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Mangrove forests transition between land and ocean, bioremediation areas, refuge and conservation of species

Bosques de manglares, transición entre la tierra y el océano, zonas de biorremediación, refugio y conservación de especies

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Abstract

Mangrove forests provide environmental ecosystem services such as degradation of organic matter, and habitat for terrestrial and bird species. Lack of knowledge causes them to be undervalued and the change of land use due to tourist activities puts their conservation at risk. The objective of this work was to carry out a limnological analysis of phytoplankton biodiversity to contribute to the knowledge and characterization of the protected natural area: La Manzanilla. Applied Methodology: Sampling of environmental variables included: pH, temperature, conductivity, total suspended solids, and dissolved oxygen, determined with a multiparameter probe. The phytoplankton samples were recovered by trawling, with a phytoplankton net, later transferred to the laboratory for analysis. Paper contribution: The populations of *Crocodylus acutus* are permanently monitored by the Ejidal community. Crocodiles are free throughout the estuary. The most abundant species of mangrove was *Rhizophora mangle*. The water column recorded temperature of 25.3 ºC, electrical conductivity of 5.15 mS/cm^2, 2.96 ppm of oxygen dissolved and 2553 ppm of suspended solids. Low light intensity along the water column and the existing abundant organic matter represents a challenge for the survival of algae. Diversity percentages of phytoplankton were cyanobacteria 34.96%, diatoms 30.78%, chlorophytes 16.72%, Charophyta 6.73% and Euglenoids 1.33%.

Biodiversity, cyanobacteria, algae

Resumen

Los bosques de mangle aportan servicios ecosistémicos como degradación de materia orgánica, habitad de especies acuícolas, terrestres y aves. La falta de conocimiento ocasiona que sean poco valorados y el cambio de uso de suelo por actividades turísticas pone en riesgo su conservación. El objetivo de este trabajo fue realizar monitoreo limnológico y analizar biodiversidad de fitoplancton para contribuir al conocimiento y caracterización del área natural protegida La Manzanilla. Metodología: las variables ambientales incluyeron: pH, temperatura, conductividad, sólidos suspendidos totales y Oxígeno disuelto, determinados con sonda multiparamétrica. El fitoplancton se recuperó por arrastre, con red de fitoplancton, las muestras se trasladaron al laboratorio para análisis. Contribución de estudio: Las poblaciones de *Crocodylus acutus* libres en el Estuario, son monitoreadas permanentemente por la comunidad Ejidal. La especie más abundante de mangle fue *Rhizophora mangle*. La columna de agua registró temperatura de 25.3 º C, conductividad eléctrica de 5.15 mS/cm^2, 2.96 ppm de oxígeno disuelto y 2553 ppm de solidos suspendidos. La baja intensidad luminosa en la columna de agua y la abundante materia orgánica, existente, representan un reto para la sobrevivencia de algas. Los porcentajes de Diversidad de fitoplancton fueron: cianobacterias 34.96%, Diatomeas 30.78%, Clorofitas 16.72%, Charophitas 6.73% y Euglenoides 1.33%.

Biodiversidad, Cianobacterias, Algas

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Introduction

Mangroves are coastal forests located in tropical and subtropical areas of the planet, they form the transition between sea and land, are associated with important deltas of rivers that flow into the sea and form shallow lagoons of brackish water. These environments are relevant for the spawning and rearing of commercially and ecologically important fish species (Velazquez-Pérez *et al*., 2020).

According to Torres et al., (2023), the monitoring of biomarkers in aquatic biota is recommended in estuarine regions because the environmental impacts caused by anthropogenic activities such as industry, of all kinds, heavy metals and polycyclic hydrocarbons are highly harmful to molecules, cells, tissues, physiology and behavior of animals in the face of environmental stress.

Mangrove forests on the banks of the world's great rivers provided ancient civilizations with food (through fishing), water, transportation, mythology, art, and religion. Some consider the mangrove to be the prelude to agriculture activities in the Mayan and Mexica civilizations. The environmental contributions of mangroves include the recovery of degraded soils, they are a carbon reservoir (organic matter), and a source of energy and nutrients (detritus) for heterotrophs and retain sediments. They promote soil conservation, as they control tidal erosion and play an important role in the protection and stabilization of the coastline against atmospheric phenomena impacts (hurricanes and cyclones). They function as a filter for pollutants. They provide shade and shelter for terrestrial and aquatic species, migratory or local. In the selected area 40 % to 70% of marine species spawn and is a habitat for 1200 animal species, also it offers protection, food, and a breeding site for oysters and shrimps. It is used for recreational and ecotourism activities. Coastal ecosystems bring benefits to the world's population and mitigate climate change impacts (Calleja & López-Arias, 2022).

The present work was carried out throughout the La Manzanilla estuary, the Ejido has 419 hectares of tropical deciduous and subdeciduous forest, used for the conservation and management of the American crocodile: *Crocodylus acutus.* The site was declared a Ramsar Site of International Importance, as well as an Environmental Management Unit for Wildlife Conservation (UMA) in 2008. see Figure 1.

Figure 1 Environmental management unit Ejido La manzanilla, located in the State of Jalisco, Mexico, a Ramsar Site
Source: Own elaboration

Mangrove forests once covered large tracts of tropical and subtropical coastline, but are disappearing at a rate of 1 to 2 percent per year, with a faster rate in developing countries threatened by tourism and shrimp farms development, expansion of human settlements, industries, agriculture, livestock, and logging (CONABIO-CONANP, 2009).

Within the mangroves of America, 11 species of plants are reported, four belong to the genus *Rhizophora and four to the* genus Avicennia, and *to the genera* Laguncularia, Pelliciera *and* Conocarpus. (Regalado et al., 2016).

In Mexico, mangrove communities represent the highest deforestation rates in the country (7.93%) compared to the national average (1.29%), the Gulf Coast of Mexico is considered one of the areas with the greatest loss of cover (CONABIO). They are used in industry for the production of latex, dyes, wood and pharmaceutical for the production of tannins.

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Methodology to be developed

Researchers from the Polytechnic University of the Guadalajara Metropolitan Area, the Centro Universitario del Sur the Universidad Autónoma de Tlaxcala and students from the Universidad Autónoma de Tlaxcala participated in the monitoring. 10 monitoring stations were established according to the geographic coordinates shown in Table 1. Station No. 1 was located at the farthest position and Station 10 was located at the closest position from the jetty, respectively.

Experimental design

No. of station	N	W
1	19º 18´23.8´´	104º 47´17,2´´
2	19º18´19.5´´	104º47´18.7´´
3	19º18´12,3´´	104º47´21,9´´
4	19º18´09,9´´	104º47´22.4´´
5	19º18´07,8´´	104º47´17.5´´
6	19º18´05,5´´	104º47´24.7´´
7	19º18´05,6´´	104º47´29.7´´
8	19º17´55,5´´	104º47´26.2´´
9	19º17´17,9´´	104º47´19.1´´
10	19º17´10.9´´	104º47´18.7´´

Table 1 Location of monitoring stations
Source: Own elaboration

Limnological monitoring. A multiparameter probe was used for the analysis of environmental variables *in situ*, pH, conductivity, dissolved oxygen, total suspended solids and temperature were determined. Secchi disc was used to determine the transparency of the body of water.

Biodiversity analysis. It was carried out by horizontal trawling with a phytoplankton net with a diameter of 30 cm, 50 cm in length and 40 µm in pore diameter, for 60 seconds. The samples were fixed with formaldehyde and transferred to the microbiology laboratory of Universidad Politécnica de la Zona Metropolitana de Guadalajara. The analysis was performed with the help of a Leica microscope, with a 10x and 40x objective lens. Databases and specialized literature were used for the classification.

Multiple alignment and construction of phylogenetic trees. A search was conducted using the database of the National Center of Biotechnology Information (NCBI), from which the sequences of *Spirulina* major strain PCC6313 16S ribosomal, RNA partial sequence were selected. For the elaboration of the phylogenetic trees, manual selection was carried out and they were elaborated with the algorithm of maximum likelihood.

Figure 2 Limnological monitoring carried out at UMA La Manzanilla, Jalisco, Mexico
Source: Own elaboration

Results

Regarding the mangrove forest, the dominant species was *Rhizophora mangle L*. (red mangrove), followed by *Laguncularia racemosa* L. (white mangrove). They provide mangrove habitat services and functions, wastewater filtration, carbon sequestration, nitrogen fixation, and ecosystem self-preservation. Mangroves are Federal property, and the Official Mexican Standard 022 aims to protect coastal wetlands, see Figure 3.

Figure 3 Mangrove tree, characteristic of the Manzanilla estuary, México, 2023
Source: Own elaboration

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The red mangrove is an evergreen tree, distributed along the coasts of the Gulf, the Pacific and the Caribbean, it grows in environments with great water movement and variable salinity, its soils have a high content of organic matter. Its height is estimated to be 30 m tall with a straight trunk, with simple or dichotomously branched adventitious roots and numerous lenticels (taproots or stilts) that are anchored in waterlogged and fiery soils. (CONABIO).

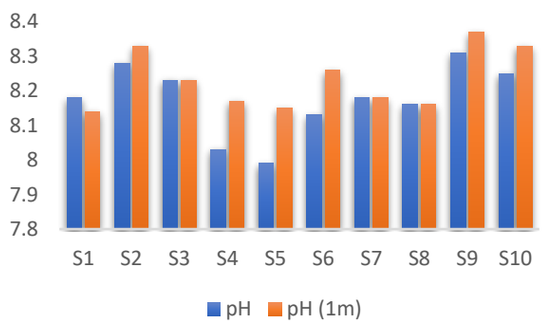
Laguncularia racemosa L. (white mangrove), known as a mangrove tree of the tropical coasts of America and West Africa, its wood is not durable, having a high density and a tendency to deform, therefore, it is used as fuel and its bark and leaves are a source of tannins, astringents and tonics. It is the tree species most tolerant to low temperatures, compared to other mangroves, it excretes salt and tolerates high salinity levels from 0 to 90 ppm, being intolerant to shade. It is usually associated with other species, it is not usually the dominant species, although it is characterized by a shallow, large, extended and horizontal root system (peg), which makes it susceptible to collapse by wind (Jimenez, (n.d.).

In a study carried out in Bahía Portete in Guajira, Colombia, the coast is bordered by dense populations of red mangrove and black mangrove, it is worth mentioning that these species are considered to be in a state of threat. (Gómez-González, 2017).

Crocodylus acutus is the crocodilian species with the largest distribution in the world, in México its distribution ranges from Sinaloa to Chiapas, the Caribbean Sea, Quintana Roo and Yucatán. In 1970 its population decreased considerably due to illegal hunting and the modification of its habitat, for which a national ban was declared and included in the list of the Endangered Species Act (ESA). It is expected that these actions would favor the increase of crocodilian populations (Lopez-Luna et al, 2013).

Figure 4 *Crocodylus acutus*, the photograph was taken in the La Manzanilla estuary, a protected natural area of international importance
Source: Own elaboration

Regarding the environmental variables, pH (determined at a depth of 30 cm) was recorded in the range of 7.99 to 8.31 with an average value of 8.2. The deeper the depth (1m), the higher the alkalinity, with values ranging from 8.14 to 8.37 (see Graph 1). Our results are similar to those obtained at Station 1 of San Juan Bay, reported on September 29, 2022, with values of 8.02 and 7.86.



Graphic 1 pH values obtained in the crocodile tree Manzanilla
Source: Own elaboration

The average dissolved oxygen level was 2.96 ppm with a range of 2.74 to 3.10. In the estuary of the Churute Mangroves, values in the range of 2 and 6.5 mg were recorded. $^{L-1}$ with hypoxia values (less than 2 mg. L-1) in the months of January to April (Marín et al., 2022).

The average value of total suspended solids was: 2553.1 ppm with a range of 2104 to 2771 ppm. The values drop as you move away from the jetty (station one). (See Figure 2).

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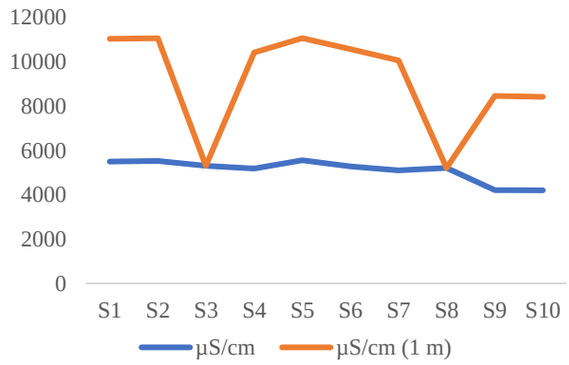
Industrial and domestic effluents carry pollutants that are transported through rivers or leachate into estuarine sediments. Pollutant molecules are usually associated with suspended particulate matter, where they become bioavailable to aquatic invertebrates, causing bioaccumulation when their detoxification levels are exceeded. For this reason, the study of metallic contaminants in sediments and biological matrices is recommended (Santos et al., 2021).

Graphic 2 Total dissolved solids content in the mangrove swamp La Manzanilla, Jalisco, Mexico, spring 2023.
Source: Own elaboration

The average temperature was 25.34 ºC with a range of 23.21 to 27.50 ºC. Our results are similar to those reported for the Churute Mangrove Estuary, which recorded temperatures in the range of 24.2 to 29.2 ºC, and in the Estero Salado, with a range of 26.1 ºC to 36.0 ºC during 2016, both areas located in the Guayas estuary in Ecuador, characterized as the largest estuary in western South America (Marin et al., 2022). The average temperature reported in Bahía Portete, La Guajira, Colombia is 29.8 ºC (October) and 25.4 ºC (January), (Gómez-Gonzalez, 2017).

Regarding visibility, the highest transparency was obtained at station 9 with a value of 68 cm and the lowest value was obtained at station 1 (boarding) with a value of 35 cm. The mean electrical conductivity was 5.1536 mS/cm^2, ranging from 4.984 to 5.788 mS/cm^2. In a study carried out on the Anil Are River in São Luis, capital of the state of Maranhao, Brazil, the transparency of the water was in the range of 0.19 to 1.41 m during the rainy period and 1.60 in the dry period, it is worth mentioning that the surface conductivity range was recorder from 7.64 to 49.29 mScm^{-1} during the rainy period and 31.8 to 55.40 mScm^{-1} in the dry period (Machado et al., 2022).

Low visibility is associated with the re-suspension of sediments by the action of the tides and organic debris derived from the degradation of mangrove leaves, known as detritus, and conductivity is influenced by the flow of seawater.



Graphic 3 Turbidity, determined with a Seshi dish in the mangrove swamp of Manzanilla, Jalisco, Mexico during the spring season
Source: Own elaboration

The ecosystem services provided by mangroves include protection from erosion of the coastline, and physical barriers against hurricanes, tropical storms, tidal waves, or tsunamis (prevents flooding), also they are a source of forest resources, flora and fauna, and promote tourism. Magroves provide a refuge and feeding area for vertebrates and invertebrates, and are a source of biomass for food chains (Garcés et al., 2021).

Regarding biodiversity, cyanobacteria were the most abundant species (34.96%), followed by diatoms (30.78%), chlorophytes (16.72%), charophytas (6.73%) and Euglenoides (1.33%). The dominant species was *Microcystis aureginosa (cyanobacteria)*, followed by Aphanothece (*cyanobacteria*), Prorocentrum micans Ehrenberg *(Dinoflagellate), Gyrosima acuminatum (diatomea) and* Chlorella *(*Chlorophyte). See Graphic 4.

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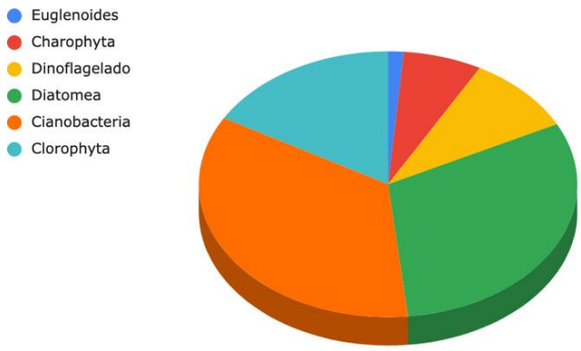

Graphic 4 Phytoplankton biodiversity identified from limnological monitoring carried out in the Manzanilla Estuary
Source: Own elaboration

In coastal environments, there are is an intense interactions of marine, river and terrestrial factors that favor primary production. They provide habitat and a great diversity of species (Delgado et al., 2022).

17 cyanophytes species were identified: *Planktolyngbia limnetica, Pseudanabaena, Pseudanabaena limnética, Pseudanabaena constricta, Microcystis, Microcystis Aureginosa, Synechococcus aeruginosos, Aphanizomenon flos aquaea, Planktothrix agardhii, Limnothrix redekei, Aphanocapsa grerillei, Spirulina getieri, Leptolyngbya lagerheinii, Rhabdogloea yucatanensis, Anabaena, Aphanothece, Oscillatoria.*

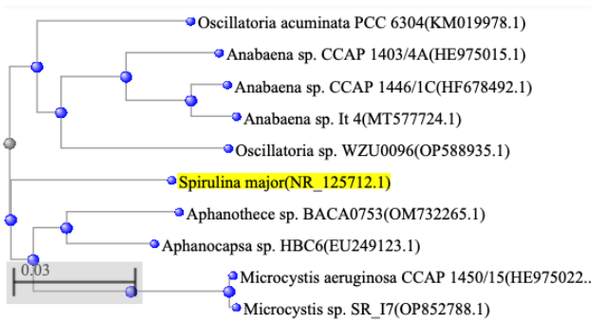

Figure 5 Cyanobacteria phylogenetic tree obtained from the Genbank database, accessed January 25, 2023
Source: Own elaboration

Furthermore, 15 diatomaceus species were identified: *Coconeis placentula Ehrenberg, Fragilaria Crotonensis, Nitzschia lancelota, Gomphonema gracile, Aulacoseira granulata var. augustissima, Gyrosima acuminatum, Navicula viridula Coscinodiscus, Entomoneis alata, Navicula Radiosa, Navicula bacilum, Cymbella minuta, Fragilaria capuchina, Pinularia ocurans, Gomphonema augustatum.*

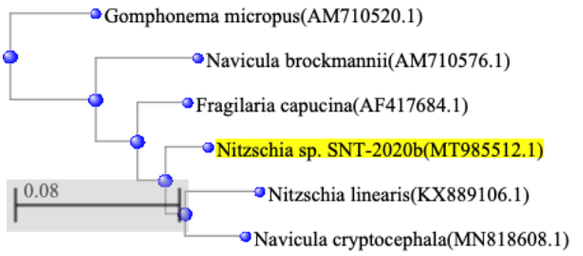

Figure 6 Phylogenetic tree of diatoms identified in the body of water
Source: Own elaboration

8 species of chlorophytes were identified: *Pediastrum simplex, Monoraphidium, Chlorella, Closterium parvulum, Chlorella, Botryococcus, Coelastrum microporum, Staurastrum gracile*

3 Charophyta species *were identified: Closterium kuetzingii, Closterium sp. Staurastrum gracile.* Regarding the dinoflagellates, the following were identified: *Prorocentrum micans Ehrenberg*. The Euglenoids corresponded to *Phacus acuminatus, Euglena* y *Euglena acus*.

Studies of prokaryotic biodiversity in tropical and subtropical estuarine ecosystems reveal a high biodiversity of archaea belonging mainly to anaerobic methanogens and methanotrophs, ammonium-oxidizing archaea and members of the *Superphyllum Asgard*. These organisms participate in the Carbon, Nitrogen and Sulphur cycle, under aerobic and anaerobic conditions with heterotrophic or autotrophic metabolisms in accordance with the existing ecosystem and are among the most productive on the planet (Torres-Alvarado y col., 2023).

Gratitude

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Conclusions

Throughout the estuary, the concentration of salts from saline intrusion causes an average electrical conductivity of 5.15 ms/cm2 (selective for some species), warm temperatures of 25.34 ºC favor microbial metabolism.

The estuary receives daily discharges of pollutants of a chemical and biological nature. The transparency range was from 68 to 35 cm, the suspended matter with an average value of 2553 ppm stains the water with a brown hue, the sedimentation of particles favors the presence of anaerobic microenvironments. Bacteria using biogeochemical cycles predominate in these ecosystems and produce soluble forms of nitrates, phosphates, and sulfates.

The most abundant algae species in the estuary: are: cyanobacteria (*Microcystis aeruginosa* and *Aphanothece*), dinoflagellates and diatoms use these ions as nutrients and through photosynthesis maintain oxygen levels of 2.96 ppm with a range of 2.74 to 3.10 ppm necessary for the life of aerobic species.

The roots of mangrove trees promote the generation of microenvironments, the presence of zooplankton filter feeders, and macroinvertebrates make this ecosystem the ideal place to detoxify organic matter. It is worth mentioning that the habitat of species of great importance and transcendence are *Crocodylus acutus*, *Rhizophora mangle* and *Laguncularia racemosa*.

The contribution of mangrove forests is undoubtedly very important for the treatment of water prior to its discharge into the river, its loss due to land use change associated with tourism activities or urban city developments, causes an irreversible negative impact. Mangroves are the most efficient natural treatment systems on the planet, not to mention all the additional contributions they provide as ecosystem services.

Clearly explain the results obtained and the possibilities for improvement.

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