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Wetland nutrient assessment in lake Patzcuaro, Michoacan, Mexico

Evaluación de nutrientes en el humedal del lago de Patzcuaro, Michoacan, Mexico

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Abstract

In the current project we have the opportunity to show a Wetland ecosystems are also located inside freshwater lakes as in Patzcuaro considered one of the most important natural lakes of Mexico due to its environmental, economic, cultural and social attributes. Extensive areas of this lake, its fauna, native flora and watershed are severely affected by sewage without treatment, fertilizers non-point runoff derived from agriculture, deforestation, and inadequate land use change. Within the most altered aquatic components from these processes is the wetland ecosystem which is the objective of this study because of its ecological and biogeochemical importance in Lake Patzcuaro. In this study the dynamics of total phosphorus and inorganic nitrogen inside the littoral wetland located in the southern shore of Patzcuaro where seven sites were established located inside the wetland, limnetic zone, and an underwater spring in a transect of 1,500 m long. The obtained values of dissolved total phosphorus and inorganic nitrogen indicated that these nutrients are retained when these components crossed the wetland ecosystem in 67.5% and 70.8% respectively. Hence, the wetland ecosystem is functioning as natural filter and the inputs from other pathways are deteriorating lake water quality.

Wetlands, Shores, Nutrients

Resumen

Dentro de los ecosistemas acuáticos se encuentran humedales como los que se encuentran en Pátzcuaro considerado uno de los lagos más importantes de México por sus atributos ambientales, económicos, culturales y sociales. Grandes extensiones del lago, así como su fauna, flora nativa y su cuenca son afectados por la descarga de aguas negras sin tratamiento, escurrimientos difusos con fertilizantes de la agricultura, deforestación y cambio inadecuado del uso de suelo. Entre los componentes acuáticos que han sido severamente alterados por estos procesos se encuentra la zona de humedal, que es el objeto del presente estudio por su importancia ecológica y biogeoquímica en el lago de Pátzcuaro. En este estudio se determinó la dinámica de fósforo total y nitrógeno inorgánico, en el humedal del litoral sur de Pátzcuaro, donde se establecieron siete sitios, ubicados dentro del humedal, zona limnética y un manantial en un transecto de 1500 m. Los valores obtenidos de concentraciones de fósforo total y nitrógeno inorgánico en agua indican que estos nutrientes son retenidos cuando pasan a través del humedal en 67.5% y 70.8% respectivamente. Por lo tanto, el humedal funciona como filtro natural y las entradas por otras vías están alterando las aguas del lago.

Humedales, Litorales, Nutrientes

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Introduction

Wetlands represent a transitional ecosystem between the terrestrial and aquatic environment where converge physical, chemical and biological processes which of fundamental importance for the function of a lake. This wetland zones are of high fragility given that these receive the first siltation discharges and deposition, hydraulic stagnation, organic matter decomposition, evaporation and desiccation. Wetlands vary in relation to its origin, size, geographical location, hydraulic regime, chemistry, vegetation, soils, and sediments (Maltby and Acreman, 2011). However, wetlands are ecosystems of high benefit since these control erosion and siltation through solid retention, furthermore wetlands capture sediments and filtrate pollutants improving water quality in lakes and rivers.

Wetlands are considered as landscape filters due to the role these have in the hydrological and biogeochemical cycles whether from natural or human sources, hence as organic and inorganic matter transformers wetlands have a very important role in the watershed nutrient cycling (Mitsch and Gosselink, 2015).

Wetlands can function as sinks, that is the net retention of a specific element or compound in which the inputs are larger than outputs. Wetlands also can be suppliers as these can export materials and compounds to another ecosystem outside of the wetland. Wetlands can be transformers from materials to compounds equivalent in amounts of input and outputs. Furthermore, wetlands are adjacent ecosystem connectors.

The degradation and loss of wetlands have resulted in the reduction of benefits and environmental services associated to ecosystem functional relationships as habitat for wildlife including fish, amphibians, reptiles, birds and mammals.

This ecosystem is highly productive due to its high organic matter and nutrient enrichment than can be regulated and transferred to open waters to increase aquatic productivity including phytoplankton and zooplankton (Alcocer et al., 2023)

Lake Patzcuaro located in the State of Michoacan, is one of the most important Mexico lakes due to its ecological importance, cultural identity and the presence of native and endemic aquatic fauna including the white fish (*Chirostoma estor estor*), acumara (*Algansea lacustris*), several species of the Goodeidae family, and the salamander known as the achoque (*Ambystoma dumerilii*). However, environmental degradation, pollution, introduction of invasive species, overexploitation, and climate change threaten the existence of these species in the lake (Suazo-Ortuño et al., 2023).

Hence it is of fundamental importance to generate criteria to preserve the structure and functional relationships of wetlands focusing on efficient strategies for ecological restoration.

Therefore, the objective of this research was to evaluate the nutrient dynamics of the wetland ecosystem located in the littoral shore of southern Lake Patzcuaro, Michoacan, Mexico.

Methods

Site selection

The wetland site under study is in the southern shore of Lake Patzcuaro. The area is covered by a complex vegetation association of hydrophyte plants species which are distributed in a profile according to the slope and depth of the water column. Aquatic vegetation is represented by 49 species included in 23 families (Lot and Novelo, 1988). The wetland water flood is permanent with fluctuations caused by rainfall. These fluctuations are controlled by differences between rainfall and evapotranspiration (Bernal-Brooks et al., 2002) and therefore lake surface also varies (Gómez-Tagle Chávez *et al.* 2002). See figure 1.

Figure 1 Geographical location of Lake Patzcuaro, Michoacán, Mexico

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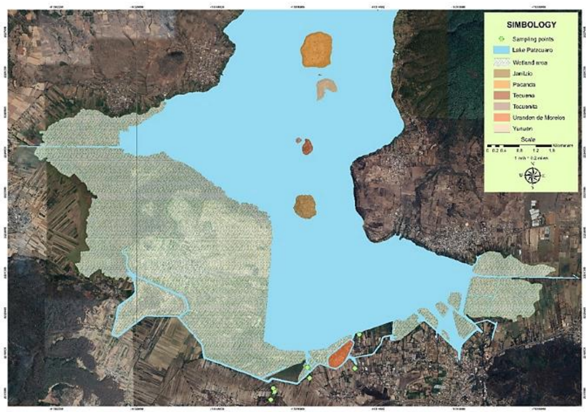
Lake Patzcuaro is in the south of the Mexican Altiplano in the following extreme UTM coordinates: 245000E – 2185000N and 197000E – 2140000N, on the southern lake shoreline. Criteria for sampling site selection included low depth, slope profile, transitional environment between land and lake water, close interaction between water and sediments, aquatic and semi aquatic vegetation profile, total solar light penetration from surface to bottom and nutrient availability in water and sediments (Figure 2).



Sampling sites: 1 = Wetland inlet, 2 = Medium wetland; 3 = Wetland outlet; 4 = Dredged channel; 5 = Water spring; 6 = Limnetic zone and 7 = Uranden Island dock

Figure 2 Wetland surface area in southern shore of Lake Patzcuaro, Mexico

Sampling

The sampling transect consisted of a 268 m in total length, including wetland environment, an artificial dredged channel, and open water with a depth interval of 0.20 – 1.5 m. Total surface area was 50.0 ha.

Sampling sites were located using a GPS receptor in Universal Transverse Mercator cartographic projection units (UTM) (Table 1).

SITE NAME	SITE	DESCRIPTION	X UTM	Y UTM
San Pedro Pareo	1	Wetland input	220929	2162020
	2	Wetland middle	221020	2162200
	3	Wetland output	220991	2162288
Uranden de Morelos	4	Artificial and dredged channel	221850	2162509
	5	Uranden native fish reserve*	221801	2162758
Open water	6	Open water	223030	2163510
	7	Uranden dock*	222914	2162721
* Water springs presence.				

Table 1 Location of sampling stations

Sampling was carried out during a period of one year including rainfall and dry seasons. Flow measurements were made at the input site of the wetland by the float technique and the Manning's equation (ILRI, 1981). Simultaneously with field sampling measurements of electrolyte conductivity, pH, and dissolved oxygen were made using a field PC-18 conductivity meter and pH. Dissolved oxygen was measured using a YSI model 52-B oxygen meter. Turbidity was measured by using a HACH 2100P turbidity meter.

Integrated water samples were collected using a Van Dorn Bottle and sediments were obtained using an Eckman dredge. Samples were transported in an ice box to the laboratory for immediate analyses.

Water quality analyses

Physicochemical variables analyses followed the criteria of APHA (2005) 21st Edition, including settleable solids, suspended solids, alkalinity, total hardness, calcium, magnesium, nitrites, nitrates, ammonia, total phosphorus, dissolved reactive phosphorus and dissolved organic matter.

For sediment analyses concentration of nitrites, nitrates, ammonia, total phosphorus and reactive phosphorus were made using different techniques (Mudroch *et al*. 1996; EPA-600/4-79-020, In: Csuros, 1997).

Results

Within the most significant results associated to the wetland biogeochemical processes are nutrients represented by inorganic nitrogen compounds, phosphorus compounds, settleable solids, turbidity, conductivity and pH (**Table 2**)

VARIABLE	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7
Temperature (°C)	16.63	17.13	18.38	20.73	19.88	20.65	20.88
Electrical conductivity (µS/cm)	496.25	390.50	360.75	423.50	330.25	755.75	351.00
Hydrogen potential (pH)	7.07	7.34	6.74	8.07	7.31	8.08	8.69
Turbidity (NTU)	4.00	5.42	2.01	19.65	6.33	73.23	10.25
Suspended solids (mg/L)	10.21	21.33	5.12	20.99	9.30	48.56	20.50
Seatteable solids (mL/L)	1.18	1.00	0.10	0.08	0.05	0.10	0.05
Alkalinity phenolphtalein (mg/L)	0.00	0.00	0.00	5.22	0.92	14.25	3.00
Total alkalinity (mg/L)	221.58	214.15	173.92	181.96	149.15	364.99	119.40
Dissolved oxygen (mg/L)	3.35	2.70	1.88	7.04	2.73	4.55	11.00
Total hardeness (mg/L)	225.75	154.07	105.42	110.82	104.59	166.67	82.00
Hardness due to calcium (mg/L)	46.41	29.38	18.12	18.91	17.19	18.24	14.15
Hardness due to magnesium (mg/L)	26.64	19.54	14.58	15.24	14.83	29.39	11.34
Ammonia (mg/L)	0.41	0.10	0.23	0.06	0.05	0.12	0.06
Nitrites (mg/L)	0.21	0.01	0.003	0.08	0.00	0.02	0.30
Nitrates (mg/L)	1.87	1.50	0.49	0.74	0.60	1.62	0.59
Total inorganic nitrogen (mg/L)	2.50	1.61	0.73	0.88	0.66	1.77	0.95
Dissolved reactive phosphorus (µg/L)	238.67	183.98	68.00	20.65	96.34	78.53	17.18
Total phosphorus (µg/L)	454.46	323.09	147.69	114.70	174.74	196.79	161.39

Table 2 Water quality values from the wetland, limnetic zone, and southern shoreline of Lake Patzcuaro.

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Settleable solids presented a decrease from site 1 to site 2 (1.18 to 0.10 mL/L). Turbidity showed a decrease from the wetland input site to the wetland output (4.00 to 2.01 NTU). However, in the middle wetland site the turbidity value was higher (5.42 NTU). Electrolyte conductivity values showed a decreasing tendency from site 1 to site 3 (496.25 to 360.75 µS/cm) maximum value was measured in lake open water (755.75 µS/cm)

In the central area of the wetland pH values increased (6.74 to 7.07), the same pattern was observed in lake open waters (8.07 to 8.69).

Average nitrite concentrations were registered gradually from site 1 to site 3 (0.21, 0.01, and 0.003 mg/L) respectively. The artificial dredged channel nitrite values of 0.08 mg/L were obtained. Nitrate concentrations values followed the same pattern in sites 1,2, and 3 (1.87, 1.50, and 0.49 mg/L) respectively. For the other sites nitrates concentration values were different where the maximum value was found in site 6 where the native fish reserve is located (1.62 mg/L).

Ammonia concentrations showed a very clear difference throughout wetland sampling stations (0.41; 0.10 and 0.23 mg/L respectively), it was observed that the middle part of the wetland lower ammonia concentration was detected in comparison to station 3 located in the wetland output. Open water maximum concentration value was 0.12 mg/L.

Dissolved reactive phosphorus concentrations showed a gradual decrease from site 1 to site 3 (238.67, 183.98 and 68 µg/L respectively). High concentrations were detected in station 5 where the native fish reserve is located (96.4 µg/L) and station 6 in open limnetic environment (78.53 µg/L).

Total phosphorus concentrations decreased from station 1 to station 3 (454.46 to 147.69 µg/L). In the limnetic zone located as station 6 a concentration of 196.79 µg/L was detected. Cluster analysis for all variables (Figure 3) classified sampling stations values in three groups. Group 1 (sampling stations 1-4) corresponding to the wetland environment, group 2 (stations 5-6) located in channel and open water o limnetic zone, and goup three (station 7) located in the Uranden dock where water springs are located.

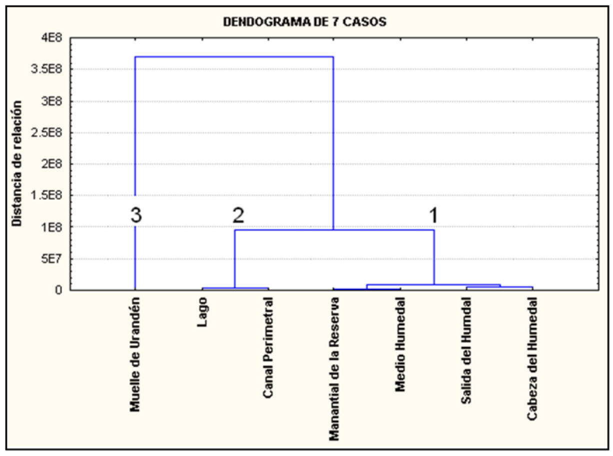

Figure 3 Spatial similarity in seven sampling stations

Results from sediments did not show a specific pattern but spatial variation (Table 3). However, maximum values were detected in the limnetic zone.

Variable	1	2	3	4	5	6	7
Ammonia (mg/kg)	88.58	66.73	69.64	118.65	96.34	134.98	99.76
Nitrites (mg/kg)	0.96	1.52	0.97	1.14	1.09	1.87	0.83
Nitrates (mg/kg)	127.64	104.93	112.19	173.30	97.64	123.75	100.17
Total inorganic nitrogen (mg/kg)	217.18	173.18	182.80	293.09	195.07	260.60	200.76
Dissolved reactive phosphorus (mg/kg)	18.88	32.97	19.02	28.74	11.25	29.81	23.11
Total phosphorus (mg/kg)	37.25	50.81	38.03	49.08	33.44	56.40	41.92
Organic matter (g/kg)	101.48	81.90	123.28	103.03	120.47	129.03	95.20

Table 3 Nutrient concentration in sediments

Ammonia sediment concentration were relatively low in the wetland environment (66.73 to 88.58 mg/kg) whereas higher concentrations were found in the limnetic zone (134.98 mg/kg). The rest of the sampling sites ranged from 96.34-118.65 mg/kg.

Nitrite concentrations were relatively low within a range of 0.83 mg/kg in sampling station 7, where water springs are located to 1.87 mg/kg in the limnetic zone. Nitrate concentrations values the range was from 97.64 to 173.30 mg/kg, where the minimum value was found in sampling station 5 corresponding to the water spring located in the native fish reserve whereas the highest concentration was in sampling station 4 near the artificial channel. Within the wetland environment no significant differences were observed in nitrate concentrations.

Dissolved reactive phosphorus showed a range from 11.25 to 32.97 mg/kg. The minimum value was detected in the native fish reserve whereas the maximum value was in sampling station 2 located in the middle wetland.

Total phosphorus values were spatially like dissolved reactive phosphorus where the maximum value was in sampling station 6 located in the limnetic zone (56.40 mg/kg) and the minimum value was recorded in sampling station 5 located the native fish reserve (33.44 mg/kg)

Discussion

During the period of sampling all sites were permanently flooded. Thus, wetland was always water saturated.

Previous studies have mentioned that the southern zone of Lake Patzcuaro is highly vulnerable due to the loss of open water coverage and morphometry deterioration trough time.

Settleable solids affect directly water transparency. In this study most of the settleable solids were mainly phytoplankton and periphyton associated to the wetland vegetation community

Although Secchi disc transparency was not possible to measure in sampling stations 1, 2, and 3 due to the macrophyte coverage, it was possible to use nephelometry indicating that turbidity is decreasing up to 49.75%

Water quality analyses results indicate a decreasing electrical conductivity of about 25% as water crosses the wetland. This suggests an equivalent of 27.30 % less in total dissolved solids.

Values of pH from the interior of the wetland showed a range from neutral to slightly alkaline indicating that bacterial decomposition stabilizes a buffer environment for the organic matter treatment.

Phosphorus concentrations indicate that the wetland metabolism allows the nutrient retention in 67.50% in dissolved reactive and total phosphorus improving in consequence water quality.

Different nitrogen forms detected inside the wetland suggest this element is affected by the amount of dissolved oxygen, pH and water temperature.

Nitrate in high amount in water and sediments is the result of its chemical stability and is the most oxidated form of nitrogen. Dissolve oxygen is the critical gas to reach oxidative forms of nitrogen. Despite dissolved oxygen was detected in the wetland environment it was possible to observe that organic matter decomposition and the oxidation process are near equilibrium.

Nitrites were the nitrogen form in minimum concentrations in water and sediments located in the interior of the wetland. This agrees with Kadlec and Wallace (2008) who reported that nitrites is chemically unstable in most wetlands and it is present in low concentrations. Higher amounts of nitrites indicate incomplete nitrogen assimilation or very high organic matter input possibly from anthropogenic sources.

Dissolved ammonia concentrations found around 0.5 mg/L were higher that maximum values tolerance in fish. Hence, this concentration of ammonia is toxic for some sensitive aquatic species (< 0.02 mg/L) (Sawyer and MacCarty, 1967). However, this compound is in ionized state due to the pH value less than 8.0. Ammonia was also detected in sediments in high concentrations with values up to 88.58 mg/kg, particularly in the input area of the wetland. Mitsch and Gosselink (2015) suggested than ammonia ion (NH_4^+) is the principal mineralized nitrogen form in most flooded soils of wetlands.

Phosphorus was detected in relative high concentrations in the wetland water column. However, in sediments amount of phosphorus were even higher. It is possible to consider that phosphorus in the wetland sediments is in the form of organic bounds or that inorganic phosphorus could be bound to mineral crystals of aluminium and iron as mentioned by Richardson (1985)

Conclusions

In summary the influence of the wetland ecosystem in the south of Lake Patzcuaro is of fundamental importance because this environment generates transitional protection boundary between the terrestrial and aquatic ecosystems. Moreover, wetlands represent a functional barrier to separate agriculture and human settlements from the lake ecosystem.

However, wetlands should be managed accordingly to avoid invasive species (Martinez-Jimenez and Gomez-Balandra, 2022) and to maintain an open water or limnetic environment to preserve natural lakes for hydrodynamic processes, aquatic productivity, fishing, navigation, and recreation.

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