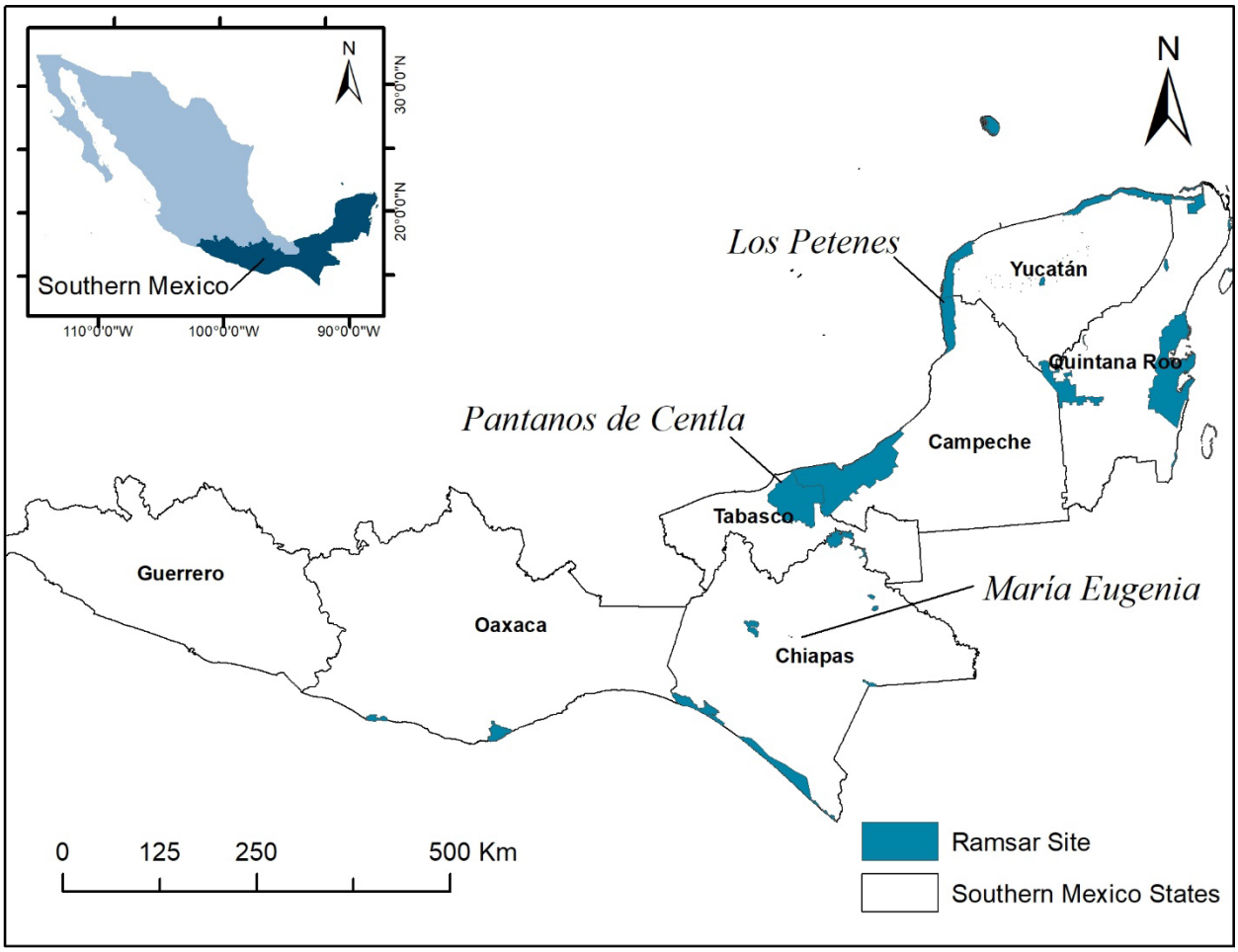

Figure 2. Location of Ramsar sites in Southern Mexico with study areas labelled. Source: shapefiles by INEGI (https://www.inegi.org.mx). (Map by T. Lobato-de Magalhães)

Highland Wetlands (Lat. 16°43' N, 92°37' W; Chiapas State) (Figures 1 and 2). We choose these wetlands as a model for the case study because they are highly significant natural places representing a vary characteristics (e.g., size, year of foundation, geographical localization, wetland type) and are the subject of other studies of our research group.

Pantanos de Centla Biosphere Reserve (3,027 km^2) is one of the oldest Mexican Ramsar sites (designed in 1995) that covers 12% of the total Tabasco State surface. Among these temporary and permanent flooded wetlands, the Grijalva River and the Usumacinta River form an estuarine ecosystem that is considered one of the most important deltas in North and Mesoamerica because of the water flow and the importance for migratory birds and plant species of freshwater marsh and mangrove (López-Jiménez et al. 2020), as dominant species *Typha dominguensis* (Cattail), *Cladium jamaicense* (Sawgrass), *Thalia geniculata* (Alligator-flag Shrubland), *Haematoxyllum campechianum* (Bloodowood Three), *Vallisneria americana* (Wild celery), and *Avicennia germinans* (Black Mangrove), *Laguncularia racemosa* (White Mangrove), and *Rhizophora mangle* (Red Mangrove) (Barba-Macías et al. 2018).

Los Petenes Biosphere Reserve (2,829 km^2) is represented by islands of forest associated with springs and water holes, which constitute a critical habitat for wildlife in the Campeche State. It contains a great diversity of ecosystems, biological wealth, and a significant archaeological heritage for the Mayan culture. That naturally fragmented wetlands are endemic to the Yucatan Peninsula, encompassing mangroves with *Avicennia germinans* (Black Mangrove), *Laguncularia racemosa* (White Mangrove), and *Rhizophora mangle* (Red Mangrove), emergent herbaceous wetlands (salt marshes) including those dominated by *Cladium jamaicense* (Sawgrass), and flooded forests with species of the Sapotaceae family (Arellano-Rivas et al. 2018).

María Eugenia (1 km^2) is the most recent Ramsar Site Mexican Ramsar site, designated in 2012. It contains urban highland wetlands that are extremely threatened and play a vital role in the provision of water to Southern Mexico cities such as San Cristóbal de las Casas, Chiapas. Locally known as "tulares", the dominant aquatic plants of these highland wetlands are *Typha* (Cattail), *Phragmites karka* (Common Reed), *Cyperus articulatus* (Umbrella Sedge), *Eleocharis montevidensis* (Spike-rush), *Schoenoplectus americanus* (Bulrush), and tree species are *Prunus serotine*, *Salix bonplandiana,* and *Sambucus canadensis* (Lot 2004; Chediack et al. 2018). *María Eugenia* is an important resting place for migratory birds, and a refuge for local species,

such as the endemic fish *Profundulus hildebrandi* (Popoyote) (Lobato-de Magalhães et al. 2020; Ramsar 2020).

To assess risks based on the experts' opinions we applied Multi-Criteria Decision Making (MCDM) following Malekmohammadi and Blouchi (2014) and took three steps: risk identification, risk characterization, and risk prioritization. We created a survey focused on the three wetlands functions and risks, which was shared with more than 100 wetland scientists and practitioners affiliated with Southern Mexico scientific organizations, including the National Commission of Protected Areas, National Commission of Water, and several universities and research institutes (source data available on request from the lead author). Surveys comprised three parts: general questions (e.g., education level, years of experience with wetland science, age, gender), functions, and risks.

Risk Identification

We identified the major wetland ecosystem functions (ecological endpoints) and ecological risks associated with these endpoints following the IUCN booklet (Dugan 1990) and reviewing the Ramsar Information for each of the 41 Ramsar sites (Ramsar 2020). Ecosystem functions were described in five major aspects: A - hydrologic flux and storage, B - biological productivity, C - biogeochemical cycling and storage, D - community and wildlife habitat, and E - other services, resulting in 17 wetland functions (Table 1). Hydrologic flux and storage address groundwater recharge/discharge, flood control and protection, and water supply. Biological productivity relates to carbon storage, food storage, non-food and wildlife resources, forage resources, agricultural and forest resources, historical or cultural resources. Biogeochemical cycling and storage involve control of erosion, sedimentation, and toxic materials, protection from storm, wastewater treatment, water quality. Community and wildlife habitat encompass biodiversity, preservation of flora and fauna, protection od threatened, rare, and endangered species. Wetland risks were described in six major aspects: A - change of natural habitat, B - use of natural resources, C - pollution, D - climate change and drought, E - change on the hydrology, and F - urbanization and wetland use, producing 40 wetland risks (Table 2).

To reduce correlated variables for both functions and risks we performed correlations and principal component analysis (PCAs) in R v. 3.6.1 (Friendly 2002; R Core Team 2020), highlighting seven ecosystem functions: 1) regulation services and hazard reduction, 2) food and non-food products, 3) erosion and contamination control, 4) biodiversity and genetic resources, 5) scientific and educational, 6) spiritual and inspirational, and 7) freshwater source, and seven risks: 1) agriculture, livestock, and aquaculture, 2) invasive and other problematic species, 3) hunting, fishing, gathering terrestrial plants, wood harvesting, 4) urban, agricultural, and industrial effluents/waste, 5) climate change and drought, 6) urbanization, and 7) recreational and tourism) that could represent all data (Table 1 and Table 2).

Table 1. Principal ecosystem functions of Southern Mexico Ramsar sites.

Major ecosystem function group	**Ecosystem function by Ramsar**	**Terminology used on the surveys**
A. Hydrologic flux and storage	• Regulation services • Maintenance of hydrological regimes • Hazard reduction • Climate regulation	1. Regulation services and hazard reduction
B. Biological productivity	• Food for humans • Wetland non-food products	2. Food and non-food products
C. Biogeochemical cycling and storage	• Erosion protection • Pollution control and detoxification • Nutrient cycling • Soil formation	3. Erosion and contamination control
D. Community and wildlife habitat (ecological)	• Biodiversity • Genetic material	4. Biodiversity and genetic resources
E. Other services	• Cultural services • Recreation and tourism • Scientific and educational • Spiritual and inspirational • Freshwater source	5. Scientific and educational 6. Spiritual and inspirational 7. Freshwater source

Table 2. Characteristics of the risk factors in Southern Mexico Ramsar wetland.

Major risk group	Risks by Ramsar	Terminology used on the surveys
A. Change of natural habitat	• Natural system modifications • Vegetation clearance/ land conversion • Wood and pulp plantations • Agriculture • Livestock farming and ranching • Annual and perennial non-timber crops • Marine and freshwater aquaculture • Habitat shifting and alteration • Problematic native species • Invasive non-native / alien species • Invasive and other problematic species and genes	1. Agriculture, livestock, and aquaculture 2. Invasive and other problematic species
B. Use of natural resources	• Biological resource use • Fishing and harvesting aquatic resources • Logging and wood harvesting • Hunting and collecting terrestrial animals • Gathering terrestrial plants	3. Hunting, fishing, gathering terrestrial plants, wood harvesting
C. Pollution	• Air-borne pollutants • Agricultural and forestry effluents • Industrial and military effluents • Oil and gas drilling • Salinization • Household sewage • Urban wastewater • Pollution • Garbage and solid waste	4. Urban, agricultural and industrial effluents / waste
D. Climate change and drought	• Climate change and severe weather • Excess heat • Storms and flooding	5. Climate change and drought
E. Change on the hydrology	• Canalization and river regulation • Water regulation • Water releases • Drainage and dredging	
F. Urbanization and wetland use	• Human settlements (non-agricultural) • Transportation and service corridors (shipping lanes) • Energy production and mining • Dams and water management/use • Unspecified development • Water abstraction • Human intrusions and disturbance • Recreational and tourism activities (Sound) (Light)	6. Urbanization 7. Recreation and tourism

Risk Characterization

In this step we estimated the severity of risks, the range of consequences and the probability of the risks through an ad-hoc consultation with a group of experts. For each identified risk, we used a semi-quantitative method to describe the relative risk scale as below.

- Severity: (1) *Very low* (<4): biogeochemical change, (2) *Low* (6–4): physical and chemical changes, (3) *Moderate* (9–7): disruption of biology, (4) *High* (12–10): hydrological changes, and (5) *Very high* (15–13): destruction of the integrity or existence.
- Consequence: (1) *Very low*: < one quarter, (2) *Low*: one quarter, (3) *Moderate*: half, (4) *High*: three quarter, and (5) *Very high*: all the wetland and the surrounding ecosystems.
- Probability: (1) *Very low*: impossible or remote under normal conditions, (2) *Low*: unlikely under normal conditions, (3) *Moderate*: possible (risks may occur from existing risks), (4) *High*: common (risks occur usually), and (5) *Very high*: certain (risks occur continuously).

We then calculated the risk level using the equation proposed by Malekmohammadi and Blouchi (2014) to expert's opinion:

Risk = severity × range of consequence × probability

Risk Prioritization

We used multi-criteria decision making (MCDM) to prioritize risks following Zhao et al. (2006) and Zhang et al. (2009). We used pairwise comparisons based on judgments of experts to weight the indexes and options of the risks and derive priority scales (Saaty 2008). Pairwise comparison matrices have been used to make proposals for corrective action to reduce risks and is recommended to be applied in Ecological Risk Assessment (ERA) for wetlands (Malekmohammadi and Blouchi 2014). This method minimizes error due to negligence and ensures accuracy in the sense that it has a built-in method to check the inconsistency of judgments (Ramanathan 2001; Malekmohammadi and Blouchi 2014). After this step managers and decision–makers should have plenty of information to identify risks (e.g., zones with different levels of risk) to guide management strategies and planning.

RESULTS

The PCAs and correlations allowed us to identify seven functions and seven risks (Figure 3; Tables 1 and 2). From the 100 wetland scientists and practitioners invited to participate on this survey, we obtained answers of 96 participants. The experts who participated in the survey were mostly male researchers (73%), with more than 5 years of experience with wetland science (62%), a level of education of master or doctorate (75%), > 36 years old (93%),

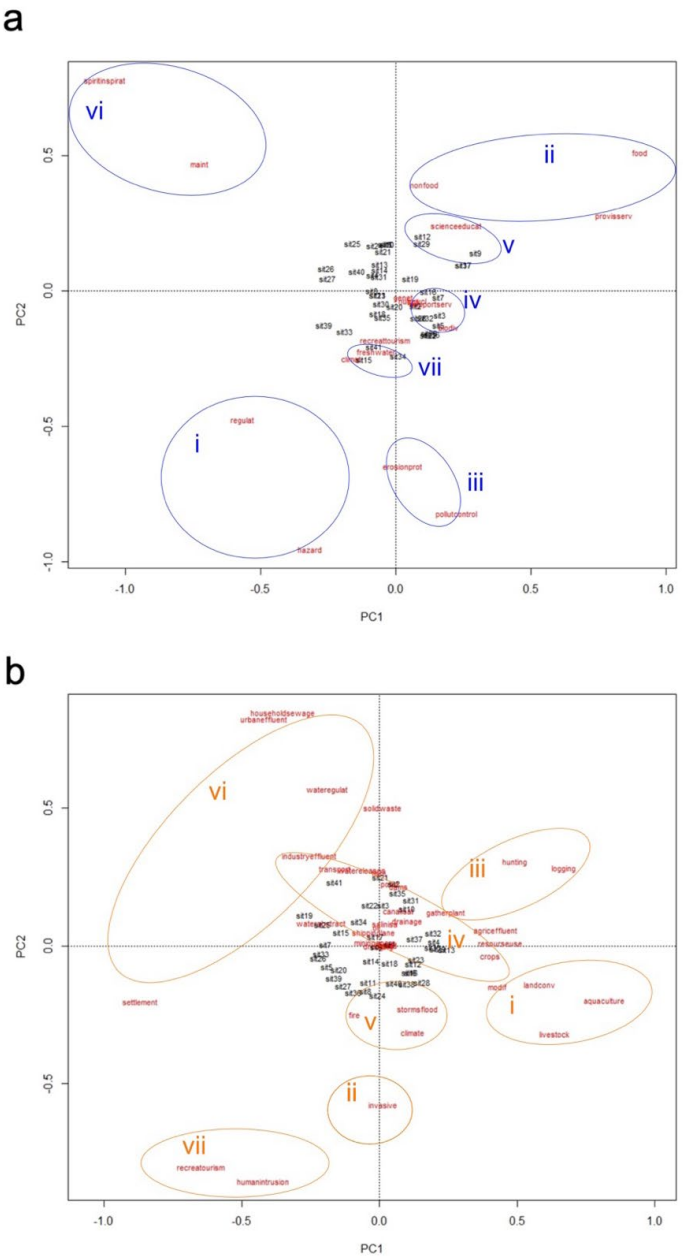

Figure 3. Principal Component Analysis for (a) ecosystem functions clusters i: regulation services and hazard reduction, ii: food and non-food products, iii: erosion and contamination control, iv: biodiversity and genetic recourses, v: scientific and educational, vi: spiritual and inspirational, vii freshwater source, (b) wetland risks clusters i: agricultural, livestock and aquaculture, ii: invasive and other problematic species, iii: hunting, fishing gathering, iv: urban agricultural and industrial effluents, v: climate change and drought, vi: urbanization, vii: recreation and tourism, of Southern Mexico Ramsar sites.

while the minority of the experts lived close to the studied wetland (30%) or was a member of an indigenous ethnic (8%) (Figure 4).

Wetland Functions

Regarding wetland functions, biodiversity and genetic resources was recognized as one of the most important functions for the three studied Ramsar sites (Figure 5a). The second most important function was regulation services and hazard reduction for Pantanos de Centla (29% experts' opinion), and food and non-food products for Los Petenes (26% experts' opinion). In María Eugenia freshwater source (43% experts' opinion) was the principal function followed by biodiversity and genetic resources (36% experts' opinion). Overall, scientific, educational, spiritual and inspirational use was of limited importance for the studied sites.

Wetland Risks

Multi criterion decision-making results showed agriculture, livestock, and aquaculture as the major risk for Pantanos de Centla, climate change and drought for Los Petenes, while urbanization was the most important risk to María Eugenia (Figure 5b). Through the prioritization of risks results we observed three different scenarios (Table 3). Overall, Los Petenes showed more conserved wetland with low-risk scenario than the other sites. Only one risk was classified as unacceptable — climate change and drought, as the other six evaluated risks were acceptable or acceptable with a conditional control. Pantanos de Centla had a moderate risk scenario, with two risks classified as unacceptable - agriculture, livestock and aquaculture and climate change and drought. María Eugenia showed a higher risk than the other sites, with three unaccepted risks - urbanization, climate change and drought, and agriculture, livestock, and

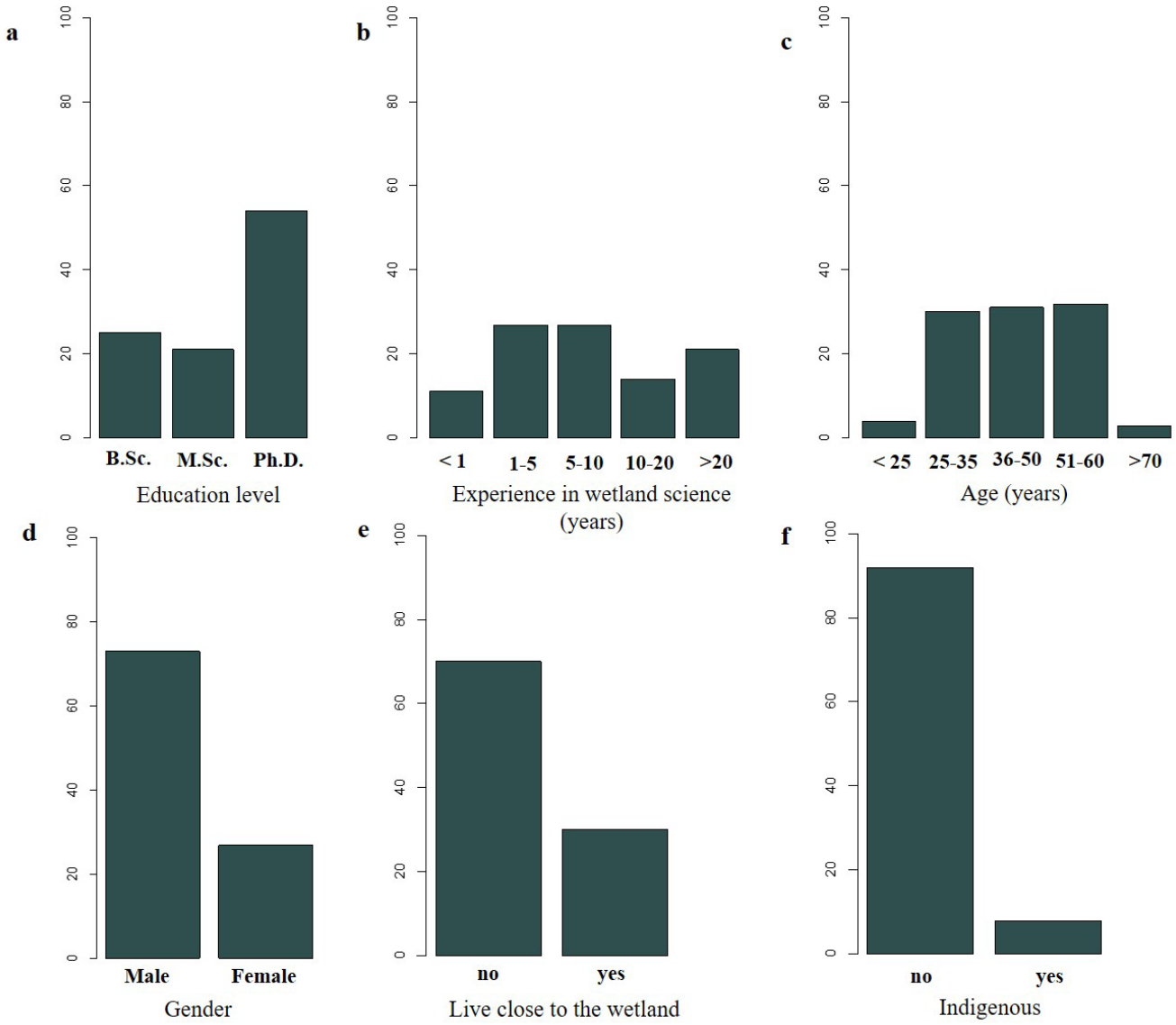

Figure 4. Results of the survey from 100 wetland scientists and practitioners affiliated with Southern Mexico scientific organizations. Information about the participants: (a) education level, (b) years of experience with wetland science, (c) age range, (d) gender, (e) if lives close to the wetland, and (f) if is part of any indigenous ethnic.

aquaculture. Of the seven risks analyzed in this study three of them were classified as acceptable or acceptable with a conditional for all sites: invasive and other problematic species, hunting, fishing, gathering terrestrial plants, and recreation and tourism.

The survey also asked for experts to identify a favorite wetland animal. Among the responses were the fish *Profundulus hildebrandi* (Popoyote), mud turtles *Kinosternon* spp. (Mud Turtle), *Dermatemys mawii* (Central America River Turtle), *Trichechus manatus* (Manatee), *Lontra longicaudis* (Neotropical Otter), dragonflies, and aquatic birds such as *Turdus rufitorques,* and *Tyto alba*. Although not asked, a few experts mentioned that they have also a favorite wetland plant, as seagrasses.

DISCUSSION

Climate change, ecosystem services, and protected areas are research priorities of many collaborative studies (Dey et al. 2020). Our study demonstrated an effective low-cost and timely alternative to assess wetland risks on a vast territory as Southern Mexico. Around 62% of the responses were made by a scientific community with huge experience in wetland science, while few participants were early-career wetland scientists or practitioners who work for governmental institutions.

The coastal wetlands, Pantanos de Centla and Los Petenes, are biodiverse ecosystems extremely important to mitigate hazards as the impacts of cyclones in the Caribbean coast (López-Jiménez et al. 2020), while the inland wetland of María Eugenia was most important for water supply (Chediack et al. 2018). The greatest risks for the latter wetland are urban development, agricultural activities, and invasive or problematic species, besides the climate change. While Gortari et al. (2015) reported the major risks for several Mexican wetlands (study focused on 78 inland wetlands) were agriculture and aquaculture, biological resource use, and pollution, our findings found that agricultural activities, climate change, and urbanization were the principal risks for the studied wetlands

Pantanos de Centla Biosphere Reserve

It is important to note that in the last two decades, lowland floodable forests have been drastically reduced by agricultural activities. The Pantanos de Centla has experienced a notable land-use change – the conversion of natural floodplain vegetation to livestock and agricultural areas (De

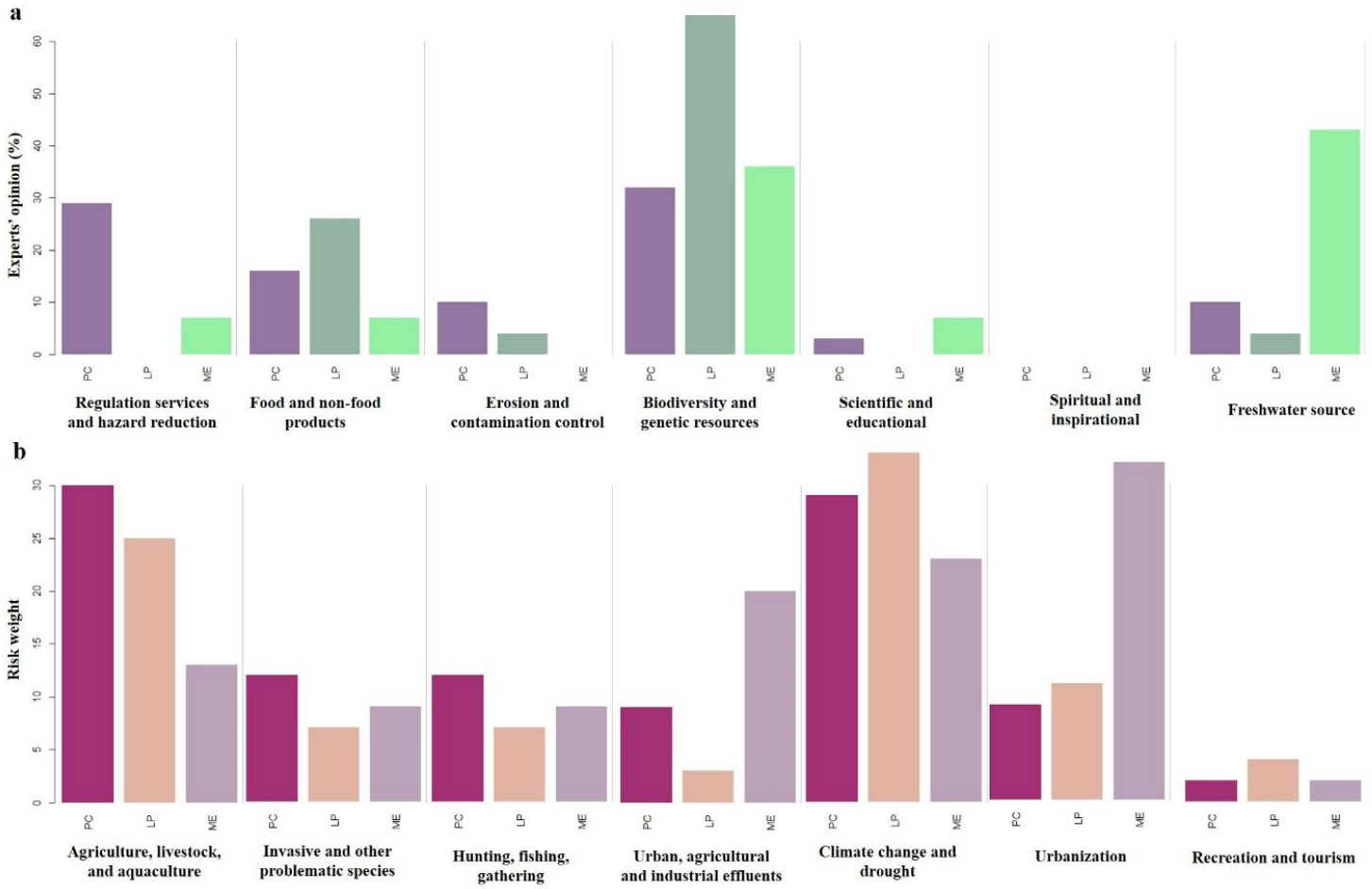

Figure 5. Results for functions and risks for three Ramsar sites in Southern Mexico: (a) major functions provided by wetlands through expert's opinion and (b) risk level for seven groups of risks. PC = Pantanos de Centla Biosphere Reserve, LP = Los Petenes Biosphere Reserve, and ME = María Eugenia Highland Wetlands.

Table 3. Results of wetland risks using Multi-Criteria Decision Making (MCDM) for three Southern Mexico Ramsar sites (based on experts' opinions of 96 regional wetland scientists).

Ramsar Site / Risk factor	Risk level	Classification	Description	Risk weight	Risk ranking number
Pantanos de Centla Biosphere Reserve					
1. Agriculture, livestock, and aquaculture	91.16	High	Unacceptable	0.30	1
2. Invasive and other problematic species	66.90	Moderate	Acceptance/ conditional control	0.12	3
3. Hunting, fishing, gathering terrestrial plants	62.58	Moderate	Acceptance/ conditional control	0.10	4
4. Urban, agricultural, and industrial effluents	62.19	Moderate	Acceptance/ conditional control	0.09	5
5. Climate change and drought	87.68	High	Unacceptable	0.29	2
6. Urbanization	58.16	Moderate	Acceptance/ conditional control	0.09	6
7. Recreational and tourism	24.00	Very Low	Negligible	0.02	7
Los Petenes Biosphere Reserve					
1. Agriculture, livestock, and aquaculture	68.96	Moderate	Acceptance/ conditional control	0.25	2
2. Invasive and other problematic species	44.32	Low	Acceptable	0.07	5
3. Hunting, fishing, gathering terrestrial plants	55.52	Moderate	Acceptance/ conditional control	0.18	3
4. Urban, agricultural, and industrial effluents	38.96	Low	Acceptable	0.03	7
5. Climate change and drought	82.16	High	Unacceptable	0.33	1
6. Urbanization	50.12	Moderate	Acceptance/ conditional control	0.11	4
7. Recreational and tourism	35.44	Low	Acceptable	0.04	6
María Eugenia Highland Wetlands					
1. Agriculture, livestock, and aquaculture	57.93	Moderate	Acceptance/ conditional control	0.13	4
2. Invasive and other problematic species	54.07	Moderate	Acceptance/ conditional control	0.09	5
3. Hunting, fishing, gathering terrestrial plants	34.33	Low	Acceptable	0.02	7
4. Urban, agricultural, and industrial effluents	80.67	High	Unacceptable	0.20	3
5. Climate change and drought	92.13	High	Unacceptable	0.23	2
6. Urbanization	120.0	Very High	Unacceptable	0.32	1
7. Recreation and tourism	34.47	Low	Acceptable	0.02	6

la Rosa-Velázquez et al. 2017). Some of the participant experts mentioned that a huge threat for this area is the illegal wood logging (timber harvest) and the use of mangrove fires to illegally hunt native threatened species for human consume (e.g., *Dermatemys mawii,* Central America River Turtle). Although Pantanos de Centla had more than 76 plant species and other animal species used by people (SEMARNAT 2020), our study highlights biological resource use as moderate risk. Interestingly, local groups and cooperatives have developed sustainable use management plans for species such as the *Crocodylus moreletti* (Mexican Crocodile). Some experts mentioned that Pantanos de Centla is highly susceptible to impacts from potential dams in the Usumacinta watershed. Additionally, this area's wetlands have different characteristics, each one with different susceptibility, pressure, and danger, with some issues limited to a geographical area. Overall, it is difficult to generalize the threats to the Pantanos de Centla, making it is necessary to regionalize the different environments and their relationship with various threats. Nonetheless, urban and industrial sources of pollution (particularly oil), agriculture and livestock, and drastic changes in hydrology, represent constant and growing threats to the health and conservation of this wetland.

Los Petenes Biosphere Reserve

The Los Petenes Biosphere Reserve remains a very well conserved area, yet some experts suggested that it is still a good time to take preventive and restoration actions in the face of the various threats. Although it is a protected area, management monitoring and planning are lacking, particularly for fishing and use of natural resources. They mentioned that there are many irregularities and ecological disorder in Los Petenes and that local people who depend on the wetland must be included on the management plan because they are key stakeholders who are committed to protecting the wetlands. Environmental education and the sustainable use of biological resources should be encouraged and, where appropriate, its regulations supervised, so that the inhabitants and the floating population make the reserve their own and preserve it in the long term.

María Eugenia Highland Wetlands

The situation for María Eugenia is critical because it suffers threats from urbanization including cutting down the little remaining vegetation and the invasion of exotic or domestic fauna. Although native fauna is still observed, native populations are decreasing, particularly for aquatic birds. Rapid intervention is required to stop faunal invasions and filling of wetlands. The Mexican state must act quickly and urgently to protect the main source of water for the city's inhabitants and the environmental services provided by wetlands against floods and disasters in this region. Urban development and filling of wetlands pose significant threats to the future of María Eugenia wetlands.

CONCLUSIONS

Our approach is of high value not only for its contribution to understanding the wetlands in the study areas but also because it can quickly capture information from the scientific community on wetland functions and risks. The methodology could be applied by the National Wetland Committee for all Mexican Ramsar sites. Furthermore, the tool could be useful to build a risk meta-analysis and support decisions-makers doing integrated wetland management plans from local to regional scales across Mexico as well as in other developing countries.

ACKNOWLEDGEMENTS

We acknowledge the collaboration of the experts who contributed for the survey. We highlight and thanks the participation of CONAGUA, CONANP, UMAR, UJAT, UNACAR, UADY, UNAM, UQROO, and ECOSUR representatives. The first author holt a postdoctoral fellowship from ECOSUR at CONACyT (National Council of Science and Technology) in Mexico (Dic 2019- Nov 2020). National Commission of Water (CONAGUA) project N. A3-S-65801.

REFERENCES

Alcocer, J. and V. Aguilar-Sierra. 2019. Biodiversity in inland waters. In: Ibáñez, A.L. (ed.) *Mexican Aquatic Environments*. Springer Nature, Switzerland, pp 43-75. https://doi.org/10.1007/978-3-030-11126-7

Arellano-Rivas, A., J.A. De-Nova and M.A. Munguía-Rosas. 2018. Patch isolation and shape predict plant functional diversity in a naturally fragmented forest. *Journal of Plant Ecology* 11(1): 136-146.

Barba-Macías, E., M.A. Mesa-Jurado, A. Espinoza-Tenorio and A. Ortega-Argueta. 2018. Biodiversity Conservation in the Pantanos de Centla Biosphere Reserve: Ecological and Socioeconomic Threats. In: Ortega-Rubio, A. (eds) Mexican Natural Resources Management and Biodiversity Conservation. Springer, Cham. https://doi.org/10.1007/978-3-319-90584-6_20

Calhoun, A.J., D.M. Mushet, K.P. Bell, D. Boix, J.A. Fitzsimons and F. Isselin-Nondedeu. 2017. Temporary wetlands: challenges and solutions to conserving a 'disappearing' ecosystem. *Biological Conservation* 211: 3-11. https://doi.org/10.1016/j.biocon.2016.11.024

Chediack, S.E., N. Ramírez-Marcial, M. Martínez-Icó and H.E. Castañeda-Ocaña. 2018. Macrófitos de los humedales de montaña de San Cristóbal de Las Casas, Chiapas, México. *Revista Mexicana de Biodiversidad* 89(3): 757-768. https://doi.org/10.22201/ib.20078706e.2018.3.2420

Darrah, S.E., Y. Shennan-Farpón, J. Loh, N.C. Davidson, C.M. Finlayson, R.C. Gardner and M.J. Walpole. 2019. Improvements to the Wetland Extent Trends (WET) index as a tool for monitoring natural and man-made wetlands. *Ecological Indicators* 99: 294-298. https://doi.org/10.1016/j.ecolind.2018.12.032

Davidson, N.C., A.A. Van Dam, C.M. Finlayson, and R.J. McInnes. 2019. Worth of wetlands: revised global monetary values of coastal and inland wetland ecosystem services. *Marine and Freshwater Research*. https://doi.org/10.1071/MF18391

De la Rosa-Velázquez, M.I., A. Espinoza-Tenorio, M.Á. Díaz-Perera, A. Ortega-Argueta, R. Ramos-Reyes and I. Espejel. 2017. Development stressors are stronger than protected area management: a case of the Pantanos de Centla Biosphere Reserve, Mexico. *Land Use Policy* 67: 340-351. https://doi.org/10.1016/j.landusepol.2017.06.009

Dey, C.J., A.I. Rego, J.D. Midwood and M.A. Koops. 2020. A review and meta-analysis of collaborative research prioritization studies in ecology, biodiversity conservation and environmental science. *Proceedings of the Royal Society* B 287(1923): 20200012. https://doi.org/10.1098/rspb.2020.0012

Dugan, P.J. 1990. *Wetland Conservation: a review of current issues and required action*. IUCN, Gland, Switzerland. https://portals.iucn.org/library/node/6048

Friendly, M. 2002 Corrgrams: Exploratory displays for correlation matrices. *American Statistical* 56: 316-324. https://doi.org/10.1198/000313002533

Gortari-Ludlow, N., G. Espinosa-Reyes, J. Flores-Rivas, J. Salgado-Ortiz and L. Chapa-Vargas. 2015. Threats, conservation actions, and research within 78 Mexican non-coastal protected wetlands. *Journal of Nature Conservation* 23: 73-79.

Landgrave, R. and P. Moreno-Casasola. 2012. Evaluación cuantitativa de la pérdida de humedales en México. *Investigación Ambiental* 4: 19-35.

Lobato-de Magalhães, T., L. Guadalupe-Cruz and E. Barba. 2020. Wetland Conservation Concerns in Southern Mexico. *Wetland Science and Practice* 37(4): 294-301.

López-Jiménez, L.N., D.A. Jiménez-López, O. Castillo-Acosta, J.A. Gallardo-Cruz and A.I. Fernández-Montes de Oca. 2020. Plantas vasculares de la Reserva de la Biosfera Pantanos de Centla, México. *Botanical Sciences* 98(1): 159-204. https://doi.org/10.17129/botsci.2279

Lot, A. 2004. Flora and vegetation of freshwater wetlands in the coastal zone of the Gulf of Mexico. In: Caso, M., I. Pisanty and E. Ezcurra. (Eds) (Spanish version) *Environmental Analysis of the Gulf of Mexico*, INECOL, INE, Harte Research Institute, Corpus Christi. https://www.harteresearchinstitute.org/environmental-analysis-gulf-mexico

Malekmohammadi, B. and L.R. Blouchi. 2014. Ecological risk assessment of wetland ecosystems using multi criteria decision making and geographic information system. *Ecological Indicators* 41: 133-144. https://doi.org/10.1016/j.ecolind.2014.01.038

Mauerhofer, V., R.E. Kim and C. Stevens. 2015. When implementation works: A comparison of Ramsar Convention implementation in different continents. *Environmental Science Policy* 51: 95-105. https://doi.org/10.1016/j.envsci.2015.03.016

Murphy, K., A. Efremov, T.A. Davidson, E. Molina-Navarro, K. Fidanza, T.C. Crivelari-Betiol, P. Chambers, J. Tapia-Grimaldo, S. Varandas-Martins, I. Springuel, M. Kennedy, R.P. Mormul, E. Dibble, D. Hofstra, B.A. Lukács, D. Gebler, L. Baastrup-Spohr and J. Urrutia-Estrada. 2019. World distribution, diversity and endemism of aquatic macrophytes. *Aquatic Botany* 158: 103127. https://doi.org/10.1016/j.aquabot.2019.06.006

R Core Team. 2020. R*:* a Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. R-project.org/

Ramanathan, R. 2001. A note on the use of the analytic hierarchy process for environmental impact assessment. *Journal of Environmental Management* 63, 27-35. https://doi.org/10.1006/jema.2001.0455

Ramsar. 2020. Ramsar sites information service. Available via https://rsis.ramsar.org/ris-search/332?pagetab=0 Accessed 2 Mar 2020

Saaty, T.L. 2008. Decision making with the analytic hierarchy process. *International Journal of Services Science* 1(1): 83–98. https://doi.org/10.1504/IJSSCI.2008.017590

Salazar-Navarro, K., A.D. Olortigue-Tello, H. Aponte and T. Lobato-de Magalhães. 2020. Wetland Science in Latin America and the Caribbean Region: Insights into the Andean States. *Wetland Science and Practice* 37(4): 232-240.

Schofield, K.A., L.C. Alexander, C.E. Ridley, M.K. Vanderhoof, K.M. Fritz, B.C Autrey, J.E. DeMeester, W.G. Kepner, C.R. Lane, S.G. Leibowitz and A.I. Pollard. 2018. Biota connect aquatic habitats throughout freshwater ecosystem mosaics. *JAWRA* 54(2): 372-399. https://doi.org/10.1111/1752-1688.12634

SEMARNAT. 2020. Política Nacional de Humedales. Available via https://agua.org.mx/wp-content/uploads/2017/07/politica-nacional-de-humedales.pdf Accessed 17 Mar 2020.

Smardon, R.C. 2006. Heritage values and functions of wetlands in Southern Mexico. *Landscape and Urban Planning* 74(3-4): 296-312. https://doi.org/10.1016/j.landurbplan.2004.09.009

van Dam, R.A., C.M. Finlayson and C.L. Humphrey. 1999. Wetland risk assessment. In: Finlayson, C.M., A.G. Spiers (eds.) Techniques for enhanced wetland inventory and monitoring. *Supervising Scientist Report* 147, 83-118, Canberra.

Zhang, K., C. Kluck and G. Achari. 2009. Comparative approach for ranking contaminated sites based on the risk assessment paradigm using fuzzy PROMETHEE. *Environmental Management* 44 (5): 952-967.

Zhao, M.Y., C.T. Cheng, K.W. Chau and G. Li. 2006. Multiple criteria data envelopment analysis for full ranking units associated to environment impact assessment. International *Journal of Environment and Pollution* 28 (3/4), 448-464.