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The works must be unpublished and refer to topics of agriculture-forest, pathology-sustainable, forest, management, horticulture, engineering and integrated water useand other topics related to Biotechnology and Agricultural Sciences.

Presentation of Content

Volume eight, issue fourteen, as the first article we present, *Wetland nutrient assessment in lake Patzcuaro, Michoacan, Mexico*, by CHACON-TORRES, Arturo, ROSAS-MONGE, Catalina and RENDON-LOPEZ, Martha Beatriz, with adscripction in the Universidad Michoacana de San Nicolás de Hidalgo and Instituto de Investigaciones sobre los Recursos Naturales, as a second article we present, *Use of silicon in the production of tomato (Lycopersicon esculentum Mill.) grape type in nutritive solution cultivation*, by SANCHEZ-MONTEON, Ana Luisa, JUAREZ-ROSETE, Cecilia Rocío, ALEJO-SANTIAGO, Gelacio and ABURTO-GONZÁLEZ, Circe Aidín, with adscripction in the Universidad Autónoma de Nayarit, as third article we present, *Dynamics of land use on the coast of delta Grijalva, Mexico, to generate development strategies*, by VILLA-PERALTA, Ana del Pilar, RAMOS-REYES, Rodimiro, MONTERO-GORDILLO, Nayme and SUAREZ-GARCIA, Sandra Manuela, with adscripction in the Instituto Tecnológico Superior de Centla, as fourth article we present, *Kinetics and diversity indices of phytoplankton in T´zonot type watery in Kopomá*, by VIZCAINO-RODRIGUEZ, Luz Adriana, RAVELERO-VAZQUEZ, Víctor, LUJAN-GODINEZ, Ramiro and CANUL-GARRIDO, Divino Miguel, with adscripction in Universidad Politécnica de la Zona Metropolitana de Guadalajara, Instituto Tecnológico de Tlajomulco and Univesidad Tecnológica del Poniente.

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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.

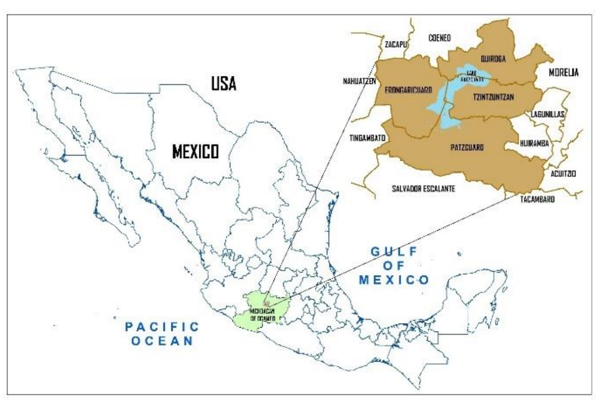

Figure 1 Geographical location of Lake Patzcuaro, Michoacán, Mexico

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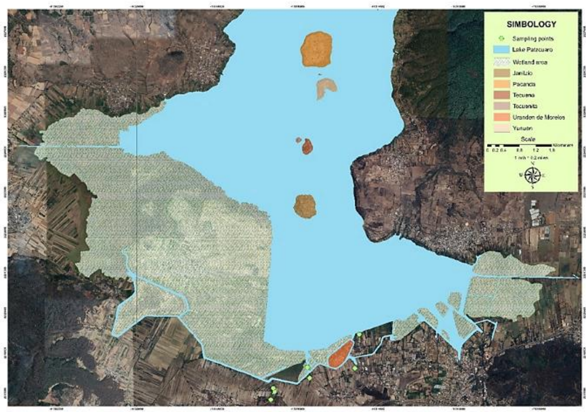
Lake Patzcuaro is in the south of the Mexican Altiplano in the following extreme UTM coordinates: 245000E – 2185000N and 197000E – 2140000N, on the southern lake shoreline. Criteria for sampling site selection included low depth, slope profile, transitional environment between land and lake water, close 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.

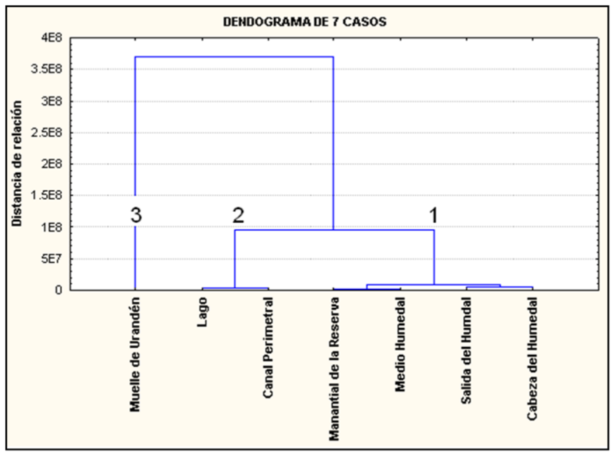

Figure 3 Spatial similarity in seven sampling stations

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.

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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)

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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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Article
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Use of silicon in the production of tomato (*Lycopersicon esculentum* Mill.) grape type in nutritive solution cultivation

Uso de silicio en la producción de tomate (*Lycopersicon esculentum* Mill.) Tipo grape en cultivo en solución nutritiva

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Abstract

The objective of the research was to evaluate the effect of silicon concentration and application method on growth and yield of grape tomato plants. An experiment was established under shade net conditions in solution culture. The factors evaluated were silicon concentration (0, 4, 6, 6, 8 and 10 g.L^{-1}) and application methods (to the nutrient solution and foliar). Nutrition was applied by irrigation of the universal nutrient solution (Steiner, 1984), at a concentration of 75%. The total number of treatments was 10. The design was completely randomized with four replications per treatment and based on the treatments, the following variables: plant height, root length, stem diameter, number of leaves, leaf area, fresh and dry weight of aerial and root biomass, number of fruits per plant, total yield and fruit diameter, length and weight. For the variables evaluated, it was identified that the concentration of 8 g.L^{-1} of SiO_2 applied to the root was the one that obtained the best value to favor vegetative growth and to obtain a greater fruit development for grape tomato plants of the Primarino variety.

Solutions, Silicon, Tomato

Resumen

El objetivo de la investigación fue evaluar el efecto de la concentración de silicio y el método de aplicación sobre el crecimiento y el rendimiento de las plantas de tomate uva. Se estableció un experimento bajo condiciones de malla sombra en cultivo en solución. Los factores evaluados fueron la concentración de silicio (0, 4, 6, 6, 8 y 10 g.L^{-1}) y los métodos de aplicación (a la solución nutritiva y foliar). La nutrición se aplicó mediante riego de la solución nutritiva universal (Steiner, 1984), a una concentración del 75%. El número total de tratamientos fue de 10. El diseño fue completamente al azar con cuatro repeticiones por tratamiento y con base en los tratamientos, las siguientes variables: altura de la planta, longitud de la raíz, diámetro del tallo, número de hojas, área foliar, peso fresco y seco de la biomasa aérea y radicular, número de frutos por planta, rendimiento total y diámetro, longitud y peso del fruto. Para las variables evaluadas, se identificó que la concentración de 8 g.L^{-1} de SiO_2 aplicada a la raíz fue la que obtuvo el mejor valor para favorecer el crecimiento vegetativo y obtener un mayor desarrollo de fruto para plantas de tomate uva de la variedad Primarino.

Soluciones, Silicio, Tomate

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Introduction

Within the vegetable group, tomato (*Solanum lycopersicum* Mill.) is a very dynamic crop due to the growing demand of the population. In Mexico, it is the first vegetable produced under protected conditions. Tomato is a herbaceous plant species of the genus *Solanum* of the Solanaceae family and species *Lycopersicum esculentum* Mill; it is native to Central America and Mexico. Tomato is one of the most cultivated Solanaceae in the world and has a large number of wild species (Reche, 2010).

One of the main problems faced by this crop is the affectation of diseases, for which different alternatives have been sought, finding a solution with the application of silicon. Silicon can be applied to the nutrient solution in different forms, such as monosilicic acid, potassium silicate, calcium silicate or sodium silicate.

Pozza *et al.* (2015), documented that the effect of silica application reduces the occurrence of diseases in dicots such as strawberry, soybean, rose and tomato; this is important, especially on safety and organic production (Gunes *et al*., 2007). The application of silica has reduced the incidence in tomato of diseases caused by pathogens such as *Ralstonia solanacearum (*Diogo and Widra, 2007) and *Pythium aphanidermatum (*Heine *et al*., 2007). In addition, Urrestarazu *et al*. (2016) reported, in a histological study conducted on tomato, that silica application increased cuticle thickness in leaves and stems.

The role of silicon in plant metabolism is not entirely clear and its essentiality as a nutrient is not proven, but the multiple benefits of silicon fertilization, especially in soilless cultivation, where this element is less accessible to plants, make some authors such as Sonneveld and Straver (1994) consider it an element in the basic solution in some crops (Urrestarazu, 2015).

A wide range of benefits that silicon provides to plants and the great role that it acquires as a protector against biotic and abiotic stresses have been described, making its addition to the nutrient solution used quite recommendable, being a useful tool for the sustainable agriculture that is currently demanded (Urrestarazu *et al*., 2016).

The supply of silicon depends exclusively on its concentration in the irrigation water used for the preparation of the nutrient solution, so if its concentration is low in the irrigation water, we can add an extra addition of silicon to the nutrient solution (Pozo *et al*., 2015).

Therefore, the objective of the present work was to evaluate the effect of the concentration and method of silicon application on the growth and yield of grape tomato plants, under the following hypothesis: The concentration and method of silicon application differ in their effect on the growth and yield of grape tomato plants.

Methodology

The experiment was conducted in a hybrid greenhouse, with a maximum height of 4.0 m and covered with plastic with 35% shading and 35% shade netting, it has wires for load support and is located at the Academic Unit of Agriculture of the Autonomous University of Nayarit, with the following coordinates: Latitude of 21˚ 25′ 36" N, Longitude 104˚ 53′ 28" W and a height above sea level 922 m.

The plants used were obtained from seeds of grape tomato variety Primarino from Rijk Zwaan®.

The seeds were placed for germination and development in a 200-cavity polystyrene container. The substrate used was sunshine peat® for germination.

Transplanting at the experimental site was performed when the seedlings had two true leaves and were five cm high. A solution culture system was used, which consisted of unicel cups with a capacity of two liters. An oxygenation system was installed in each of the containers.

The factors to be evaluated were the concentration of silicon to be supplied and the methods of application (to the nutrient solution and foliar). Nutrition was applied by irrigation of the universal nutrient solution (Steiner, 1984), at a concentration of 75% of all its ions. In this case, the total number of treatments was 10 (Table 1).

Treatment	Description
1	Nutrient solution (root) + 0 g.L^{-1} SiO_2
2	Nutrient solution (root) + 4 g.L^{-1} SiO_2
3	Nutrient solution (root) + 6 g.L^{-1} SiO_2
4	Nutrient solution (root) + 8 g.L^{-1} SiO_2
5	Nutritive solution (root) + 10 g.L^{-1} SiO_2
6	Nutrient solution (foliar) + 0 g.L^{-1} SiO_2
7	Nutrient solution (foliar) + 4 g.L^{-1} SiO_2
8	Nutrient solution (foliar) + 6 g.L^{-1} SiO_2
9	Nutrient solution (foliar) + 8 g.L^{-1} SiO_2
10	Nutrient solution (foliar) + 10 g.L^{-1} SiO_2

Table 1 Description of treatments

The design was completely randomized, with four replicates per treatment. The experimental unit was a pot with one plant.

The nutrient solution was maintained at a pH range of 5.5 to 6.5 during the evaluation period and soluble fertilizers were used for its preparation. The nutrient solution was renewed every two weeks during the vegetative stage and every week during the flowering and production stage. Constant oxygenation was maintained by means of an air compressor. The nutrient solution lost by evapotranspiration was renewed every 48 hours. Insect and disease control was done with preventive applications. The plants were trained on a transverse wire for load support using hooks, rings and raffia for this purpose.

Morphological variables s evaluated

Plant height

Plant height was evaluated in centimeters on days 24, 31 and 38 after transplanting (ddt) from the substrate level using a flexometer graduated in cm.

Root length

This variable was measured on the last day of the experiment using a flexometer graduated in cm.

Stem diameter

This variable was measured in centimeters on the last day of the experiment with a Foy analog vernier®.

Number of leaves as

The number of leaves per plant was counted at the time the experiment was concluded.

Leaf area r

Leaf area in cm^2 was determined at the end of the experiment using a CID Biosciences model CI-202 Portable Laser Leaf Area Meter®.

Fresh and dry weight of aerial and root biomass

The aerial part of all plants was cut and the fresh weight of the aerial part and the fresh weight of the root were recorded with a digital balance (Ohaus® CS200, China). The material was dried in a forced air oven at 70 °C to constant weight to record the dry gram weight of the aerial part and the dry weight of the root.

Performance variables evaluated:

Number of fruits per plant

Fruits were counted during the evaluation period (3 weeks).

Total yield

The fruits harvested in each cut were weighed by treatment using a digital scale Joma Center® I-2000 (China).

Fruit diameter, length and weight

Fruit diameter was measured in cm with a Foy analog Vernier® . Fruit length was measured with a ruler graduated in cm. Fruit weight was recorded in grams using a digital scale Joma Center® model I-2000 (China).

Statistical analysis

Experimental data were analyzed under a factorial model with the statistical program SAS (2009) and means will be compared with Tukey's test (Steel and Torrie, 1960).

Results

The analysis of variance showed significance for the factor [Silicon] for the variables root length and leaf area. For the factor Method of application, it showed significant differences for the variables number of leaves and leaf area. And the interaction [Silicon] x application method only showed significant differences for the leaf area variable (Table 2).

Source of variation	G. L.	Root length (cm)	Stem diameter (mm)	Number of sheets	Leaf area $(cm)^2$
		Pr>F			
[Silicon]	4	0.0074 *	0.705	0.1021	<0.0001 *
Method of application	1	0.1769	0.3055	0.0493 *	<0.0001 *
[Silicon] x Method of application	4	0.554	0.559	0.1257	<0.0001 *
CME		15.31	0.023	1.788	24531.56
CV		16.18	14.79	14.35 *	12.54
C.V.: Coefficient of variation Values with ¨*¨ in each variable show differences					

Table 2 Analysis of variance for morphological variables in grape tomato during the evaluated period

Plant height

During the different measurement dates, there were no differences in any of the different measurement dates (Table 3). These results differ from those reported by Borda *et al.* (2007) in the cultivation of forage oats (*Avena sativa* L.) where the contribution of silicon favored cell elongation, greater turgor and efficient conversion of assimilates. These three effects resulted in a greater increase in height and stem diameter.

SiO concentration$_2$ g.L^{-1}	24 ddt	31 ddt	38 ddt
0	68.875 a	99.625 a	124.750 a
4	72.875 a	105.625 a	131.875 a
6	64.875 a	98.375 a	128.625 a
8	68.938 a	104.250 a	132.000 a
10	64.750 a	91.959 a	121.959 a
Method of application			
Root	69.725 a	102.150 a	102.150 a
Foliar	66.400 a	97.784 a	97.784 a

Table 3 Mean values for height of grape tomato plants measured during the period evaluated. Means with different letters in each variable are significantly different (Tukey P≤0.05)

Root length

For the factor [Silicon], the one that obtained the highest value for root length was obtained with the treatment of 0 g.L^{-1} of silicon, while differences were found with the concentration of 10 g.L^{-1} where was reduced by 25.47 % with respect to the control. However, the treatments of 4 g.L^{-1}, 6 g.L^{-1} and 8 g.L^{-1} showed no significant difference with respect to the treatment of 0 g.L^{-1} (Table 4). This differs with the experiment of Villalón-Mendoza *et al.* (2018) in the cultivation of chile piquín (*Capsicum annuum* L. var. Glabriusculum) where fertilization with silicon at different concentrations did not obtain differences on root length.

Stem diameter

This variable did not show significant differences during the experiment. Contrary to the statements of Amador *et al.* (2013) where in sugarcane crops, the stems where silicon was applied showed a 14% thickening compared to the control. Quero (2008) mentions that, apart from grasses, silicon is often essential for crops such as tomato and cucumber, where he gives as an example the biological presence of silicon.

Number of leaves

The mean test showed no significant differences for the factor [Silicon] On the other hand, Bent (2008), affirms an increase in the number of leaves in cucumber (*Cucumis sativus*) due to the supply of silicon during the development of the crop.

For the application method factor, the highest number of leaves was obtained with root application, exceeding foliar application by 8.88%. Although no pest or disease damage occurred in the present work, Gómez-Camacho, *et al.* (2006) reported greater resistance in leaf tomato (*Physalis philadelphica*) plants to wilt caused by *Fusarium oxysporum*, where the plants were applied soluble silicon at 0.1 and 0.2%.

Leaf area

With the application of 8 g.L^{-1} of silicon via root, a greater leaf area was obtained with an increase of 39.67% with respect to the control, while the foliar application of 6 g.L^{-1} of silicon reduced the leaf area 35.42% with respect to the treatment of 0 g.L^{-1}. Therefore, if the leaf area is to be increased, the most appropriate treatments would be doses between 6 and 10 g.L^{-1} via root and 8 to 10 g.L^{-1} via foliar (Figure 1). The leaf area index provides information on the amount of photosynthetic surface present in relation to the total surface of the ecosystem or study area and is related to vital processes such as photosynthesis, respiration and productivity (Nafarrete, 2017).

The leaf area of plants changes once leaves reach maturity, after it has fully developed, the plant loses leaves because of ethylene synthesis and sensitivity to ethylene (Yepes & Buckeridge, 2011).

SiO_2 concentration g.l.$^{-1}$	Root length (cm)	Stem diameter (mm)	Number of sheets	Leaf area (cm)^2
0	25.7 a	1.07 a	9.12 a	1027.0 c
4	24,513 ab	1.05 a	10.25 a	1000.77 c
6	26.32 a	0.97 a	8.37a	1027.2 c
8	25.0 a	1.00 a	9.62 a	1763.77 a
10	19.2 b	1.02 a	9.20a	1423.04 b
Method of application				
Root	25.0 a	1.05 a	9.75 a	1363.34 a
Foliar	23.3 a	1.000a	8.8 b	1133.43 b

Table 4 Mean values of morphological variables in grape tomato plants by effect of silicon concentration and application method. Means with different letters in each variable are significantly different (Tukey P≤0.05)

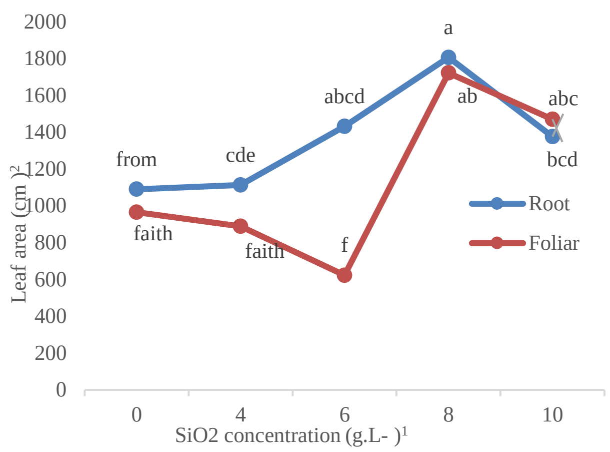

Figure 1. Interaction of different treatments and concentrations for leaf area

The analysis of variance showed no differences in any of the study variables for the factor [Silicon]. For the application method factor, there were significant differences for the variables of aerial biomass dry weight and root fresh and dry weight (Table 5).

Source of variation	G.L.	Fresh weight of aerial biomass (g)	Root fresh weight (g)	Dry weight of aerial biomass (g)	Root dry weight (g)
		Pr>F			
[Silicon]	4	0.5419	0.7444	0.7098	0.4539
Method of application	1	0.0802	<0.0001 *	0.0318 *	0.0016 *
[Silicon] x Method of application	4	0.2952	0.0913	0.0460 *	0.2524
CME		937.27	556.65	33.48	31.90
CV		19.57	23.48	20.19	37.19*

Table 5 Analysis of variance for fresh and dry weight of aerial and root biomass in grape tomato during the evaluated period. C.V.: Coefficient of variation Values with ¨*¨ in each variable show differences

It was observed that the fresh weight of the root with the application of silicon via root had a weight gain of 32.41% compared to the foliar application. Similarly, in root dry weight, a weight increases of 33.90% was obtained with the application of silicon via the root as opposed to the foliar application.

For the variable of aerial biomass dry weight, the one that obtained the highest value was the silicon application to the root with 13.41% more weight compared to the foliar application (Table 6).

SiO concentration$_2$ g.L^{-1}	Fresh weight of aerial biomass (g)	Root fresh weight (g)	Dry weight of aerial biomass (g)	Root dry weight (g)
0	143.88 a	93.88 a	30.40 a	12.05 a
4	169.50 a	108.13 a	29.41 a	16.21 a
6	157.00 a	100.00 a	28.66a	16.16 a
8	160.38 a	104.25 a	28.42 a	16.87 a
10	151.42 a	96.08 a	26.35 a	14.62 a
Method of application				
Root	165.20 a	119.90 a	30.71 a	18.28 a
Foliar	147.66 a	81.03 b	26.59 b	12.08 b

Table 6 Mean values for fresh and dry weight of aerial and root biomass of grape tomato by effect of silicon concentration and application method . Means with different letters in each variable are significantly different (Tukey P≤0.05)

Performance variables

The analysis of variance showed significant differences for the factor [Silicon] in the fruit length variable. For the factor application method and the interaction [Silicon] x application method, no differences were found for any of the variables (Table 7).

Source of variation	G.L.	Number of fruits	Total yield (g)	Diameter (cm)	Length (cm)	Weight (g)
		Pr>F				
[Silicon]	4	0.9647	0.9951	0.7925	0.0087 *	0.4758
Method of application	1	0.5769	0.7705	0.0914	0.0781	0.2631
[Silicon] x Method of application	4	0.0441	0.0718	0.5475	0.1022	0.3327
CME		47.822	2499.6	0.0968	0.1770	1.5385
CV		22.611	27.003	21.508	18.659	25.509

Table 7 Analysis of variance for grape tomato fruit yield characteristics measured during the evaluated period. C.V.: Coefficient of variation Values with ¨*¨ in each variable show differences

Number of fruits per plant

The concentration of silicon and the method of application did not affect the number of fruits (Table 8). This differs with that reported by Quiroga (2016) in cucumber (*Cucumis sativus* L.) where foliar silicon supply presented higher number of fruits.

SiO concentration$_2$ g.L^{-1}	Number of fruits	Total yield (g)
0	30.500 a	187.51 a
4	30.000 a	182.58 a
6	32.125 a	179.51 a
8	29.750 a	187.24 a
10	30.541 a	188.90 a
Method of application		
Root	31.200 a	187.48 a
Foliar	29.967 a	182.82 a

Table 8 Mean values for grape tomato fruit yield . Means with different letters in each variable are significantly different (Tukey P≤0.05)

Total yield

This variable did not show significant differences for any of the three factors. Contrary to the results of Pinedo (2011) who found the highest values, supplying silicon in higher concentrations per hectare in the cucumber crop. In different crops, the benefits of silicon-based fertilizer applications for crop productivity and quality have been shown more clearly (Datnoff *et al.* 2001). Silicon helps to improve the efficiency of absorption of some elements such as phosphorus and calcium, where the latter mentioned, serves as a mediator with plant hormones, growth regulator and plant senescence, this favors better photosynthesis resulting in higher crop production and yield (Quiroga, 2016).

Fruit diameter, length and weight

It was observed that the treatment that obtained the best result in fruit length was the silicon treatment of 10 g.L^{-1} presenting a 27.23% greater length compared to the treatment of 4 g.L^{-1}, followed by a difference of 25.16% with the treatment of 0 g.L^{-1} ; where these were the lowest mean values. With this, it can be deduced that as the silicon intake is lower, the length values will decrease considerably. Likewise, with the treatments with 6 and 8 g.L^{-1} results similar to the other treatments were obtained. This effect was also observed by Pinedo (2011) in the cucumber crop where he obtained the highest values in quantity, diameter, length and weight, applying the highest concentration of silicon (Table 9).

SiO concentration$_2$ g.L^{-1}	Diameter (cm)	Length (cm)	Weight (g)
0	1.467 a	2.055 b	4.671 a
4	1.346 a	1.998 b	4.424 a
6	1.500 a	2,335 ab	4.913 a
8	1.401 a	2,140 ab	4.766 a
10	1.517 a	2.746 a	5.535 a
Method of application			
Root	1.532 a	2.376 a	5.086 a
Foliar	1.360 a	2.133 a	4.638 a

Table 9. Mean values for physical characteristics of grape tomato fruit. Means with different letters in each variable are significantly different (Tukey P≤0.05)

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Conclusions

For the grape tomato crop, Primarino variety, the best results for leaf area were obtained with a concentration of 8 g.L^{-1} of SiO_2.

The use of silicon supplied to the root favors the morphological variables of leaf number and leaf area. It also favors the fresh and dry weight of the root.

For the fruit length variable, better results were achieved with the concentration of 10 g.L^{-1} of SiO_2. This caused an increase in fruit length compared to the control. However, with the concentration of 8 and 6 g.L^{-1} of SiO_2 similar results were achieved.

Therefore, it is recommended to use the concentration of 8 g.L^{-1} of SiO_2 applied to the root since it was the one that obtained the best value to favor vegetative growth and this leads to obtain a greater fruit development for tomato plants grape variety Primarino.

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Dynamics of land use on the coast of delta Grijalva, Mexico, to generate development strategies

Dinámica de usos del suelo en la costa del delta Grijalva, México, para generar estrategias de desarrollo

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Abstract

The present investigation analyzed the change of coverage in the periods 2000-2018, through the digitalization and visual interpretation of orthophotos and satellite images, a comparative analysis was made between the digitization carried out in both years to identify the losses and possible strategies in the area of study and the coastline was analyzed. The results show that the loss of highest observance was the mangrove area, suffering a decrease of 4.78% and in profits the uses for hydrophytic vegetation, family gardens, urbanization and bodies of water, hydrophilic vegetation being the most profitable with a 5.24 %. For the analysis of the coastline, a loss of 262.2 meters in a period of 18 years was obtained in the area adjoining the Gulf of Mexico and, finally, by comparing the map of change of uses with that provided by the Program of Management Ecological State of Tabasco 2013, gives us a vision of the lack of compliance with the same program, which leads to poor application and use of land, generating environmental degradation and this in turn contributes to increased vulnerability to impacts caused by climate change.

Changes in uses, Vegetation cover, Coastline

Resumen

La presente investigación analizó el cambio de cobertura en los periodos 2000-2018, mediante la digitalización e interpretación visual de ortofotos e imágenes satelitales, se hizo un análisis comparativo entre la digitalización realizada en ambos años para identificar las pérdidas y posibles estrategias en el área de estudio y se analizó la línea de costa. Los resultados muestran que la pérdida de mayor observancia fue la zona de manglares, sufriendo una disminución del 4.78% y en ganancias los usos para vegetación hidrófita, huertos familiares, urbanización y cuerpos de agua, siendo la vegetación hidrófita la de mayor ganancia con un 5.24%. Para el análisis de la línea de costa se obtuvo en la zona colindante al Golfo de México una pérdida de 262.2 metros en un periodo comprendido de 18 años y por último, al comparar el mapa de cambio de usos con el proporcionado por el Programa de Ordenamiento Ecológico del estado de Tabasco 2013, nos da una visión de la falta del cumplimiento del mismo programa, lo que conlleva a la mala aplicación y uso del suelo, generando degradación del medio y esto a su vez contribuye al aumento de la vulnerabilidad a los impactos provocados por el cambio climático.

Degradación, Análisis, Vulnerabilidad

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Introduction

Human activities, primarily through greenhouse gas emissions, have unequivocally caused global warming, with global surface temperature reaching 1.1 °C above 1985 - 1900 in 2011-2020. Global greenhouse gas emissions have continued to increase between 2010-2019, with uneven historical and current contributions from unsustainable energy use, land use and land use change, lifestyles, and consumption and production patterns in all regions (IPCC,2023).

Land use change and loss of vegetation cover is one of the main problems of concern to humankind, as it directly affects biodiversity, contributes to local, regional and global climate change and is the primary source of soil degradation (López, 2006). The negative processes of land and vegetation use change have been documented as the second environmental problem at the global level, since they affect natural capital, microclimatic stability, the provision of environmental services and the increase in the concentration of greenhouse gases in the atmosphere, in addition to limiting at the local level the possibilities of sustainable management of the territory and its natural resources (Rosete, Pérez, Villalobos, Navarro, Salinas, & Remond, 2014).

México se encuentra dentro de las tendencias mundiales, presentando importantes procesos de cambio de uso y cobertura del suelo en sus casi dos millones de kilómetros cuadrados de superficie. En general se observan una gran cantidad de cambios que están por arriba de la media mundial en cuanto a tasas de deforestación, incremento de las áreas de cultivo y pastoreo, expansión urbana y muchos otros como la erosión a causa del aumento del nivel del mar efecto producido por el cambio climático (Rocha, WP, *et al*., 2017).

The cities and communities of the country do not escape this process, the population growth according to the press release of INEGI, 2000 showed for the year 2000 a total amount of 97.48 million inhabitants. In 2015 it passed to a total of 119, 530, 753 inhabitants which has meant not only a growth in the number of settlers if not also a physical growth and the continuous increase of its urban limits and consequently decrease of natural or semi-natural coverages (INEGI, 2015).

Under this approach, a large number of research initiatives have been promoted at global, regional and local scales, recognizing land use dynamics as an important component of the global environmental system and a precursor factor of global climate change. The studies carried out indicate that the monitoring and analysis of the urban expansion process and its resulting conversions of natural and semi-natural land cover is carried out through the study of land use and land cover changes (Sandoval, 2009).

Likewise, specific works have been carried out in different areas of the country that have indicated and quantified the impact caused by soil alteration processes; in this sense, in Tabasco, analyses have been carried out on land use change in several areas of the territory, such as in the municipality of Comalcalco, where the dynamics of land use change from 2000 to 2010 were identified (Ramos-Reyes et al., 2016a).

In the municipality of Centla in the Pantanos de Centla Biosphere Reserve, a study was carried out to evaluate the spatio-temporal vegetation and land use from 1990 to 2000 (Guerra, & Ochoa, 2006).

Given this problem, the main objective of this study is to study the dynamics of land use change, as well as the influence of anthropogenic activities as the main driver of change, to understand the causes, impacts and consequences that these transformations have on climate change, as well as the loss of the coastal coastline, and to identify possible development strategies, all this in a period between 2000 and 2018.

The use of Geographic Information Systems (GIS) and remote sensing (RP) tools was necessary to carry out this spatial monitoring study, since they provide transition information on the dynamics of land use over the years.

Methodology

In order to fulfill the proposed objectives, a methodological route was established that contemplates the preparation or pre-processing of the images, which consisted of cropping them to the study area.

A polygon of approximately 20,000 ha was obtained with the cutout, which included the study area, and the study area was delimited with the ArcGIS 10.2 program. The 2000 map was generated with a black and white orthophoto of the same year, while the 2018 map was generated with an image obtained from the European satellite called Sentinel with a false color (RGB 1, 2, 3). The 2018 map was verified with information collected in the field using GPS equipment. Both maps were developed at a scale of 1:20 000, for the digitization and identification of land uses a visual interpretation was carried out on screen applying the criteria of tone, shape, size and texture (Chuvieco, 2008).

To identify the different land uses present in the study area, digital sources of information were used, such as maps from the 2000 National Forest Inventory and the State Ecological Management Program 2013-2018, in addition to information from the National Institute of Statistics and Geography and the National Commission for the Knowledge and Use of Biodiversity.

Land use change matrix

The temporal analysis of changes in land use will be carried out with the tools of the ArcGis 10.2 program in which the digitization was performed, in this digitization the different types of uses were categorized, which were necessary to locate to perform a standardization and achieve the matrix of land use change. To obtain this change of use matrix, it was necessary to convert the vector format (Shapefile) into a numerical matrix format (Raster) to perform the map algebra. A numerical value was assigned to each category from 1 to 9 for the 2000 map and from 1 to 90 for the 2018 map so that the map algebra could be obtained. To continue with the interpretation of the land use changes, the files should be imported from Raster format to Shapefile format.

Scale and pixel size

The scale at which the maps were digitized was 1:20 000, there is a direct relationship between cell size and scale and can be calculated using the following formula: where the scale is equal to the cell size multiplied by 96 and divided by 0.0254. Therefore, if the scale is 1: 20,000, the cell size is 5.29 meters.

Shoreline digitization

For the digitization of the coastline, ArcGIS 10.2 software was used to generate the coastline of the study area for both proposed years 2000 and 2018 to subsequently determine changes over time. An orthophoto was used for the year 2000 obtained from the National Institute of Statistics and Geography and for the year 2018 the Sentinel satellite image was obtained from the European Space Agency both digital materials corresponding to the entire coastal area of the municipality of Centla, the spatial resolution of the image obtained from the Sentinel satellite and the orthophoto are projected 10 m.

Once the spatial information on which to digitize the coastline was established, the indicator to be followed for its delineation was chosen. We chose to use the high water line (HLW), defining it as the wet/dry boundary and interpreting it as the line defined by the difference in coloration that marks the receding tide (Dolan et al. 1978). The digitization was carried out by a single person, valuing the ratio of time invested and accuracy obtained, the digitization scale was set at 1:5000, this line will be traced in an area of approximately 24 kilometers.

Comparison of the coastline

Already having the coastline of the year 2000 and 2018 will be analyzed to see if there is coastal erosion and accretion, and to determine possible indicators of climate change.

Strategies for land use

Based on the results obtained from the digitization of the study area, proposals for possible strategies for land use in the region will be determined in order to reduce the deterioration of the environment and thus ensure harmonious and sustainable development between society and the natural environment. These proposals should be based on the current State Ecological Management Program (PESOE, 2015).

Results

Analysis of land use changes on the coast of the Grijalva Delta, Mexico.

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Based on the work carried out in the ArcGis operating system for the digitalization of the orthophoto for 2010 and for the satellite image for 2018, the following results were obtained, where the surfaces in m2 are defined for the year 2000 and 2018 acquiring a classification of nine categories which are, acahual, coconut groves, water body, home garden, mangrove, pasture, urbanization, hydrophytic vegetation and oil zone (see Table 1).

	Surface 2000 (Ha)	%	Surface 2000 (Ha)	%	Profit	%	Lost	%
Acahual	5, 041.27	3.88	4, 839.41	3.69			201.86	**-4**
Coconut groves	1, 900.43	1.44	1, 182.28	0.90			718.15	**-37**
Water body	4,788.76	3.68	4, 796.11	3.65	7.35	**0.15**		
Family orchard	127.92	0.1	714.47	0.54	586.55	**82**		
Mangrove	15, 734.9	12.1	9, 603.47	7.32			6, 131.43	**-39**
Pasture	14, 484.8	11.14	14, 270.9	10.88			213.9	**-1.4**
Urbanization	578.44	0.44	723.05	0.55	144.61	**20**		
Hydrophytic vegetation	87, 349	67.18	94, 943.2	72.42	7, 594.2	**8**		
Oil area	42.63	0.03	28.04	0.02			14.59	**-34**
Total hectares	130, 019.19	100	131, 100.94	100				

Table 1 Land uses 2000 and 2018
Data: Orthophoto digitization in ArcGis 10.2 Geographic Information System

Land use for the year 2000 was distributed as follows, 67.18% (87, 349 Ha) of the surface was occupied by hydrophytic vegetation, 12.1% (15, 734.9 Ha) corresponded to mangrove surface, 11.14% (14, 484. 8 Ha) for grasslands, acahual 3.88% (5, 041.27 Ha), water bodies with 3.68% (4,788.76 Ha), coconut groves 1.44% (1, 900.43 Ha), 0.44% (42.63 Ha) for urban zone, .01% (127.92 Ha) for home gardens and 0.03% (42.63 Ha) of oil zone.

While for 2018 it was distributed as follows, 72.42% (94, 943.2 Ha) of the surface was occupied by hydrophytic vegetation, 10.88% (14, 270.9 Ha) corresponded to grassland surface, 7.32% (9, 603. 47 Ha) for mangroves, acahual 3.69% (4, 839.41 Ha), water bodies with 3.65% (4, 796.11 Ha), coconut groves 0.90% (1, 182.28 Ha), 0.55% (723.05 Ha) for the urban zone, 0.54% (714.47 Ha) for family orchards and 0.02% (28.04 Ha) for the oil zone. If we observe in the comparative table there are losses in some categories such as mangrove, coconut groves, pasture, acahual and oil zones; the land use with the highest loss is the mangrove zone with a decrease of 4.78%. And in terms of gains we have land uses for hydrophytic vegetation, home gardens, urbanization and water bodies, being hydrophytic vegetation the one with the greatest gain with 5.24% more surface area compared to the distribution of 2000.

The hydrophytic vegetation category is predominant, with a total of 67.18% for 2000 and 72.42% for 2018, due to the fact that most of the territory to be studied is located in the area of the Centla Marshes, which have been considered as little altered areas. In the state of Tabasco there are extensive areas of wetlands, of which the Pantanos de Centla Biosphere Reserve (RBPC) stands out. This site, which is part of the 58 Mexican wetlands recognized for their international importance according to Ramsar and ranks fifth in extension in the Mexican Republic with an area of 302 706 ha covering marine-coastal and inland water wetlands (Barba-Macías, E et al., 2006).

According to De la Rosa, 2016 in his research in part of this same study area mentions the majority of the extensive and temporarily stable cover was hydrophytic vegetation, which only lost 2.8% of its area since the application of the decree as a reserve surface area designated as a natural protected area, a portion was allocated to agriculture (36,501 ha) and low flooded forests (20,122 ha). In contrast, the most transformed cover was low flooded forest, with 12% of its extension converted to hydrophytic vegetation (36,181 ha) and agricultural use (13,704 ha). The extension of water bodies increased (4.3%), while mangroves decreased (0.45%).

The area dedicated to agriculture doubled and replaced 16,209 ha of hydrophytic vegetation and 2,376 ha of low flooded forests; this transition was observed even in the core of the reserve. The greatest change was recorded in the core area, where 33% hydrophytic vegetation was eliminated and the buffer zone experienced the greatest loss of low flooding forest (De la Rosa, 2016).

The other land uses for the same period 2000 to 2018, had variations in losses or gains (Graph 1), home gardens with gains in occupied area of 586.55 Ha, urbanization with gains of 144. 61 Ha and water bodies 7.35 Ha; for losses, the mangrove area is notoriously decreased with a detriment of 6, 131.43 Ha, coconut groves with 718.15 Ha, pastures 213.9 Ha, acahual 201.86 Ha and the oil area with losses of 14.59 Ha.

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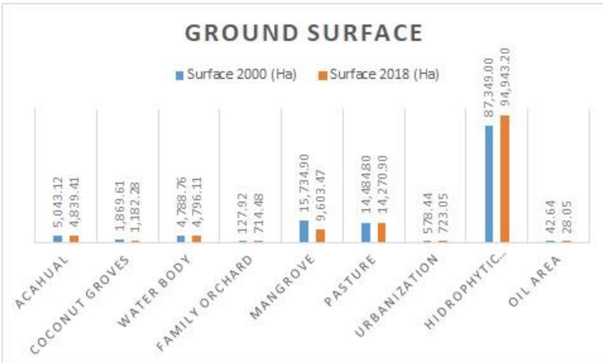
Home gardens, urbanization and hydrophytic vegetation showed recoveries of 82, 20 and 8%, respectively. Mangroves, coconut groves and the oil zone showed a decrease of -39, -37 and -34%.



Graphic 1 Land area in the period 2000 - 2018
Source: Information generated in the ArcGis 10.2 Geographic Information System.

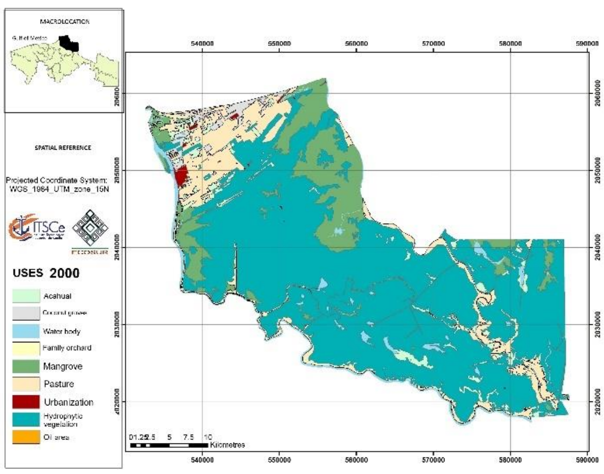


Figure 1 2000 land use on the coast of the Grijalva Delta, Tabasco, Mexico.
Source: Orthophoto digitizing in ArcGis 10.2 Geographic Information System.

Figure 1 shows the land use map of the Grijalva Delta coast in 2000, showing that the largest land uses are hydrophytic vegetation, mangroves and grasslands, while acahual is only found in small portions near the grasslands, as well as coconut groves, with an area of 1,900.43 ha (1.4%)

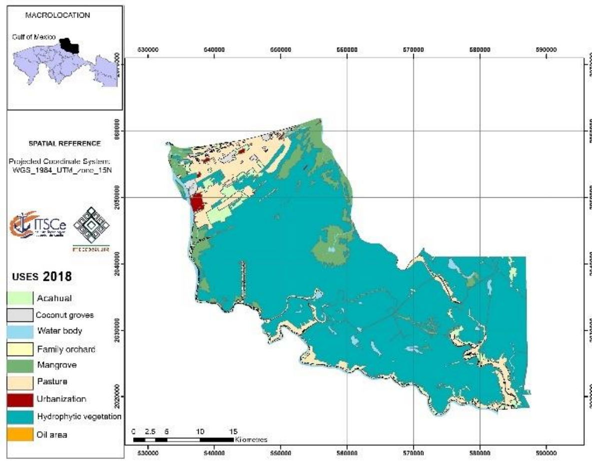


Figure 2 2018 land uses on the coast of the Grijalva Delta, Tabasco, Mexico
Source: Digitization of Sentinel satellite image from the European Space Agency in ArcGis Geographic Information System 10.2

The 2018 map (fig.2) shows that the most dominant uses continue to be hydrophytic vegetation (72.42%), pasture (10.88%) and mangrove (7.32%). Home gardens are the fastest growing with a surface area of 586.55 ha, which represents 82%.

Graphic 2 Gain and persistence of water bodies on the coast of the Grijalva Delta, Tabasco, Mexico
Source: Information generated in ArcGis 10.2 Geographic Information System

Ramos-Reyes et al. (2016b) have studied extreme events attributed to climate change that occur in coastal areas, such as intense hurricanes, severe flooding and sea level rise (SLR). According to Nicholls, 2002, these climatic events provoke irreversible changes causing loss of coastal lands that have been eroded and flooded.

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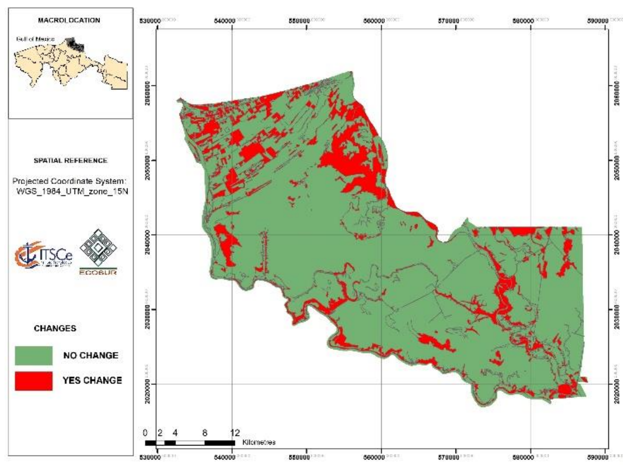
In Figure 2 we observe the gains and persistence of land uses categorized as water body in which a notorious increase is defined in coastal areas and river margins resulting in losses in urban areas (4. 79 Ha), acahuales (41.95 Ha), pastures (129.54 Ha), coconut groves (23.34 Ha), home gardens (11.17 Ha), hydrophytic vegetation (232.25 Ha), oil zone (0.65 Ha) and mangrove area (90.78 Ha).

According to the PESOE, 2015, the regions most prone to be affected by flooding are those located in coastal areas, as is the case of the forest community in Centla, as well as the populations located on the banks of the Grijalva, Mezcalapa and Usumacinta rivers, mainly.

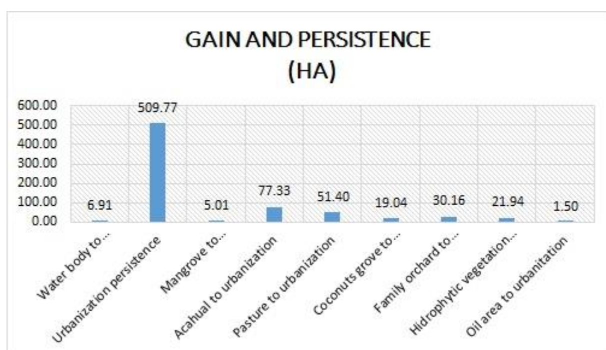
Mangroves are a type of land use with significant losses, with a specific gain towards water bodies totaling 90.78 ha. Based on research by Yáñez et al, 2014, mangrove forests are considered among the most vulnerable ecosystems in the tropical/subtropical band of the planet and subjected to diverse environmental stressors at the continent/ocean interface, placing mangroves at severe risk to the impacts of climate change, particularly in terms of geomorphological, sedimentological, biogeochemical processes, geographical distribution, morpho-physiological resilience and the uncertainty of the sustainability of the environmental services provided by these amphibious forests, among other aspects.

In the same context, the PESOE, 2015 mentions that important modifications are likely to occur in mangroves that may be affected by sea level rise projecting where seawater could enter up to 40 km inland in extreme cases. In terms of plant formations that are in these risk conditions are coastal wetland ecosystems and dune vegetation and marsh vegetation or hydrophytic vegetation.



Graphic 3 Gain and persistence of mangrove land uses on the coast of the Grijalva Delta, Tabasco, Mexico
Source: Information generated in ArcGis 10.2 Geographic Information System

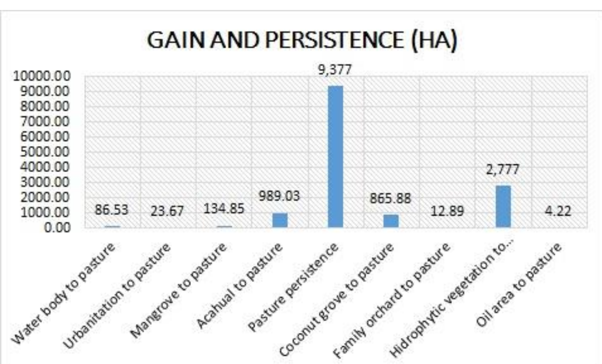
The scarce and almost null increase in land uses destined for mangrove areas is analyzed (Graph 3), (Hernández-Melchor et al, 2016) states that in the state of Tabasco 19,922.9 ha of mangrove have been lost, due to land use change originated by activities such as the oil industry, the establishment of cultivation areas and grazing areas. Mangroves are of great environmental importance, as this ecosystem is characterized by its rich biodiversity, and also serves as protection against saline intrusion into the soils bordering the coast and protects the population from storms and hurricanes (Ramos-Reyes et al., 2016a).



Graphic 4 Gain and persistence of urban land uses on the coast of the Grijalva Delta, Tabasco, Mexico
Source: Information generated in ArcGis 10.2 Geographic Information System

Figure 4 shows the loss of various uses such as acahual (77.33 ha), which were increased in uses destined for urbanization, pastures are also in decline (51.40 ha), being replaced by the expansion of urban development, areas of lower population identified as home gardens were also replaced by the increase in population re-categorized as urban. Based on the publications of Capdepont-Ballina J. & Marín-Olán P., 2014 in which he mentions that in the administration of Mario Trujillo García (1971-1976) began the economic transformation of the entity, which became evident towards 1980, bringing with it an increase in population who demanded more and better services, calling it modernization, understanding it as an improvement in the material life of Tabasco, which was boosted by the exploitation of hydrocarbons, but to the detriment of social and ecological life; In 1970 the rural population was greater than the urban population and the primary sector economy predominated, but in 1990 this situation was already different due to the rebound of secondary activities such as hydrocarbon extraction and the urban growth of the headwaters of the municipalities impacted by this sector, which could be proven for the study area of this project that in the year 2018 the increase of urban zoning and the loss of areas for the development of family orchards is interrelated with the oil boom in our state.

In 1990 Centla had a total population of 70,053 inhabitants, occupying the seventh place from highest to lowest number of inhabitants, while in 2010 there was an increase of 102,110 inhabitants, occupying the eighth place in growth (INEGI, 1990 and 2010).



Graphic 5 Gain and persistence of pasture land use on the coast of the Grijalva Delta, Tabasco, Mexico
Source: Information generated in ArcGis 10.2 Geographic Information System

In Tabasco, economic activities have been conditioned by the natural environment and markets. A series of stages characterize a product throughout its economic history: 1) traditional crops, cocoa, copra; 2) banana monoculture (late nineteenth century to mid-twentieth century); 3) livestock expansion (1950-1970) and the oil stage (1976- 2013).

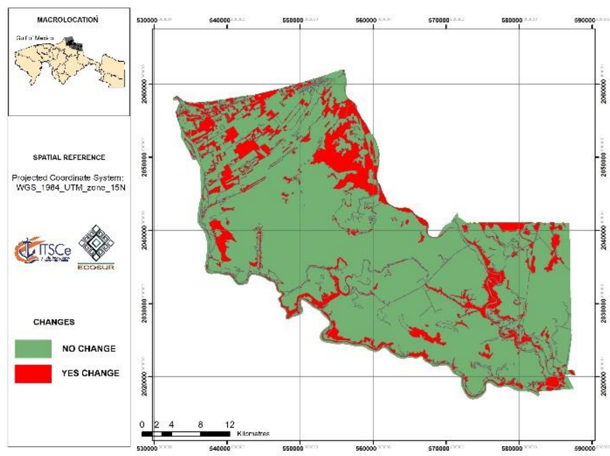


Figure 3 Matrix of land use changes from 2000 to 2018 on the coast of the Grijalva Delta, Tabasco, Mexico
Data: Information generated in the ArcGis 10.2 Geographic Information System

The results of changes in the period analyzed from 2000 to 2018 showed changes in 23,064.2 ha and the majority of the area remained unchanged with a total of 106,857 ha.

According to De la Rosa 2016, the reduction in natural cover reflects the extractive pressure on natural resources and a marked process of land use change within Pantanos de Centla Biosphere Reserve, even in restricted protection zones and core zones. Observing the change matrix map (Fig. 3), it is clear that changes occur more rapidly in areas that are even considered natural protected areas. It is likely due to poor management and the growth of community zones that exert pressure on natural resources, changes in land use, changes due to poorly designed public policies, and changes that have developed naturally (hurricanes, temperature variations, etc.) whose scope surpasses conservation efforts within the protected area and its surrounding area.

Analysis of the coastline (2000-2018)

According to the results obtained by digitizing the lines for the year 2000 through an orthophoto and for the year 2018 using a SPOT image from the European satellite called Sentinel with a false color (RGB 1, 2, 3), the coastline was digitized at scale 1:5 000, which includes part of the coastline of the municipality of Centla (Fig. 10) starting in the town of El Bosque to the mouth of the San Pedro river with a total length of 23, 858.34 meters.

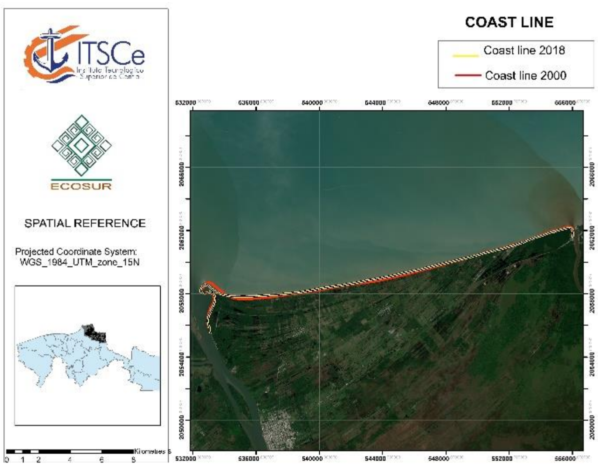


Figure 4 Digitization of coastlines 2000 - 2018
Source: Information generated in ArcGis 10.2 Geographic Information System

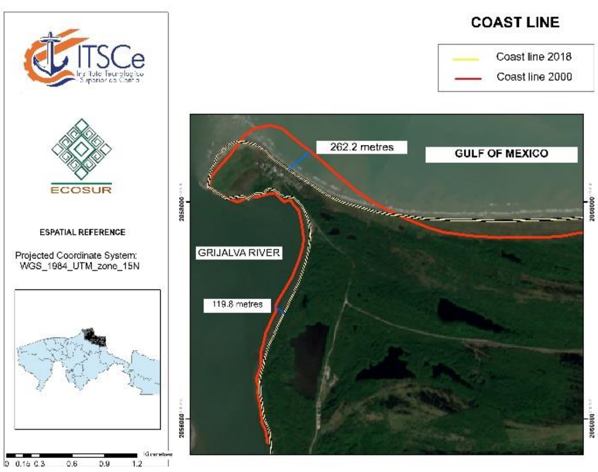


Figure 5 Erosion of the Grijalva river mouth
Source: Information generated in ArcGis 10.2 Geographic Information System

The coastal areas of the state of Tabasco are highly susceptible to being flooded by extreme phenomena as a consequence of Global Climate Change (GCC) in the municipalities of Cárdenas, Paraíso and Centla, with soils being more susceptible to flooding due to the poor drainage of the gleysols that are associated with wetlands and swamps (PESOE, 2015).

According to the same PESOE 2015, it indicates in an analysis during 40 years between 1950 and 1990 an increase in the Gulf level of around 13 cm in its Mexican part and in a linear projection determines that the sea level rise would reach 90 cm by the year 2100, putting at risk by the effects of the tide considerable portions of the State, however, recent studies point out that it could reach in some areas a meter and a half.

The site with the greatest loss of coastline was identified in the regions that present peninsular forms, as is the case of the locality of the forest, which is mostly surrounded by water from the Gulf of Mexico, and another area of the same locality that is located around the mouth of the Grijalva River.

Figure 5 shows that in the area adjacent to the Gulf of Mexico there is a loss of 262.2 meters over a period of 18 years, which means an annual loss of -14.5 meters. Other studies that address the same topic have reported annual losses, such as the case of Sánchez Magallanes and El Alacrán, with retreats of -4 and -7, respectively (Hernández-Santana et al., 2008).

Ramos-Reyes et al. (2016b) in coastal areas of the same state of Tabasco, in the municipality of H. Cárdenas located sites where coastal vulnerability is present according to vulnerability parameters, concluded that the Villa de Sánchez Magallanes presents red focus on an extreme scale before the phenomena of climate change, reaching up to 5m per year, reaching serious problems of erosion and loss of the coast, affecting citizens living along the entire coastal coastline.

If we relate the results obtained in (fig. 5) with the previous predictions of sea level rise, we can consider that what was described by the authors of the PESOE are not wrong, generating already in the forest community a conflict for the loss of territory and gain of the sea, affecting not only human localities but also populations of coastal wetlands, dune vegetation and marsh vegetation.

Sustainable development strategies

Comparative analysis of land use with that established in the State Ecological Management Program.

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To determine the activities carried out in the study area and consider whether these activities contribute to and comply with the territorial ecological management plan, an intersection of the map indicating the environmental management units and the digitized map was carried out to determine the change in land use, and the following result was obtained (Fig. 6).

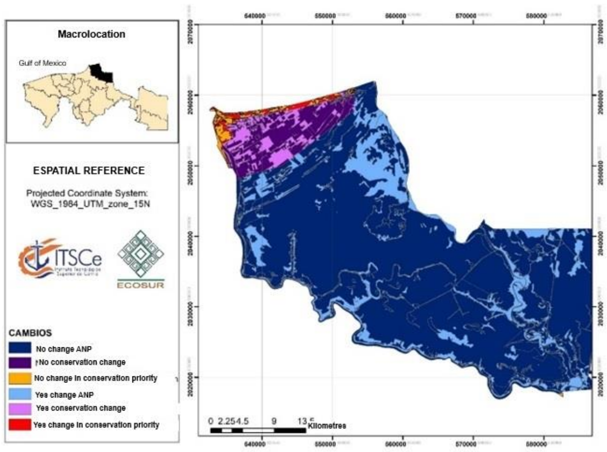

Figure 6 Comparative map of land use and the Environmental Management Unit of the POEE
Data: Information generated in the ArcGis 10.2 Geographic Information System.

According to the PESOE, the study area is categorized into three Environmental Management Units (UGA's), which are natural protected area, conservation area and priority conservation area, with the main one accounting for approximately 90% of the territory corresponding to natural protected area, 4% for the priority conservation area and 6% for the conservation zone.

Priority conservation zones are those areas of state or federal jurisdiction that must be protected or conserved because the reduction or loss of their natural properties would increase the risk to the population and its heritage, the loss of endemic species or risks, as well as the loss of strategic natural resources for the social and economic development of the state. Some of these, among others are, coastal areas, dunes, mangroves, river margins, gallery forests and mountain slopes (PESOE, 2015).

The environmental management units (UGA's) of conservation are the areas of the state territory that present little altered ecosystems, since they maintain in good condition their structure, function and ecological processes.

In addition, they may or may not contain species that are in a risk category according to the Mexican Official Standard. The environmental services provided by these parts of the state territory are strategic to reduce the risks to the human population and its heritage in the face of hydrometeorological phenomena, coastal erosion and the effects of climate change. The use of natural resources in this area must be evaluated technically, legally and economically by trained personnel and the corresponding environmental authorities (PESOE, 2015).

Protected natural areas are the areas of the state territory, decreed as protected natural areas of federal, state or municipal jurisdiction, based on the General Law of Ecological Balance and Environmental Protection and the Environmental Protection Law of the States of Tabasco, or equivalent (PESOE, 2015).

The results of the comparative map show that within the protected natural area there are modifications to the soil for productive activities, with the same intensity as the modifications observed outside of the natural area, which indicates that although there is a management plan for Pantanos de Centla Biosphere Reserve, it is not being implemented or does not have the necessary improvements to counteract the effects of land use changes.

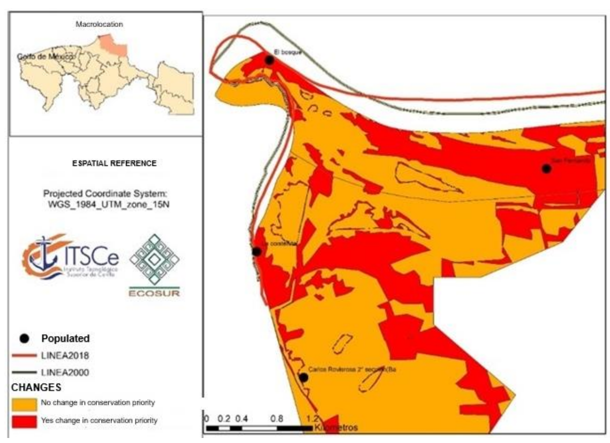

Figure 7 Coastal zone map of the municipality of Centla
Source: Information generated in ArcGis 10.2 Geographic Information System

The increase in population causes greater demand on natural resources, as well as an increase in the area suitable for industrial and housing developments, regardless of the filling of some bodies of water. The areas with more changes are those linked to the presence of high population density.

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If we observe Figure 7. We will notice that the areas with population presence are the ones that have had the greatest changes as is the case of the coastal communities of El Bosque, San Fernando, La Costeñita and Carlos Rovirosa 2nd Section, which contributes to the conclusions given in the (PESOE, 2015) where it mentions that the greater the population, the greater the changes in land use and population affectations.

According to the PESOE, 2015, there are several vulnerable areas throughout the state of Tabasco due to population growth and the activities that this growth entails, it can be observed that there is great vulnerability in the coastal zone, especially at the mouth of the Grijalva-Usumacinta river, In general terms, population growth is concentrated in areas of greater vulnerability to flooding, with the Grijalva basin region being the most vulnerable, including in some cases the Chontalpa region (Paraíso, Comalcalco, Cunduacán and part of Cárdenas). This in turn represents a conflict in inappropriate land use, since the areas of greatest conflict are being populated at an accelerated rate due to inappropriate human settlements.

Development strategies according to the State Ecological Management Program

One of the main primary activities in the municipality of Centla is fishing, which is considered a source of income for many families. However, due to the various oil activities and the decrease in free fishing, these families have been affected, so based on the PESOE, 2015, it is proposed as a strategy for this area to promote productive actions through the reactivation of the capacity of primary activities according to the agricultural, livestock, fishing and forestry vocation, so it is proposed to develop in this area the activity of aquaculture, with aquaculture projects that favor the use of native species over exotic ones.

Ecological guidelines	Strategy	Description	Production activity
Promote productive activities	Reactivate the capacity of primary activities according to the agricultural, livestock, fishing and forestry vocation.	Aquaculture projects must favor the use of native species over exotic species, the latter being restricted by the corresponding authority.	Aquaculture

Table 2 Proposed strategy for sustainable development in the study area
Source: PESOE, 2015

Conclusions

For the analysis of land use changes, the study area was digitized with orthophotos for 2000 and a satellite image for 2018, in which nine land uses were identified in the Delta coast, Tabasco, Mexico, for both dates, which were: coconut groves, pasture and mangrove, acahual, hydrophytic vegetation, home gardens, urban area, bodies of water, and oil zone. Hydrophytic vegetation was found to cover the largest area, with a total of 87,349 ha in 2000 and 94,943.2 ha in 2018.

Anthropogenic activities are the main factor in the loss of biodiversity in the Grijalva Delta Coast and the effects generated by climate change due to the increase in sea level invading land areas, since most of the changes in land cover occur near the coast and river banks, in addition to the mismanagement of natural resources and ignorance of the consequences that their daily activities cause to the ecosystem, which lead to degradation and desertification. This contributes to the erosion and deterioration of the coastline.

The coastline was also spatially evaluated with orthophotos from 2000 and a satellite image from 2018, finding greater erosion at the mouth of the Grijalva River and on the coast of the community of El Bosque, and observing coastal accretion, due to sediments from the river that are dragged and deposited in the first meters of the coast. The coast of the Grijalva Delta is vulnerable to the effects of climate change, mainly the mouth of the Grijalva River, in the community of El Bosque, with losses of great importance and concern with about 262.2 meters in a period of 18 years, which means an annual loss of -14.5 meters.

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Kinetics and diversity indices of phytoplankton in T´zonot type watery in Kopomá

Cinética e índices de diversidad de fitoplancton en T´zonot tipo aguada en Kopomá

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Abstract

The cenotes, made up of a mixture of karst soil, fresh and salt water, provide ecosystem services: water, climate, landscape, and headquarters for religious and recreational activities. They are niche species that are part of the trophic chains and conserve valuable genetic information product of their evolution and adaptation to the ecosystem. It is important to know them before they can be lost due to anthropogenic activities. The objective of this work was to study the spatiotemporal biodiversity of phytoplankton in the Chen Ha Cenote. Monitoring activities included spring, summer and winter seasons. Environmental variables were monitored with a multiparameter probe. Classification of microorganisms by microscopy. The pH was slightly alkaline in all monitoring results. Temperature varied from 28.7 to 32 ° C, dissolved oxygen ranged from 2.4 to 3.2 ppm. Conductivity was 2.962 during spring and 2650 microS.cm^2 in wintertime. 41 species were identified in spring, 27 in summer and 29 in winter. During the spring and winter seasons diatoms predominated. *Navícula, Coelosphaerium* and *Nitzschia* were the dominant species in spring, summer, and winter periods, respectively. In accordance with the Jackard similarity index, greater similarity was observed between spring and winter showing a value of 0.458, compared to summer with a value of 0.3877.

Biodiversity, Karst, Microorganisms

Resumen

Los cenotes, conformados de una mezcla de suelo kárstico, agua dulce y salada, aportan servicios ecosistémicos: agua, clima, paisaje, sede de actividades religiosas y recreativas. Son nicho de especies que forman parte de las cadenas tróficas y conservan valiosa información genética producto de su evolución y adaptación al ecosistema. Es importante conocerlas antes de que puedan llegar a perderse derivado de actividades antropogénicas. El objetivo del presente trabajo fue estudiar la biodiversidad espaciotemporal de fitoplancton, en el Cenote Chen Ha. El monitoreo incluyo primavera, verano e invierno. Las variables ambientales se monitorearon con sonda multiparamétrica. La clasificación de microorganismos mediante microscopia. El pH fue ligeramente alcalino en todos los monitoreos. La temperatura 28.7 a 32 ° C, el Oxígeno disuelto desde 2.4 hasta 3.2 ppm. Conductividad 2.962 en primavera a 2650 microS.cm^2 en invierno. Se identificaron 41 especies en primavera, 27 en verano y 29 en invierno. En primavera e invierno predominaron las diatomeas. *Navícula, Coelosphaerium* y *Nitzschi*a fueron las especies dominantes en primavera, verano e invierno, respectivamente. En conformidad con el índice de similitud de Jackard se observó mayor similitud entre primavera e invierno 0.458, respecto del verano con valor de 0.3877.

Biodiversidad, Karst, Microorganismos

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Introduction

Water is a finite, vulnerable and vital natural resource; however, its availability is not homogeneous at the national level (CONAGUA). It is worth mentioning that it is the duty of the environmental authorities to guarantee for the human population the availability of quality water and its treatment. For some, water is considered a global heritage inherent to the communities and ecosystems in which it is found, however, for others it is an economic resource with monetary value.

95% of the soil of the State of Yucatan is made up of $CaC0_3$ limestone rocks (Karst landscape) and groundwater. (Estrada-Medina et al., 2019). The dissolution of the rock favors the fragmentation of the surface soil, which collapses leading to formation of a great diversity of cenotes.

Cenotes are described as caves flooded with a mixture of fresh and salt water. They are classified as open when the wetland is exposed to the sun's rays, semi-open when part of the surface is open and closed when they are located in caverns with absence of light. The cenotes are a source of water for the human population, their geographical distribution in Yucatan includes the ejido and private lands. It is worth mentioning that the sale of these properties is associated with the sale of water (Cortés, 2018).

The tourist development of the region and the influx of visitors to the Peninsula encourages the privatization and exploitation of cenotes as a tourist attraction linked to archaeological sites. The packages include tourist guides as well as the commercialization of handicrafts of fabric, stones, wood, symbols of the region, pyramids, calendars, catrinas etc. Tour packages are marketed through websites or all-inclusive hotels (Jouault, 2021).

In the related literature there are few records of the biodiversity of phytoplankton species in these bodies of water, which allow measuring or modeling, predictive patterns of diversity at the spatio-temporal scale. It is worth mentioning that some species disappear faster than those allowed by natural extinction processes associated with the accelerated transformation and degradation of natural ecosystems, which puts their conservation at risk.

According to Zuria et al., 2019, the spatial distribution of species is associated with environmental characteristics, the distribution and behavior of other species and the impact of humans. It is worth mentioning that each species houses into its genome the information of millions of years of evolutionary adaptations.

The present work is the first to report the incidence of phytoplankton present in the Cenote Chen ha during the spring, summer and winter seasons of 2022-2023.

Phytoplankton includes autotrophic organisms, with photosynthetic capacity, which considered initiators of trophic chains, and are distributed both in marine environments and fresh aquaculture waterbodies including lakes, rivers and dams. In the coastal environment, diatoms and dinoflagellates are abundant and although their distribution is not homogeneous under certain conditions, harmful algal blooms (HAB) can proliferate in both salt and fresh water (Moreno Diaz, 2015).

According to the literature, a niche is made up of the biotic and abiotic conditions in which a given species reaches its development and subsistence. These are described in a two-dimensional geographical space (latitude and longitude) and a multidimensional environmental ecological space (Mota Vargas et al., 2019). The study of alpha diversity allowed to monitor the richness of species in a community considered homogeneous and the effects on it due to changes in the environment.

Figure 1 demonstrates the changes in the ecosystem derived from the climatic seasons, associated with environmental variables such as light intensity, temperature, rainfall, as well as the impact on vegetation.

Figure 1 Image of the Chen Há cenote in spring, summer-autumn and winter
Source: Own elaboration

Methodology to be developed

For monitoring, 4 analysis stations were established. Environmental physicochemical parameters were determined with a multiparameter probe: pH, temperature, dissolved oxygen, conductivity, and total suspended solids.

Diversity of phytoplankton. It was determined by the dragging sampling technique carried out over 1 minute with a net of 40 micrometers pore diameter and 30 cm net diameter. The samples were analyzed by microscopy, with objectives lens 30 and 40 X. Diversity analysis was determined according to Shannom and Weber's methodology for alpha diversity and Jackard's methodology for beta diversity. (Vizcaíno-Rodríguez et al., 2021).

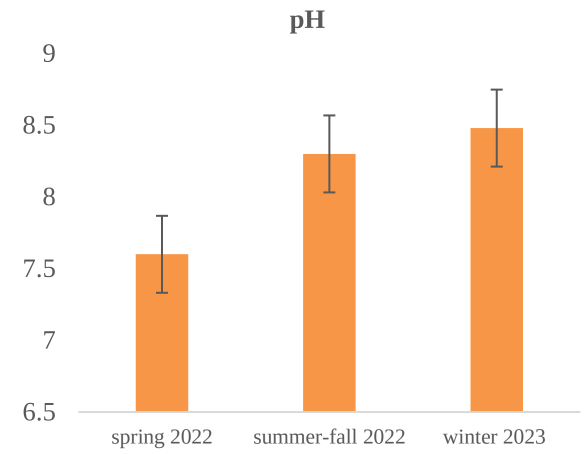
Phylogenetic analysis

An International Nucleotide Sequence Database Collaboration NCBI y Blast (Basic Local Alignment Search Tool) was used for cianobacterias, *Chroococcus turgidus* CCIBt3508 ribosomal RNA gene, partial sequence, 16S-23S ribosomal RNA intergenic spacer, complete sequence, and 23 S ribosomal RNA gene, partial sequence.

For the analysis of diatoms was used the sequence of *Navicula trivialis* 18SrRNA gene (partial), ITS1, 5,8S rRNA gene, ITS2 abd 28S rRNA gene (partial), strain 2-HV25, clone 2. The cleaning of sequences was carried out visually, in relation to the preserved sites. NCBI diagrams were used.

Results

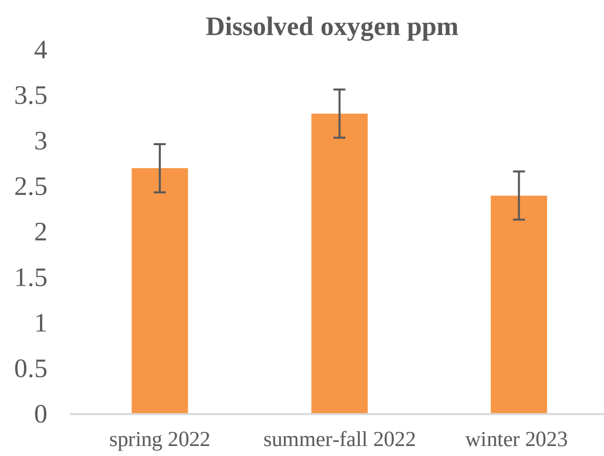
The pH of the water body changed in each season, according to Figure 1. The most acidic pH was obtained during spring, and the most alkaline in winter. Our results are slightly more alkaline than those reported for the cenotes of the municipalities of Yucatan: Tekit, Homun, Cuzamá and Sanahcat, with a range of 6.92 to 7.70. (Cruz et al., 2018).



Graphic 1 pH value in the Chen Ha cenote, spring, summer-autumn and winter 2023
Source: Own elaboration

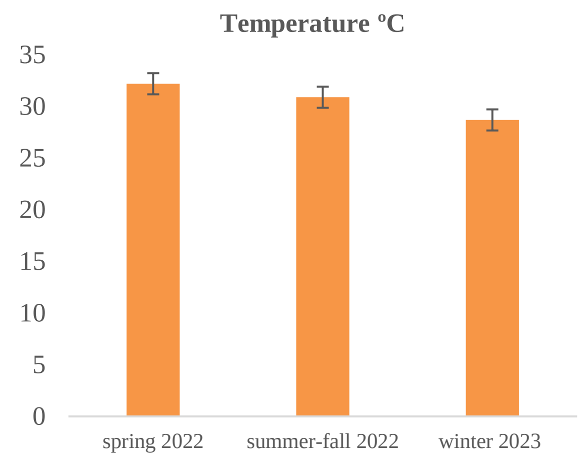
The alkaline pH favors photosynthetic activity and high concentrations of dissolved oxygen which stimulates the growth of bacteria heterotrophs which are important in organic degradation (Sardi-Saavedra et al., 2016).

The range of dissolved oxygen was varied 2.4 mg/L to 3.3 mg/L, the highest value was detected in summer. See graph 2. The results obtained are lower than those reported for the blue cenote of Quintana Roo with values of 8.8 mg / L in dry and rainy season, and 6 mg / L in winter season, respectively. The authors reported the presence of oxygen in the entire water column, except for 50 m in the rainy season. (Cervantes-Matínez, 2009).



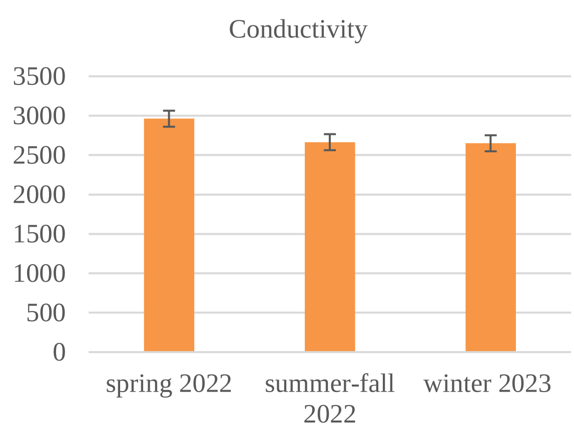
Graphic 2 Dissolved oxygen in the Chen Ha Cenote, monitored by multiparameter probe 2023
Source: Own elaboration

The highest temperature was detected in spring with a value of 32 º C and the lowest value in winter was 28.7 º C. The results are similar to those reported for the Blue Cenote, which presented an average annual temperature of 29.2 +/- 0.9 °C. The authors reported higher temperature values in dry and rainy seasons. The body of water was classified as warm-tropical (Cervantes-Matínez, 2009). Temperature influences the abundance of phytoplankton and bacteria (Abarzúa, 1995). (See graph 3).



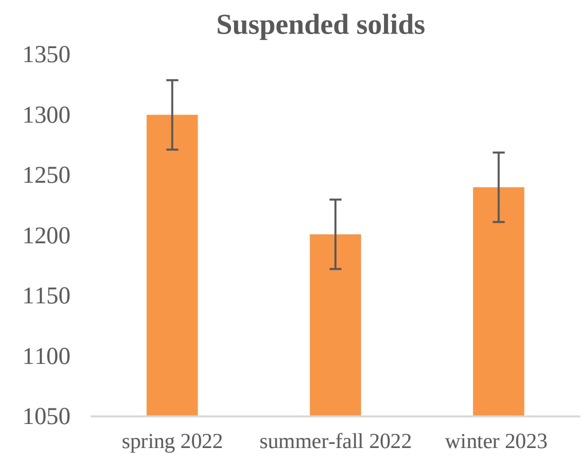
Graphic 3 Temperature recorded in the Cenote Chen-Ha in the spring-winter cycle 2022 – 2023
Source: Own elaboration

The highest conductivity values were observed during spring with a maximum value of 2962 microS.cm^{-2} and the lowest value during the winter with 2650 microS.cm^{-2}. These results coincide with what is reported in the literature for water samples from cenotes in the State of Yucatan with a minimum value of 688.0 micro–S.cm and a maximum value of 2381.0 micro S.cm with an average of 1175.78 micro S.cm. (Cruz- Sánchez et al., 2018) Figure 4.



Graphic 4 Conductivity recorded in the Chen Há cenote, April 2022- January 2023
Source: Own elaboration

Suspended solids were found in the range of 1300 to 1200 ppm the highest values were reached during spring (graph 5). The results are higher compared to those reported with a range of 515.77 ppm as a minimum value and 2381.0 ppm as a maximum value. For cenotes of the State of Yucatán (Cruz-Sánchez et al., 2018). The values exceed the values allowed by the Official Mexican Standard NOM-127-SSA1-2021 Water for human use and consumption, whose limit of total dissolved solids was 1000 mg.L.



Graphic 5 Content of suspended solids in the water body of the Chen-ha spring-winter 2022-2023 cenote
Source: Own elaboration

The diversity of phytoplankton species changed as a function of the climatic season shown in Figure 2. The present species at the moment were *Coelosphaerium*, *Microcystis wesenbergii*, *Microcystis aureginosa*, *Botryococcus*, *Chroococcus turgidus*, *Mougeotia Scalaris*, *Aulacoseira granulate*, *Pinularia accurans*, *Nitzschia*, *Navicula*, *Gomphonema angustatum* var *sarcophagus*, *Prorocentrum micans* Ehrenberg for all monitoring they are in the center of the diagram. The greatest diversity was observed in spring time with 41 species, 27 in summer-autumn and 29 in winter time.

In the biodiversity analyses, 20 species of cyanophytes were identified: *Coelosphaerium*, *Woronichinia naegeliana*, *Microcystis novacekki*, *Microcystis wesenbergii*, *Microcystis aureginosa*, *Microcystis flos-aquae*, *Microcystis incerta*, *Aphanocapsa elachista*, *Botryococcus*, *Nodularia* sp., *Planktothrix agardhii*, *Anabaena affinis*, *Pseudanabaena Limnética*, *Oscillatoria* sp., *Lyngbya*, *Microcystis wesenbergii*, *Chroococcus turgidus*, *Rhabdogloea yucatanensis*, *Merismopedia Tenuissima*, *Sinechocystis*.

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11 Chlorophytes species were identified: *Pandorina charkowiensis*, *Crucigenia cuadrata*, *Mougeotia Scalaris*, *Closterium Mesotaenium macrococcum*, *Staurodesmus extensus*, *Tetrastrum*, *Pleurotaenium Nägeli*, *Chlorella*, *Selenastrum gracile*, *Kirchneriella*. Two Euglenophytes: *Euglena spirogyra*, *Colacium vesiculosum.* 16 diatoms: *Aulacoseira granulata*, *Pinularia accurans*, *Nitzschia*, *Navicula*, *Surirella*, *Gomponema*, *Gomponema acuminatum*, *Gomphonema angustatum var sarcophagus*, *Skeletonema costatum* (Greville), *Diatoma vulgaris*, *Entomoneis alata*, *Asterionella*, *Cymbella auxospore*, *Craticula*, *Tabellaria ventricosa*, *Synedra.* Three dinoflagellates: *Prorocentrum micans* Ehrenberg, *Peridinium Cinctum*, *Gonyaulax* spp.

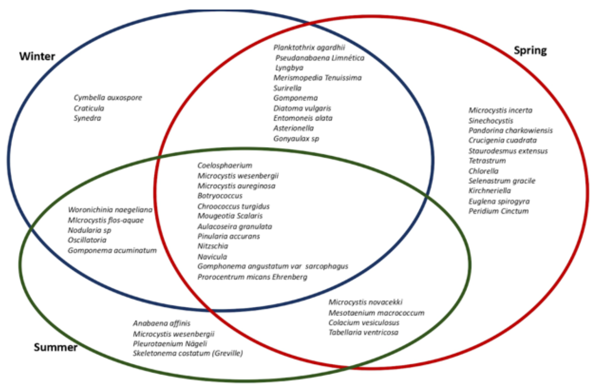

Figure 2 Diversity of phytoplankton species detected in the Chen Ha Cenote, during spring, summer and winter.
Elaboration: own.

Regarding the most abundant species in spring and winter seasons were diatoms. In spring the dominant species were *Navícula*, Surirella *and Pseudanabaena Limnética*, in summer (cyanobacteria) *Coelosphaerium*, Woronichinia naegeliana and *Microcystis aeruginosa* and in winter: *Nitzschia*, *Navicula*, *Entomoneis alata* and *Mycrocystis Flos-aquae* (cyanobacteria) (See Figure 3).

Figure 3 Diversity of phytoplankton present in the cenote Chen Ha, *Coelosphaerium, Entomoneis a., Botryococcus, Surirella, Merismopedia tenuissima, Navícula, Aulacoseira granulate*
Source: Own elaboration

According to Riquelme and Avendaño-Herrera (2023), the formation of a diatom bloom is related to the microbial community and its biomolecules that are released into the environment such as vitamins and growth factors. The bacteria-microalgae interaction is highly specific, bacteria use their ability to absorb, recycle nutrients and organic substances produced by phytoplankton in a symbiosis process.

It has also been demonstrated the presence of algae antagonist bacteria, with the ability to cause inhibition and lysis of microalgal cells and are a key factor for the decay of phytoplankton blooms associated with a rapid bacterial colonization of microalgal cells causing phytoplankton cell death. This fact provides continuity to the flow of carbon in the aquatic environment.

Phylogenetic analyses favor studies of evolutionary relationships between organisms, their distribution and role in the environment and trophic web. Microalgae are both prokaryotic and eukaryotic photosynthetic cells.

In photosynthetic eukaryotes, the 18 S gene, located in the small subunit of the ribosome, contains phylogenetic information with sufficient variability to distinguish between different taxa. The amplification of the 18 S gene by PCR with specific oligonucleotides allows the identification of classes or different phyla in eukaryotes as well as the creation of databases to search for coincidences or phylogenetic relationships (Andrade, 2017).

Figure 4 represents the phylogenetic tree of Diatoms. They are classified into two main groups in the first *Gomponema* is separated from the rest of organisms. The second group is bifurcated into two subgroups, there is greater similarity between *Asterionella* sp. and *Cratícula Pseudocitrus* with respect *to Nitzschia anatoliensis*. In the last group, greater similarity was observed between *Entomoneis* cf. *Alata* y *Surirella* con respecto de *Navícula trivialis*.

Diatoms form one of the most diverse groups of phytoplankton, they are fundamental participants in the recycling of carbon and silicates, and their silica wall is characteristic of the group.

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Their origin is estimated in the Jurassic period, they have a high potential for adaptation, they are mostly photosynthetic and it is estimated that in the oceans they represent 50% of the biomass (Lora-Vilchis, 2020).

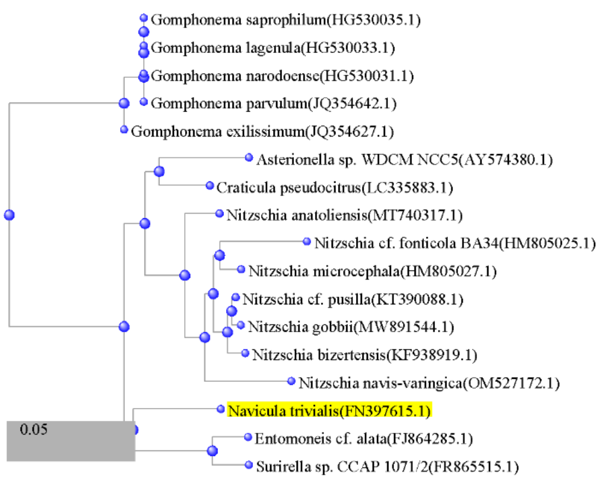

Figure 4. Phylogenetic tree of diatom algae identified in the different climatic seasons in the Cenote Chen Há, in the period April (2022) – March (2023)
Source: Own elaboration

In the case of prokaryotes, 16 S ribosomal RNA (rRNA) is the most widely used macromolecule in studies of bacterial phylogenesis and taxonomy. The 16S rRNA molecule contains highly variable regions, and includes regions of 20 or 30 bases that are completely exclusive to a single prokaryotic species (Andrade, 2017).

Figure 5 shows the phylogenetic tree of the cyanobacteria identified. They fall into two main groups. Greater similarity was observed between Microcystis *and* Synechocystis sp. with lesser similarity with respect *to Chroococcus turgidus*, *Gloeocapsa* is separated into a different group. According to the literature, the main causes that favor the development of these microorganisms include changes in salinity, contributions of fresh water from runoff with nutrient transport and temperature increases (Moreno, 2015).

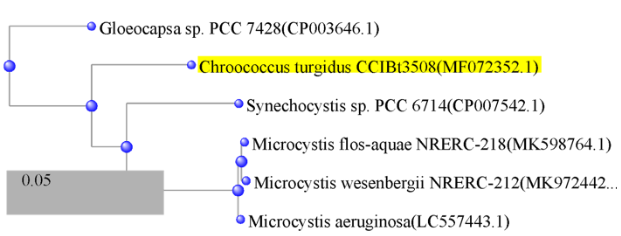

Figure 5 Phylogenetic tree of cyanobacteria identified in Chen Ha
Source: Own elaboration

These trees were selected for including the most abundant species in the water body. According to the literature, during the formation of a phytoplankton bloom in an aquatic environment the highest production of bacteria (3x107 bacteria per mL) is obtained after the maximum production of chlorophyll estimated at 80 mg.mL; it is worth mentioning that recent studies have shown a rapid increase of viral particles after the maximum concentration of bacteria (106 -109 particles x mL-1). These results have been corroborated in the laboratory. (Riquelme & Avendaño-Herrera, 2023).

It is worth mentioning that the summer period in which the pH increased, diversity decreased and cyanobacteria dominated, this allows to demonstrate that the body of water is very fragile and that the origin of runoff with high content of organic matter puts its preservation at risk. Our results coincide with those reported by Laura et al., (2018) who identified pH as one of the main environmental factors that determines the presence of cyanobacteria. They report that in slightly acidic pH (pH = 6) cyanophytes are scarce. In our study the pH was found slightly alkaline with values ranging from 7.5 to 8.5.

Species diversity is the result of ecological interactions between species and the environment, evolutionary and biogeographic history of regions. In particular, alpha diversity reflects the ecological relationships found in a specific space and time frame (Pérez-Hernández, 2015). There is currently great interest in the development of sensors that allow the composition of microalgae with the use of spatial sensors that interact with the properties of ultraviolet light and the reflection and refractive index, chlorophylls and accessory pigments of photosynthesis (Firme et al., 2023).

According to the Shannon-Wiener diversity index, an average level of diversity was observed in all seasons, the greatest diversity was detected in winter. With values of 2,809 for spring, 2,389 for summer-autumn and 2,946 for wintertime. See Figure 6. Less diversity was observed with respect to that reported for the month of August with a value of 3.01 for the Shannon Wiener index in Laguna La Viuda (Lima-Peru) in 2016. (Laura et al., 2018).

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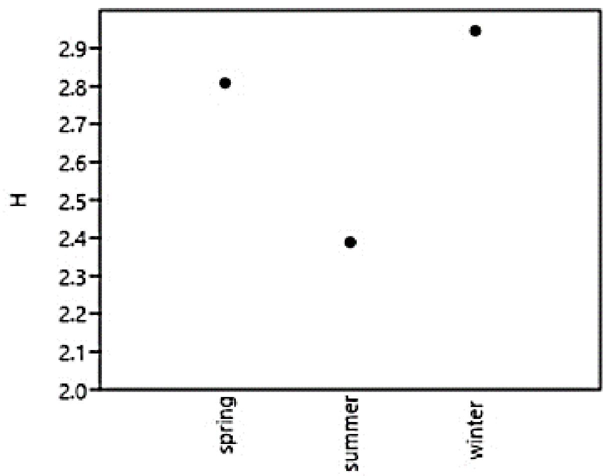

Figure 6 Shannon – Wiener biodiversity index determined for cyanobacteria and phytoplankton monitored in Chen Ha in spring, summer-autumn and winter.
Source: Own elaboration

The beta similarity index is defined as the variation or change in the identity of species between sites either by gain or loss of species (Perez-Hernández., 2015). According to the Jackard index, greater similarity was observed between the spring and winter seasons with a value of 0.458 with respect to summer – autumn with a value of 0.3877. (See Figure 7). Our results coincide with those reported by Huanaco et al., (2018) who mentions that in the study carried out by them, phytoplankton diversity is variable and is related to seasonality.

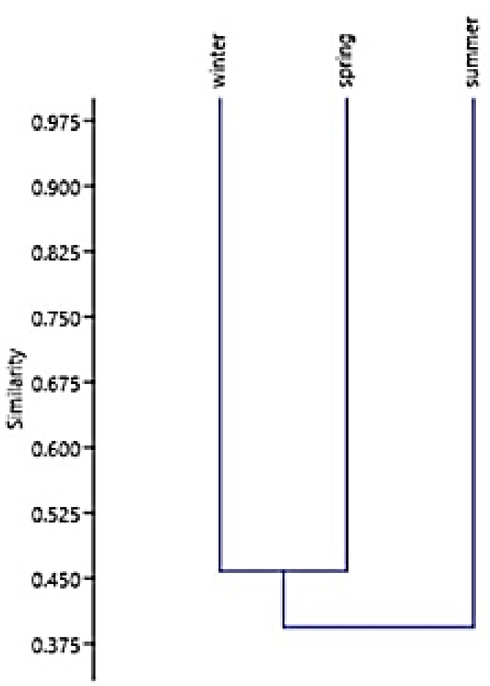

Figure 7 Beta similarity index, calculated from the biodiversity of cyanobacteria and phytoplankton monitored in the Chen Há cenote
Source: Own elaboration

Biological diversity includes the ecosystems in which species inhabit and interact and the genetic variability they possess. Biodiversity is valued from three biological, economic and cultural perspectives.

There is a significant degree of association between the abundance of phytoplankton and heterotrophic bacteria, with particular patterns of interdependence for each season of the year. The exudate of organic substances from active phytoplankton and the supply of carbon from dead phytoplankton are the main sources of organic matter for heterotrophic bacteria. (Abarzúa, 1995).

Each living being is a reservoir of irreplaceable evolutionary information with potential applications, is part of the trophic chains and is a source of inspiration. The Conservation of ecosystems has great value since they offer ecosystem services such as source of raw materials, climate regulation, erosion and diseases control and recreational activities (CONABIO), 2016. The identification of photosynthetic microorganisms by means rRNA sequencing is the method of choice for determining high taxonomic relationships. However, some organisms are known only by their molecular characteristics without having knowledge regarding their abundance, distribution or in situ role of their physiological characteristics (Andrade, 2017).

Bioremediation as a method for detoxification or removal of pollutants from the environment called high photosynthetic rate algal systems are recommended due to the high rate of algal biomass and oxygen. These systems provide a pleasant environment for bacteria to degrade organic matter (Sardi-Saavedra et al., 2016).

The knowledge of the genes and enzymes used in the metabolic process as well as the use of genetic engineering tools will allow the generation of microalgae species as industrial microorganisms and not only as laboratory models (Incera et al., 2022).

In matters of biodiversity, Mexico is recognized as megadiverse since it has about 70% of the known species on the planet, this is a privilege, however it also entails a commitment it is necessary to study the biodiversity associated with the different ecosystems, as well as sharing the results obtained that allow decisions to be made in favor of the environment, This is the main aim of this work to contribute to the knowledge of the richness of phytoplankton species that inhabit an open-air cenote in Chololá, Yucatán, Mexico, in which it was possible to demonstrate that diversity changes with environmental conditions throughout the year and that the alkaline pH that predominates in this body of water favors the development of cyanobacteria.

The cenotes are valuable because they are the niche of species related to the origin of life, but also for their economic value: tourism and recreation as well as cultural and religious values to which these resources are associated.

Gratitude

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Conclusions

The biodiversity of phytoplankton species changed depending on environmental variables, the most abundant species in both spring and winter seasons were diatoms and cyanobacteria in summertime. The dominant species were *Navícula*, *Coeloshaerium* and *Nictzschia*, for spring, summer and autumn seasons respectively. Regarding richness, average diversity was recognized in all seasons, with values of 2,809 in spring, 2,389 in summer-autumn and 2,946 for winter. Regarding alpha diversity, greater similarity was observed between the spring and winter seasons with a value of 0.458 with respect to summer – autumn with a value of 0.3877.

The main factors contributing to species diversity in the water column were identified as alkalinity, temperature and nutrients from rainwater runoff.

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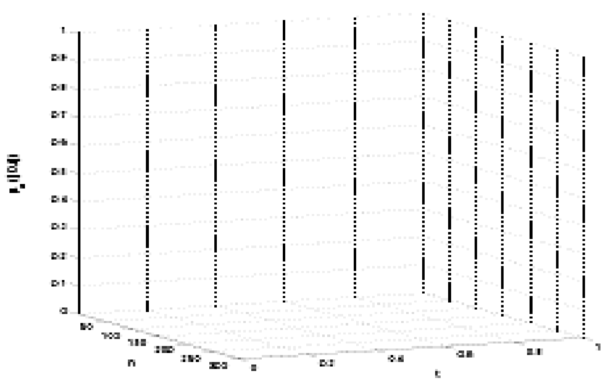

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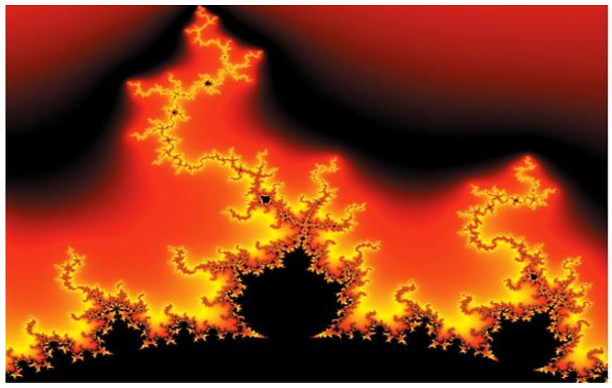

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