Colegio de Postgraduados

Biological importance and environmental quality of the Laguna Santa Ana in Zacatecas, Mexico

Orozco-Salazar, A.[1]; **Macias-Patiño, M.**[2]; **Valdez-Romero, E.**[1]; **Delgadillo-Ruiz, L.**[1]; **Mercado-Reyes, M.**[1*]

[1] Unidad Académica de Ciencias Biológicas, Av. Preparatoria S/N Col. Agronómica, Zacatecas, Zacatecas, México, C.P. 98600.

[2] Unidad Académica de Ciencias Químicas/Programa de Ingeniera Química, Edificio E6, cubículo 7, Campus Siglo XXI, Carr. Zacatecas - Guadalajara Km. 6, Col. Ejido La Escondida, Zacatecas, Zacatecas, México, C.P. 98160.

* Correspondence: marisa.mercado@uaz.edu.mx

ABSTRACT

Objective: To determine the environmental quality and diversity of the waterfowl species of the Laguna Santa Ana, located in the municipality of Fresnillo, Zacatecas.

Design/Methodology/Approach: A physicochemical analysis of the water was carried out to determine its organic matter pollution. In addition, the Bradford method was applied to establish protein levels, and an optical emission spectrometry was conducted to detect heavy metals. The Shannon-Weiner diversity index (H') was carried out to identify and count the populations of the lagoon.

Results: The physicochemical analysis of water recorded 55 and 230.6 mg/L BOD5 and COD, respectively. High protein levels (0.27-2.95 mL/mL) indicated organic pollution and high arsenic levels. The Shannon-Weiner index (2.7) recorded a high waterfowl diversity.

Study Limitations/Implications: Biological abundance was not determined, as a result of the sample size. The changes regarding waterfowl diversity may be the consequence of the seasonal conditions.

Findings/Conclusions: The Laguna de Santa Ana has a high waterfowl diversity, including species of international interest; however, organic pollution has caused a a significant environmental deterioration.

Keywords: wetlands, organic pollution, waterfowl, Zacatecas.

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INTRODUCTION

As a result of their environmental characteristics, wetlands are the most productive ecosystems of the planet. They perform different ecological functions during hydrological and chemical cycles (Carrera, 1999). Mexico is located between the Nearctic and Neotropical biogeographic regions. This situation provides the country with a wide soil, climate, and ecosystem diversity, enabling the development of a wide variety of wetlands. Mexico has 11.4 million hectares of wetlands. Out of this total, 56% are located in the mainland (DUMAC, 2020) and are the habitat of different Nearctic resident and migratory waterfowl species (Baldassare and Bolen, 1994; Wilson and Ryan, 1997). The biological diversity of the wetlands is related to their biota and geographical location within the Mexican territory

(Cervantes, 2007). Five physiographic regions converge in the Mexican plateau: Sierra Madre Occidental, Central Plateau, Sierra Madre Oriental, Bajío, and the Trans-Mexican Volcanic Belt (Leopold, 1959). The three first areas make up the Northern plateau, where the State of Zacatecas is located. The wetlands of this area include permanent and seasonal swamps, and they are located in enclosed basins or endorheic wetlands. Wetlands have been substantially altered or destroyed by agriculture, overgrazing, pollution, salinization, and industrial use (Carrera and de la Fuente 2003, Clemente *et al.*, 2014). The Laguna Santa Ana is a lacustrine system with a permanently flooded subsystem and saline brackish (Semeniuk and Semeniuk, 1997). This wetland is vital for the recharge of the basins of the hydrological area of El Salado, the Fresnillo-Yesca basin, and the Fresnillo sub-basin (CONAGUA, 2015). It is part of the Central Migration Route of the American waterfowls and, consequently, it is their habitat during winter (Roberts *et al.*, 2023). The sandhill crane (*Antigone canadensis* Linnaeus, 1758) and the Mexican duck (*Anas diazi* Ridgway 1886) are the most important waterfowl species of this area. Mainly as a consequence of the destruction of their habitat, sandhill cranes are considered vulnerable and are included in the threatened species list for this area (Clemente-Sánchez *et al.*, 2014). In addition, due to its population dynamics, the Mexican duck is also included in the NOM-059-2010, as a threatened species. Other species of national and international interest in the area include the northern shoveler (*Spatula clypeata* Linnaeus, 1758) and the greater white fronted goose (*Anser albifrons* Scopoli, 1769). However, the wetland faces major problems that cause great damages to the area. Some of these problems include approximately 172,000 ha close to the wetland that are mainly used for irrigated agriculture (CONAGUA, 2015) and livestock raising (mainly cattle and horses). In early 2000, a brewery started to discharge treated water into the wetland. In addition, wastewater from the nearby Santa Ana community, garbage, and poaching have damaged the environmental quality of the wetland. Therefore, the hypothesis of this research was that the Laguna Santa Ana has a low environmental quality, as a consequence of the damage caused to the ecosystem, reducing the occurrence of waterfowls in the area. Consequently, the objective of this research was to determine the environmental quality and waterfowl diversity of the Laguna Santa Ana, in Zacatecas, Mexico.

MATERIALS AND METHODS

Study area

The Laguna Santa Ana is in northern Zacatecas, in the municipality of Fresnillo (23° 13' 19.4" N, 102° 44' 01" W). According to the Koppen Climate Classification, modified by García (2004), the climate is BS1kw (semidry), with summer rains and a lower proportion of winter rains.

Water sampling collection and waterfowl diversity analysis

In order to determine the water quality of the area where migratory and resident waterfowls inhabit, a manual punctual water sampling was carried out in 12 strategic points, following the guidelines for monitoring discharges and superficial and underground water (Contreras *et al.*, 2004). The samplings were divided as follows: the samples from points 1 to 8 were taken from the inner lagoon, near the discharge and the waterfowl areas, while the samples from points 9 to 12 were taken from the course of the discharge of the brewery; the aim of this process was to determine protein content. The samples were observed under a microscope to identify water microhabitats and microorganisms.

In order to determine water quality, samples were taken from 4 strategic points, taking care to prevent air bubbles, at a 15-30 cm depth. The samples were stored in a cooler until the lab analysis was carried out, following the guidelines of the Norma Mexicana de Aguas Residuales (DOF, 1980).

An intensive monitoring was carried out to determine biological diversity, following the fixed radius point count method (Hernández *et al.*, 2019). The procedure was carried out during winter (January and February 2019) when waterfowls are present in the wetlands. The monitoring points were established at less than 50 m from the birds. Four collaborators counted the specimens. They were distributed around the area where the waterfowls were located, near the discharge of the treated water released by the brewery. Optical equipment, including 30×50 binoculars and telescopes, were used, following the guidelines of the Manual para monitores comunitarios de aves (Ortega *et al.*, 2012). A reference bibliography specialized on Mexican waterfowl was used to identify the species (Peterson and Chalif, 1989; DUMAC, 2009). Subsequently, the data were subjected to a Simpson's diversity index (DSi) and the Shannon-Weiner diversity index (H') to determine the waterfowl species diversity (Roswell *et al.*, 2021).

Quality analysis of the water from the Laguna Santa Ana

The field water samples were subjected to a quality evaluation, using different types of analyses. The Bradford method or Coomassie brilliant blue (Bradford, 1976) determined the protein levels of the samples, while the physicochemical characteristics of wastewater were established using the method proposed by the Norma Mexicana de Aguas Residuales (DOF, 1980). An optical emission spectrometry with an induced coupled plasma was used to detect heavy metals in the water and soil of the reservoir, following the recommendations of the NOM-147-SEMARNAT/SSA1-2004 (DOF, 2004).

RESULTS AND DISCUSSION

Protein analysis

The Bradford method indicated a 0.27-2.95 μL/mL range of protein concentration, recording higher values in spring (Table 1). The protein content in the samples was associated with the presence of bacteria. According to Saker *et al.* (2022) microorganisms in polluted water increase during the warmest seasons of the year, because high temperatures are ideal for the reproduction of microorganisms.

Previous studies suggest that proteins can be found in water polluted by industrial discharges. This situation allows the formation of decomposers, which are microhabitats for different invertebrates, including arthropods that are a great part of the waterfowls' diet, including the following families: Chironomidae, Cyprididae, Corixidae, and Hyalellidae. These species are deeply related to polluted environments, because they are resistant to environmental conditions altered by organic matter and heavy metals (Tapía *et al.*, 2018).

Table 1. Protein levels during the three sampling periods (2019).

1	**2**	**3**
15/03/2019	**29/04/2019**	**11/09/2019**
1.7 μL mL^{-1}	2.95 μL mL^{-1}	0.27 μL mL^{-1}

The analysis identified the presence of the Spirulina (*Arthrospira*) micro-algae (Figure 1). Gutierrez-Salmeán *et al.* (2015) have described the high protein, fatty acids, carbohydrates, minerals, and vitamin content of these micro-algae.

Physicochemical analysis of water from the Laguna Santa Ana

Regarding the physicochemical analysis, water recorded a 9.16±0.56 average between the sampled areas. Castro-González *et al.* (2019) studied the water from the Río Grande in Texas, USA, and established that an alkaline pH indicated that metals could precipitate in the sediments or be absorbed by other suspended particles.

The physicochemical studies carried out in this research found heavy metals in the water, with high arsenic (As) content (59 ppb) in the area of occurrence of the birds and a higher As content (434 ppb) in the innermost sample collection point of the lagoon. Del Águila-Juárez *et al.* (2005) reported >1 Cr and Cd values, proving a moderate pollution level in the Lerma River basin. These results match the Cd findings of this research; the

Figure 1. A: Aquatic microhabitat; B: Paramecium with Spirulina parts inside it; C: Spirulina and Protist; D: Arthropods.

>1 values obtained suggest that the Laguna Santa Ana has a moderate-to-minimum pollution level.

CONAGUA (2013) has established chemical oxygen demand (COD) and biological oxygen demand (BOD5) as organic matter pollution indexes (Table 2). Consequently, high levels of both indexes indicate a high pollution level, taking into account that CONAGUA (2013) has established that the parameters for BOD5 are >30-<120 (polluted) and >120 (very polluted) and for COD are >40-<200 (polluted) and >200 (highly polluted).

Migratory waterfowl diversity analysis

The monitoring identified 22 waterfowl resident and migratory species in the area (Figure 2). The Shannon-Weiner Diversity Index and the Simpson's Diversity Index recorded 2.7 and 0.076 values, respectively, suggesting a high diversity level (Roswell, 2021).

The higher number of waterfowls was recorded in the effluent, the reservoir, and the mouth of the treated water discharge of the brewery, which is in the municipality of Calera de Víctor Rosales. The pollution and turbidity levels are lower in this area and the water oxygenation values (up to 9.6 mg/L) are permissible for aquatic life, according to

Table 2. Pollution index results from the Laguna Santa Ana.

Variable	Point 1	Point 2	Point 3	Point 4
Temperature °C	14	15	19	20
pH	8.51	8.88	9.61	9.67
Total dissolved solids mg L^{-1}	2.76	2.32	19	16.9
Conductivity mhos/cm	5.43	4.64	38	33.7
Total hardness as ($CaCo_3$) mg L^{-1}	111	89	322	111
Chlorides (-Cl) mg L^{-1}	273	332	6,986.00	3.72
Nitrates (NO_3) mg L^{-1}	1.5	0	1.9	4.7
Total phosphorus mg L^{-1}	158	130	310	680
Total phosphates mg L^{-1}	154	102.5	257.5	570
Total nitrogen Kjeldahl mg L^{-1}	5	0	6.25	15
Dissolved oxygen mg L^{-1}	9.6	5.9	6.1	6.1
Turbidity NTU	38	369	102	216
Free residual chlorine mg L^{-1}L	0	0	0	0
COD mg L^{-1}	65	137	719	1.195
BOD_5 mg L^{-1}	98	31	27	64
Total Coliforms NMP mL^{-1}	7	15	<3	<3
Coliformes fecales MPN mL^{-1}	<3	4	<3	<3
E. coli units	Positivo	Positivo	Negativo	Negativo
Mercury mg kg^{-1}	<1	<1	<1	<1
Chromium mg kg^{-1}	0.03	0.02	0.05	0.08
Lead mg kg^{-1}	0.16	0	1.36	0.11
Arsenic mg kg^{-1}	59	49	43	434

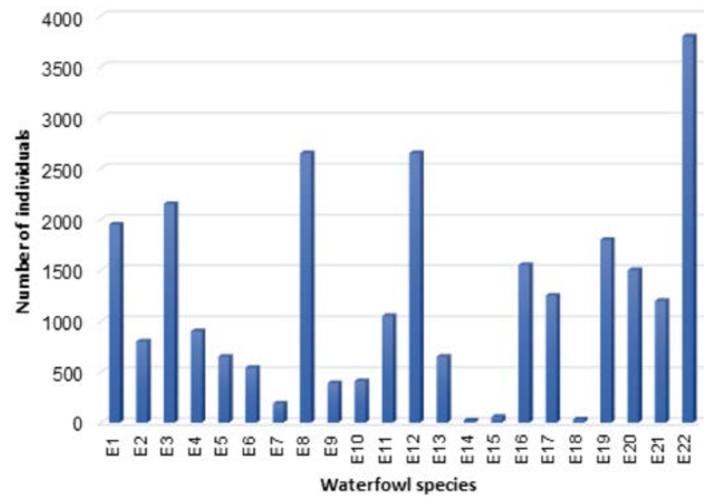

Figure 2. Number of individuals per species. E1: *Anas acuta*; E2: *Anas americana*; E3: *Anas clypeata*; E4: *Anas cynaptera*; E5: *Anas discords*; E6: *Anas creccacarolinensis*; E7: *Anas platyrhinchos*; E8: *Anas steptera*; E9: *Aythya affinis*; E10: *Bucephala albeola*; E11: *Oxyura jamacinensis*; E12: *Anser albifroms*; E13: *Chen caerulescens*; E14: *Ardea herodias*; E15: *Bubulcus ibis*; E16: *Fulica americana*; E17: *Himantopus mexicanus*; E18: *Pelecanus erythrorhynchos*; E19: *Recurvirostra americana*; E20: *Actitis macularius*; E21: *Calidris melanotos*; E22: *Antigone canadensis*.

CONAGUA (SEMARNAT, 2013). A higher number of waterfowls have been reported in the treated water discharge areas of the wetlands, possibly as a consequence of its increase of nutrients and the formation of artificial wetlands. The high pollution levels of these areas can be an important source of diseases (Jarma *et al.*, 2021).

The counting identified 22 waterfowl species, including the sandhill crane, which recorded the highest number of individual (3,800) in the lagoon. This result is extremely important, because this species is included in the special protection category of the NOM-059-SEMARNAT-2010 (DOF, 2010). Consequently, this wetland is very important for waterfowl diversity and as habitat for migratory species. Clemente (2014) pointed out that the state of Zacatecas is in the southern limit for the migration of this species and that the wetland of the Laguna Santa Ana is part of their winter habitat.

The diversity of waterfowl species in the Laguna Santa Ana suggests its biological importance as a winter habitat for migratory species. Ayala *et al.* (2013) reported similar biodiversity indexes in other regions, including the Tláhuac swamp and the Chalco and Mexico lagoons, which they describe as "important areas for bird preservation." The Laguna de Santa Ana has a high diversity index. On the one hand, the presence of internationally important migratory birds and threatened bird species, such as the sandhill crane, shows its importance as habitat for priority species. On the other hand, the wetland is moderately polluted, which damages its environmental quality. However, organic matter pollution can alter the food habits of some duck species, as a consequence of the increase of the invertebrate populations that are part of their diet (Szalay and Resh, 2000). Meanwhile, the environmental degradation of the wetlands could cause a long-term damage to the waterfowl population (Cotín, 2012). Therefore, determining the anthropogenic vulnerability of the wetland is fundamental, as well as the pollution to which it is exposed. In addition, restoration and preservation actions should be carried out, since this research shows the biological importance of the area as a habitat for internationally important waterfowl species.

CONCLUSIONS

The water quality analysis recorded low-moderate to high pollution values, depending on the area of the lagoon where the sample was taken from. The results highlight the arsenic content of the whole lagoon. The diversity indexes recorded high values regarding migratory waterfowl species, including ecologically important species listed under the preservation status of the NOM-059-SEMARNAT-2010.

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