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Adaptation of a freshwater ecosystem zonation as a baseline for bioindication

(« Ik Kil cenote, Yucatán, Mexico [10 Pic] » 2013)

Sous la direction de : Karl Matthias WANTZEN
Chaire UNESCO Fleuves et Patrimoine

Lorène MFUNDU KONDI

Adaptation of a freshwater ecosystem zonation as a baseline for bioindication

Resume: It is a research work on the advancement of hydro-eco-regions in Mexico. It reports on what can be found as scientific data on this subject. Even with little data available that can locate the hydro-echo-regions, several approaches to them have been proposed in recent years, with a desire to get as close as possible to the truth.

Directeur de recherche : Karl Matthias WANTZEN
Chaire UNESCO Fleuves et Patrimoine
Auteur : Lorène MFUNDU KONDI
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1. Introduction

Freshwater ecosystems occupy only 0.8% of Earth's surface, but they are estimated to harbor at least 100,000 species, or nearly 6% of all described species (Dudgeon et al. 2006)
The Convention on Wetlands, for instance, requires that sites nominated as wetlands of international importance—with wetlands defined to include all freshwaters—be evaluated against a "biogeographic regionalization" criterion (Ramsar Bureau 2006).

An habitat is the environmental or ecological area in which an organism lives. In other words, habitat is the natural environment occupied by an animal, plant, or other organism. An organism or population naturally prefers to live in a particular environment when it is abundant with resources. Then this particular environment eventually becomes their habitat. The habitat can be a body of water, the bark of a tree ... any area with a source of energy or nutrients for an organism.

A biogeographic zone is a climatically and ecologically relatively homogeneous geographical area in terms of plant formations and temperatures.

It was essential to create biogeographic zones and to locate them in order to have a more precise idea of the zoning of the different habitats on a territory. This knowledge will make it easier to identify and even make assumptions about the settlement of organisms in a given area.

In running water ecosystems, the definition of zones is not done in the same way.
What is interesting at the level of hydro-ecoregion is the watershed. In fact, by taking a watershed as the study area, with fish fauna and especially fish as living organisms (most often, these are the best studied organisms), it will be more obvious to determine which hydro-ecoregion is in question. This is because the fish fauna normally remains in its watershed, thus facilitating the study.

The hydro-ecoregion approach differs from the biogeographic approach, which is based on biogeographic regions drawn from the distribution of aquatic insects, notably Limnofauna Europea from Illies and Botosaneanu, which have classified the different zones of a river taking into account benthic invertebrates. They then describe three "universal" zones: the crenon (spring zones), the rhitron (upper river, fast) and the potamon (lower river, slow). Each of these zones is home to qualitatively homogeneous populations. The boundaries between these different subdivisions are at the level of the main confluences, but in this classification, there is no tangible relationship with the functioning of the ecosystem itself. Moreover, the geological characteristic is insufficient.
As it has been previously mentioned, the hydro-ecoregions have as controlling factors the physical and ecological functioning of the watercourses. This idea of a top-down approach, linking the functioning of the ecosystem to the geographical characteristics of the basin is based on the concept of hierarchical control of ecosystems, an idea expressed by Lotspeich (1980).(Wasson et al. 2004)

The hydro ecoregion system will allow the grouping of environments with the same characteristics based on geography while including geology and altitude. This works by linking the ecosystem to the geographic characteristics of the basin. It forms a nesting of physical

structures controlled by geomorphological processes from the basin to the micro-habitats. Geology, relief and climate will be essential determinants of the functioning of the running water ecosystems, so the hydro-ecoregions are delimited on the basis of these determinants. Therefore, within the same hydro-ecoregion there should be rivers with similar physical, chemical and biological characteristics, and the same gradient of upstream to downstream evolution. The same habitat types will be found within the same hydro-ecoregion, but a habitat is not necessarily specific to a single hydro-ecoregion.

A hydro ecoregion is defined as an area that is homogeneous in geology, relief and climate. It is one of the main criteria used in the typology and delimitation of surface water bodies.
Typology is the determination of characteristic features in a dataset to distinguish types, systems, etc...

The hydro ecoregions were established with the aim of defining a biological, physicochemical, and hydro morphological reference framework according to the type of environment.
The role of ecoregions is to serve as a plan for conservation, representing natural communities before they have been altered by humans and providing a structure for eventual restoration to their natural state. The ecoregion approach has been adapted to aquatic ecosystems in order to define regional objectives for water quality and management.
Regions with poor data use freshwater fish species but this is a limitation for places such as islands where freshwater fish species do not provide much information.
It is important to have a good typology that will reflect the natural functioning of ecosystems and their biological structure. The choice of the typology must be based on elements not modified by human activity, the objective being to define sets of environments with the same biological characteristics in an environment not impacted by man. This choice of typology is essential because it will enable rivers to be grouped into coherent management units. Thus, watercourses of the same types should present the same sensitivity to impacts, notably anthropic impacts.

A global scale map is intended to present the biogeographic regionalization of freshwater systems.
The map used at the global scale to differentiate freshwater ecoregions is based on the distribution and composition of freshwater fish species by integrating major ecological and evolutionary patterns.
It is important to map species data because it can reveal areas of high biodiversity that are not recognized. Moreover, it allows the identification of exceptional and threatened freshwater systems. There is no better way to have a global knowledge base to increase biogeographic knowledge on a global scale.(Abell, Thieme, Revenga, Bryer, Kottelat, Bogutskaya, Coad, Mandrak, Balderas, Bussing, Stiassny, Skelton, Allen, Unmack, Naseka, Ng, Sindorf, Robertson, Armijo, et Petry 2008)

Each country has its own system of data collection that will be more or less complete to be able to locate the hydro-eco-regions. Some countries are very advanced in this field and allow precise geolocation. Other countries have not yet carried out precise data collection, so the geolocalization of areas is not precise and even possibly erroneous (because not all the information allowing a precise judgment is gathered).

If we take the example of Europe, due to the directive European framework that aims to achieve good ecological status in aquatic environments, hydro-eco-regions are used as a good implementation tool.

The indicators taken into account are relief and climate such as those that define hydro-ecoregions in France. The third criterion makes the difference because it is not geology but human activities in the watershed.
When eco-regions have been found, aquatic invertebrates are used to validate the regions. It is important to ensure that the indicators used are meaningful for the region. This will ensure that eco-hydro regions are well defined.
In addition, reference values will be used as a support to identify the different regions and will be calibrated for the whole country. The reference values are there to provide a framework and will differ from region to region. Indeed, each region has its own characteristics and cannot be compared with the same criteria. The specificity of the region is therefore taken into account.
The way of describing hydro-eco-regions in France has been adapted in other countries such as Belgium, other countries such as Spain, Austria and Germany use a comparable regional approach.

The French territory is divided into hydro-ecoregions, using the criteria used to qualify these hydro-ecoregions will help to identify that of Mexico knowing that these are universal criteria. From the French point of view, the hydro ecoregion is a homogeneous spatial entity from the point of view of the physical determinants that control the overall organization and functioning of aquatic ecosystems. At the scale of the basin, the primary universally recognized determinants of the ecological functioning of rivers are geology, relief, and climate. This concept is inspired by the theories of hierarchical control of hydro systems and is particularly based on the nesting of physical scales, from the basin to the micro-habitat.
Three geological types, four relief types and three climate categories were determined. It follows the leading structures of aquatic diatom and invertebrate populations.

Several hydro-ecoregion classifications exist for Mexico, however the accuracy of the data for Mexico is not exhaustive. Therefore, there are still uncertainties about the actual division of the hydro-ecoregions.
Taking into account the situation of the hydro-ecoregion in Mexico, the objective of this work is to continue progressing on this topic so that a territorial basis for projects to register aquatic biodiversity can be established. It would be interesting to be able to find a monitoring approach by region in order to facilitate the decision-making process regarding the areas and species to be protected, to identify heritage species in order to make the best decision regarding the choice of a future development, restoration, conservation and preservation of a space.

2. Methods

Finding accurate and complete data about Mexico is not easy. So, to conduct my research I relied on well-known documentation on this specific subject such as articles or books. From these reliable sources I was able to find other sources, especially by going to look at the inspirations of these works.
Of course, the use of keywords in scientific search engines was also used.

3. Results

3.1. Geography

Mexico located in North America holds huge contrast regarding it landscapes. Bordered by the Atlantic Ocean on the east and the Pacific Ocean on the west its diverse geography comes from its geological structure.
In the northern half of Mexico several important North American structural features found in the USA continue in Mexico
At low altitude in the east as in North America, the sediments are rich in oil. These structural conditions and these richness are found towards the southeast as far as Tabasco.
The coastal plains are limited towards the interior by the mountainous rim of the eastern Sierra Madre, a sedimentary chain often limestone, which can be compared to the Rocky Mountains. On the plateau, the short, faulted chains that arise in the middle of the North American Nevada basins are similar to those of the Mexican Chihuahua; this type of relief also exists at the western foot of the mountainous axis in North American Arizona, as in Sonora, (a state north of Mexico).
In the same way, the vast lava plateaus cut by faults in Oregon are similar to those of the western Sierra Madre and the Baja California Peninsula.
The formation of the vast hydrographic basin of Rio Grande del Norte (Rio Bravo) originating in Colorado, more precisely in the San Juan Massif, designates the national border between Mexico and the United States for the last 2018 km of its course. It ends up throwing itself into the Gulf of Mexico.
There is a neovolcanic axis that cuts the country along the east to west by its central part between the Gulf of Mexico and the Pacific Ocean.
In eastern Mexico, the arrangement of the structural units is again interrupted by the Tehuantepec isthmus. Here the Gulf and the Pacific are separated by only a little more than 200 km.
Although Mexico is a medium-sized country with these two sea facades, it has the variety of subtropical and tropical climates that are characteristic of the eastern and western facades of the continents.
On the western side there is a desert linked to the subtropical anticyclone, to be more exact, two semi-deserts are separated by the western Sierra Madre.
To the north of these deserts, the Mediterranean climate appears at the North American border. In the south, we are no longer talking about winter rain but summer rain, it will be more and more abundant as we move away from the tropics.
On the eastern side of Mexico, at the latitude of the tropics, the desert disappears because the rainfall will be homogeneous throughout the year.
In the south of the country the rains will be very abundant, it will not leave the place to a dry season, which allows the dense forest to go up to the latitude of Tampico. On the contrary, the lowlands of the Yucatan, especially on their north-western side, will have a strong summer dry season and a much lower total rainfall.
The large mountainous masses will play an essential role in causing rainfall and changing temperatures. In addition, there are local climatic contrasts. For example, there is the beginning of a monsoon phenomenon on the Pacific coast of Nayarit and Southern Sinaloa: the rains are important, superior to those of the Pacific coasts and important autumn rains prolong the summer. Another remarkable thing is the extension southward of the cold spells coming from the Great Plain and the eastern United States.
Finally, it should be noted that the eastern Sierra Madre forms a clear climatic barrier. On either side of it, in just a few kilometres, one abruptly goes from the most humid area of Mexico on the eastern slope to a dry ridge. (Ibáñez 2019)

3.2. Climatology

Mexico has four different climates distributed as follows:

- Tropical rainy climates with no cool season:

This climate will be found in the south of the country and especially on the west coast until reaching the state of Sinaloa and in the east until the state of Veracruz. It represents 14.6% of the territory.

- Steppe Climates

This climate is found in central Mexico until it reaches the state of Chihuahua in the west from Zacateus and in the east it is found as far as the state of Coahuila de Zaragoza. It represents 13.01% of territory

- Desert Climates:

it is located mainly in the state of Baja California, to the west in Sonora and part of the state of Coahuila. It represents 52.47% of territory

- Middle latitude rainy climates with mild winters:

This climate is found in the south in the state of Oaxaca, going up towards the capital of Mexico City, dividing towards the west it is found all along the west coast to the north of the country and in the east this climate fades towards the state of Tamaulipas, it corresponds to 19.92% of territory.

Figure 1- Map representing climate in Mexico

(« Carte climat Mexique, Carte des climats et météo du Mexique » s. d.)

Some general characteristics of Mexico's natural environments come from both structural and climatic elements. It can be said that arid and humid climates come from environments where the climatic factor dominates, while recent volcanism prevails the environment depends more on the geological structure.
Because of these criteria, Mexico can be divided into three different environments:
Semi-arid environments, which occupy more than half of the country and are characterized by easily penetrable reliefs, except for the western Sierra Madre mountain range. The flat elements occupy most of the space, dominated by isolated mountains. Vegetation does not completely cover the ground and among the many species of thorny bushes, cacti are in the majority. River flows are low and the endorheism is frequent, (the watershed does not flow into a sea but on the contrary is closed, retaining its surface water or not in a basin) especially between two mountain ranges.
In rainy tropical environments vast sectors are occupied by steep slopes and high altitudes. Savannas are rare, one encounters rather thorny, thick bush - where sometimes cacti have their place - and forests more or less humid. One passes from bush to deciduous forest, or from dense forest to deciduous forest. Rivers have abundant flows; moreover, they are subject to violent floods, especially when typhoons dump huge amounts of water on the eastern mountains in the fall. Therefore swamps occupy a notable place in the plains.
The natural environment related to recent volcanism appears only in a limited area near the neo-volcanic axis. It is here that we find the most marked variety in the landscapes: the contrasts in altitude are abrupt, resulting in climatic and vegetal contrasts; the hydrographic network is disorganized: lakes and endorheic basins appear, but also springs.

3.3. Elevation

Altitude is one of the key criteria for assessing hydro-eco-regions within a country.
This map represents the altitude depending on where you are in Mexico. The lowest altitudes are found around the periphery of Mexico with a greater percentage on the east coast. Before reaching very high altitudes, we observe a very fine gradient that takes us to the middle of the highest altitudes. These high altitudes are in the center of the country. Indeed, the closer we get to the center the higher the altitudes will be and the further we move away from it, going towards the west or east coasts and the lower these altitudes will be.

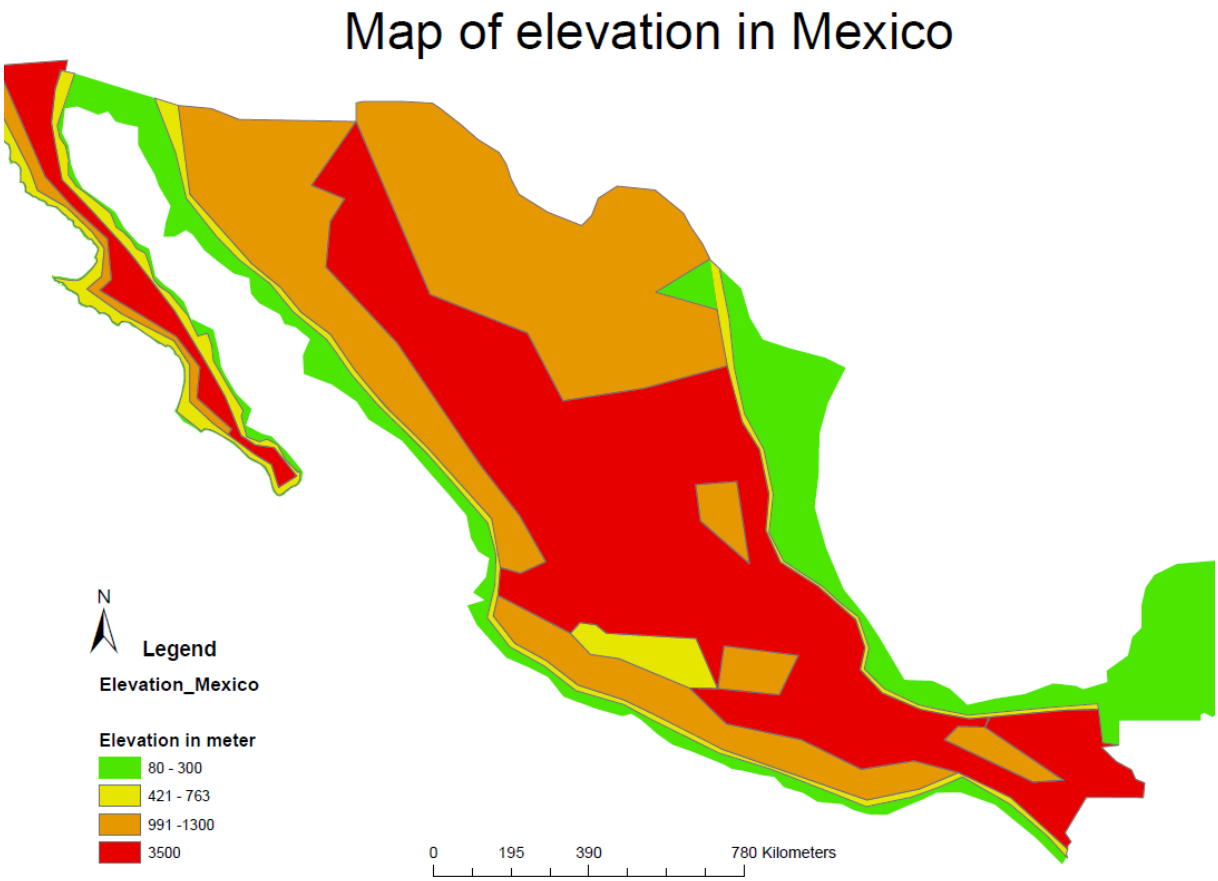


Figure 2- Map of elevation in Mexico

3.4. Hydrology

Mexico has a long coastal zone of more than 10,000 km with 144 lagoons and estuaries on the Pacific coast, the Gulf of Mexico, and the Caribbean coast. These systems are going to be very important for fish production. A wide variety of tropical fish will be found in the Gulf of Mexico and on the east coast of the Yucatan Peninsula. On the Pacific coast seals, sea lions and some mammals such as humpback and gray whales are temporarily living there. The coral reef is also present there. The knowledge of these ecosystems is still very limited, the current knowledge of these ecosystems is limited to the areas of Terminos, Alvarado and the lagoons of Madre.(« Biomes of Mexico: Main Characteristics » s. d.)

There are approximately 731 hydrological basins representing an average annual volume of 471.5 billion cubic meters of renewable fresh water. 87% of runoff water flows through 50 basins, these 50 basins alone cover 65% of the territory's surface.

17 of the 50 basins will discharge into the Gulf of Mexico and the Caribbean Sea, 32 will discharge into the Pacific Ocean and the Sea of Cortez.

The average rainfall in the country is 1489 billion m3, of which 71.6% is evaporated/transpired, 22.2% will flow into rivers and the remaining 6.2% will infiltrate the soil. There are 653 aquifers currently registered in the country of which 106 are overexploited. 55.2% of all groundwater comes from aquifers overexploited by many diverse activities such as agriculture in the first

place and then supply for the public and industry. This overexploitation has had many repercussions on natural resources such as the disappearance of lakes and wetlands, the loss of ecosystems, the reduction of the base flow of rivers, a deterioration of water quality, all sela is due mainly to the intrusion of saline water.

Regarding the aquatic ecosystems in Mexico, they are from three different types:

- Lotic- Rivers and streams systems

This system is a key resource in food webs as it houses a great diversity of fish, mollusk, crustacean and insect species. They have a great biodiversity due to the high degree of endemism. Unfortunately, this area became very degraded due to their use caused by the scarce protection. Therefore, maintaining these communities requires special management. In some other cases we need to protect this system from desiccation, road construction and other types of exploitation. (Ibáñez 2019)

- Lentic- Lakes and Ponds Systems

These systems are not depending on land systems but stem from the natural environment that surround them. Among these different ecosystems, there is tectonic-volcanic origin lakes, crater lakes, alpine-tropical lakes but also oases and sinkholes. Other lakes are in the state of desiccation due to their evolution and climate situation. These lakes are located in the arid basins of northern Mexico called playa Lakes. Saline lakes are in the central and northern regions of the country, they are mostly threatened climate change and anthropic activities. (Ibáñez 2019)

- Wetlands

Wetlands are dynamic, complex, and highly productive ecosystems. The different biota communities in continental wetlands are: " the low floodable jungle, gallery vegetation, the mangrove, the floodable palm grove, the savannah, the floodable thorn scrubland, the popal, the floodable thorn scrub, the thornless scrub, , the tular, the reed bed, and floating vegetation can be highlighted". They provide food, shelter, habitat reproduction areas for birds, reptiles, amphibians, mammal, fish, and invertebrate species due to their different physical structure, geographic location, and chemical composition. Wetlands also have an impact regarding sedimentation, flooding, and runoff but also on water supply and purification.(Ibáñez 2019)

3.5. Biomes

A biome is a vast biogeographic region that extends under the same climate; in Mexico, there are eight different biomes spread throughout the country. (Larousse s. d.)

- Alpine tundra

Alpine tundra can be found at high altitudes all over the world, even in tropical regions, these lands are generally covered with snow for most of the year. It is the coldest of the biome in Mexico, its particularity is the low annual pluviometry, and it makes it like a desert. Nevertheless, it remains a humid place. The alpine tundra is found at the heights of the Popocatepetl and Iztaccihualtl volcanoes, the Orizaba Peak, Nevado de Colima and Nevado de Toluca. The mosses and lichens are representative of this area and there are hares, teporingos (a variety of rabbits) and rattlesnakes to name a few species.

- Desert

The desert is one of the largest biomes in Mexico characterized by a dry climate, hot days and cold nights, it is found in northern Chihuahuan and north central Mexico as well as in the Sonora Desert. In terms of flora, we find bushes and thorny shrubs, cacti and succulents. Rodents, lizards and snakes but also toads, birds and owls are part of the fauna.

- Chaparral

Known for temperatures above 40°C, this ecosystem is found on the north-western coast of Mexico and in regions of California. Concerning the flora, there is a dominance of xerophytic trees (plants tolerating extremely dry environments) but we can also find strawberry trees, chestnut trees, oaks ... Several plants have also developed fire resistance adaptations to survive the fires that are frequent during the dry season. Many species of animals are present in the chaparral such as rats, lizards, squirrels, ducks and birds.

- Coniferous forest

This biome covers most of the western Sierra Madre with often negative temperatures in winter. A characteristic of this biome is that the soils are rich in humus, the vegetation is mainly coniferous. This environment is home to large mammals such as deer, caribou and elk, we also find predators such as lynx or bear but also small rodents.

- Tropical rainforest

The tropical forests are located near the coast of Mexico. This climate is found especially in the south of Veracruz and Tabasco as well as the highlands of Oaxaca and Chiapas. One of the characteristics of this environment is that their soil is thin, sometimes acidic and contains few nutrients. Rainfall is frequent and abundant. The flora is characterized by scrub (clumps of woody plants), grasses and small forests in some areas. The fauna is very diverse, amphibians, reptiles, many birds, snakes, tigers, jaguars ... populate this ecosystem.

- Wet Jungle

Located in the regions of Tabasco, in the south of the Yucatan Peninsula and the Sierra de Chiapas, but also in some small areas such as the Sierra Madre del Sur in the states of Oaxaca and Guerrero. Heavy rainfall throughout the year and the high rhythm of this ecosystem. Due to the constant rainfall, the plants keep their foliage green throughout the year. A variety of palms and orchids are present in addition to ferns, bromeliads, mosses and lichens. Concerning the fauna, spider monkeys, raccoons, anteaters, the solitary eagle, the scarlet spider, the royal toucan, iguanas, boas and many other species are present in this environment.

- Meadow

In the northern part of Mexico are the grasslands characterized by low predominant vegetation and a dry season lasting 6 to 9 months. The flora is then composed of different species of grasses, shrubs and in some areas there are forests. The fauna includes carnivores such as wolves, coyotes and pumas but also ruminants such as bison, deer and wild horses.

- Steppes

Located in the regions of Sonora, Baja California, Chihuahua, Coahuila, Nuevo Leon, Durango, Zacatecas and parts of San Luis Potosi the steppe is characterized by an arid climate with a wide variation in temperature between summer and winter, the flora is then herbaceous with many varieties of cacti, we can also find xerophytic plants. Rodents, quails, coyotes, armadillos and pumas are species that can be found in this ecosystem.

Nineteen ecoregions have been identified in Mexico and eight border ecoregions (six at the border with the USA, one at the border with Guatemala, Belize and Honduras and one at the border with Guatemala.

3.6. The hydro-ecoregion based on the article Freshwater Ecoregion of the world

Freshwater ecoregions are based on the distribution and composition of freshwater fish species while incorporating major evolutionary patterns. The map of the Earth's freshwater regions that has been created using these parameters is an essential tool that will assist in regional conservation planning efforts by first providing a knowledge base and increasing biogeographic knowledge. Through this regionalization, areas of high biodiversity have been discovered but also threatened freshwater systems.
The map was created using the best available information describing the biogeography of freshwater. Freshwater fish were the subject of the study that made this possible. Indeed, fish are the most studied taxa worldwide. However, although the study of fishes is widespread worldwide, knowledge about them is very different depending on where in the world one is located. Many ponds around the world are not yet well sampled. In areas with a lack of species data, a top-down analysis has been carried out using expert knowledge of the species to map the areas. For areas with good species knowledge, a bottom-up approach was carried out, species knowledge was used to produce watershed maps and species data was used to assess biogeography.
For the delineation of ecoregions in Mexico, this was based on qualitative assessments of similarity-dissimilarity of the main basins with the help of standard administrative hydrographic regions. Ecoregions that are transnational with the United States have merged their species lists. None of the sources used can be qualified as definitive and error-free, the chosen information base for habitats is that of FishBase.

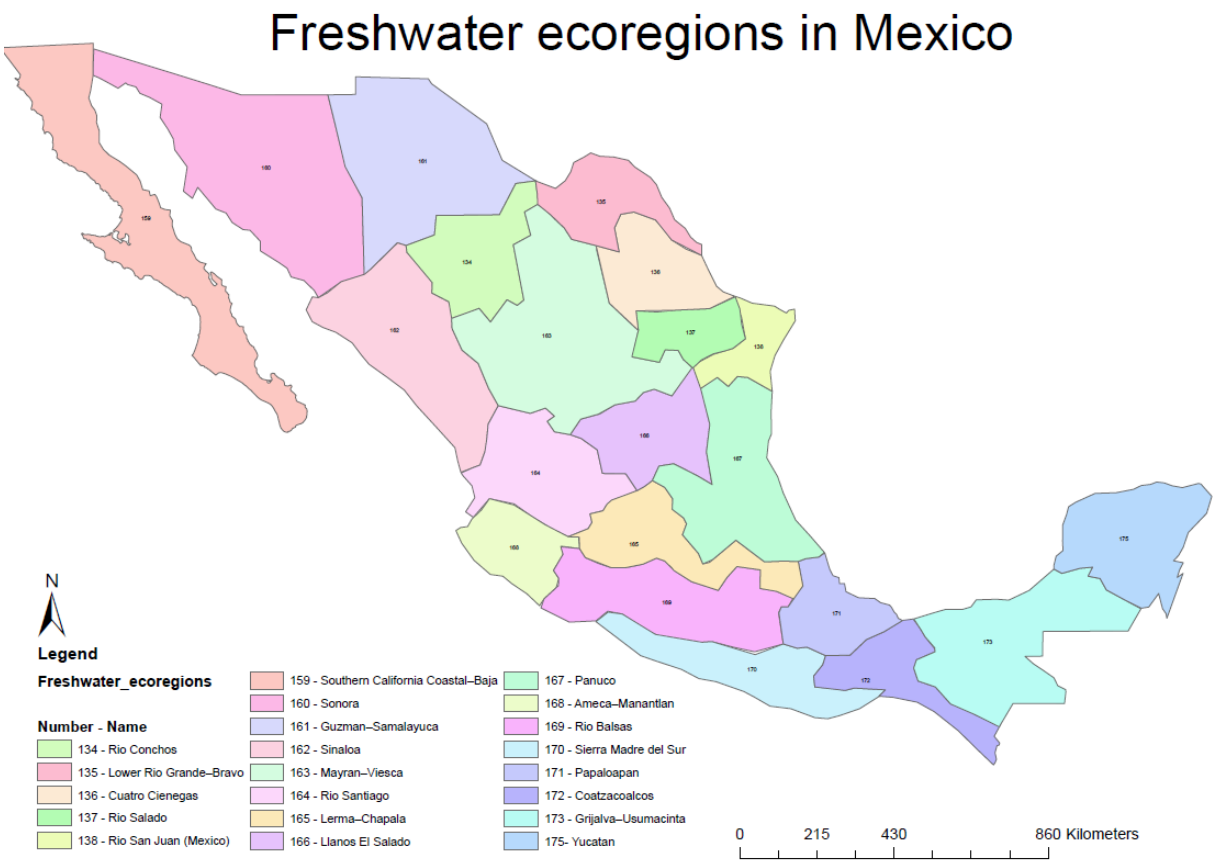


Figure 3- Map of the freshwater ecoregions

3.7. The hydro-ecoregion based on the book "Mexican Aquatic Environments"

Different representation of Mexico hydro ecoregions does exist. One of them describes 27 ecoregions, 19 are in Mexico only and 6 others are parts of different countries with a border with Mexico. These different ecoregions have been grouped in 6 different large hydrological regions. (Ibáñez 2019)

- Northwest region
- Tropical Pacific region
- Northem plateau region
- Central region
- Gulf of Mexico region
- Southeast region
-

The method used to classify the regions differs from the one used by the FEOW because it was based not only on the distribution of endemic fish species alone, but also on ecological and evolutionary patterns and different habitat types. The National Commission for the knowledge and Use of Biodiversity (CONABIO) has created 110 priority hydrological regions to develop a reference framework for the conservation and sustainability of the use of the environment. Starting from the watershed, the selection of these priority areas was made by looking at the biologically rich areas, general knowledge of the area, or lack of information about the area, what the main activities are, possible negative impacts and/or potential impacts on the environmental services that the area can provide. It was considered important to create these zones to conserve biodiversity and to ensure that awareness of the importance of protecting a natural area is paramount whether at the regional, national, or even international level. This

representation is dated from the 2000s and since the location of the hydro-eco-regions has changed.

3.8. Types of habitats in Mexico

The Freshwater Ecoregions of the world (FEOW) that represent biogeographical regionalization of the Earth freshwater biodiversity provide different hydro ecoregions. Through this regionalization the data shows the richness and endemism numbers for freshwater fish, amphibians, turtles, and crocodiles. Addition information that are found is ecoregion boundaries, topography, climate, habitat, ecological and evolutionary phenomena. Treats are analysed, therefor everything that can have a negative impact is examined. Information such as the land cover conversion, area equipped for irrigation, human footprint, the presence of large cities, urban land cover and water stress. Although there is a multiple of hydro ecoregions in Mexico, there is only 12 types of Major Habitat. (« Freshwater Ecoregions of the World » s. d.)

- Large Lakes
- Large River Deltas
- Polar Freshwaters
- Montane Freshwaters
- Temperate Coastal Rivers
- Temperate Floodplain Rivers and Wetlands
- Temperate Upland Rivers
- Tropical and Subtropical Coastal Rivers
- Tropical and Subtropical Floodplain Rivers and Wetlands
- Tropical and Subtropical Upland Rivers
- Xeric Freshwater and Endorheic Basins
- Oceanic Islands

The freshwater Major Habitat Types are more or the less similar to the biomes for terrestrial systems. It regroups ecoregions with biological, chemical and physical characteristics similarities. The ecoregions have a large scale it means that there is not only one type of habitat in the hydro ecoregion, but it can contain smaller type in addition to the dominant one.
The description of the Major Habitat types from Mexico will only be described here. Four of the twelve habitats are present in Mexico.
Large groups of freshwater habitats as well as terrestrial biomes are groupings of ecoregions with similar biological, physical, and chemical characteristics. Ecoregions are large in scale so each ecoregion contains multiple habitats.
The four major habitats found in Mexico are the following:

- Xeric Freshwaters and Endorheic (Closed) Basins

These are freshwater ecoregions dominated by endorheic aquatic systems (i.e., regions where river waters do not reach the sea) (Larousse s. d.) or freshwater ecoregions found in arid, semi-arid or dry sub-humid environments. The fauna found in this ecosystem knows how to adapt to ephemeral and intermittent floods or, on the contrary, to water levels that will be lower at certain times of the year.

- Temperate Upland Rivers

These are freshwater ecoregions defined by mid-latitude rivers that are different from floodplains and are characterized by the absence of floodplains.

- Temperate Floodplain Rivers and Wetland Complexes

These are freshwater ecoregions dominated by a single large, mid-latitude river system often characterized by a cyclical peripheral floodplain. In this ecosystem we often find wetland complexes composed of internal deltas (def), marshes, swamps always associated with the main river system.

- Tropical and Subtropical Coastal Rivers

These are freshwater ecoregions dominated by numerous small to medium-sized basins with low latitudes. These ecoregions may contain coastal lagoons, small lakes and wetlands but are characterized primarily by riverine ecosystems. What will most characterize this ecoregion are the many small to medium sized basins that drain into the ocean, instead of a single large river and floodplain that drains into the ocean.(« Freshwater Ecoregions of the World » s. d.)

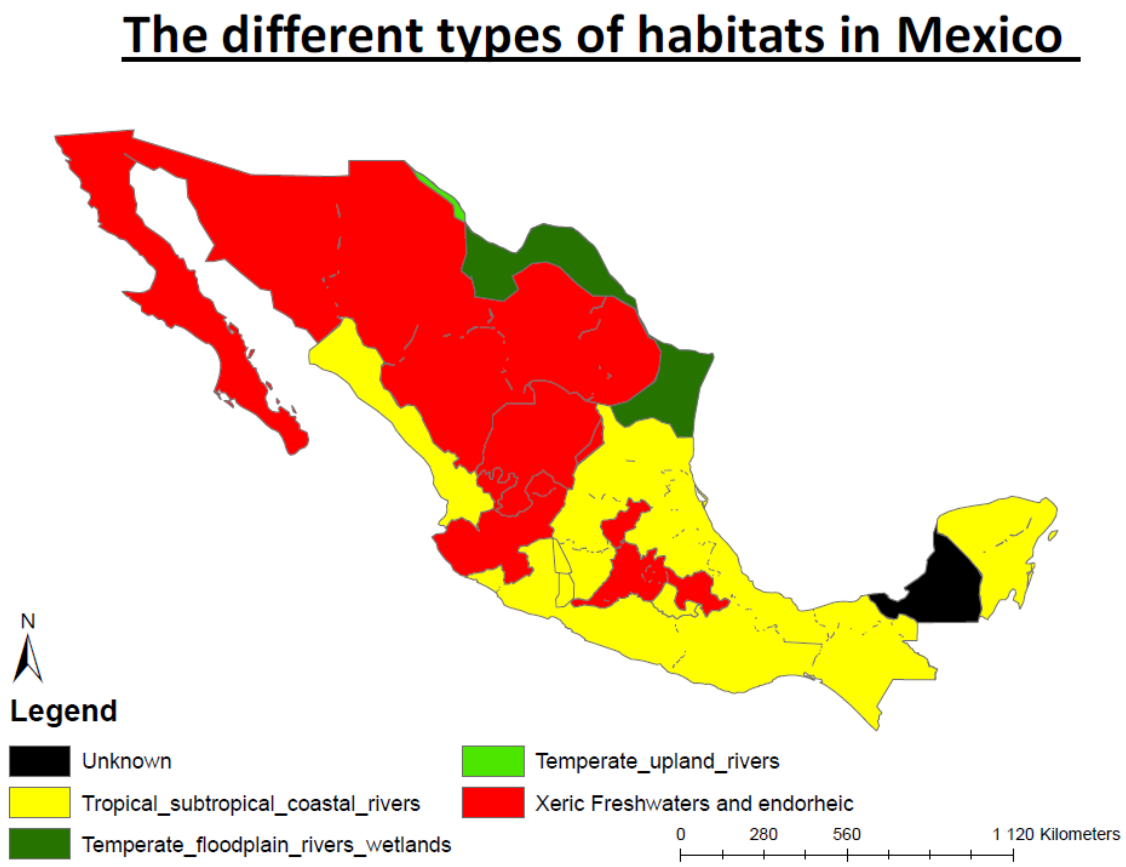


Figure 4- Map of the different types of habitat

Table 1- Habitats location

LOCATION				
Types of Habitats	Xeric Freshwaters and Endorheic (Closed) Basins	Temperate Upland Rivers	Temperate Floodplain Rivers and Wetland Complexes	Tropical and Subtropical Coastal Rivers
	Guzman - Samalayuca	Upper Rio Grande - Bravo	Lower Rio Grande - Bravo	Upper Usumacinta
	Sonora			Sinaloa
	Southern California Coastal - Baja California			Rio Santiago
	Rio Conchos			Panuco
	Mayran - Viesca			Ameca - Manantlan
	Rio Salado			Rio Balsas
	Cuatro Cienegas			Sierra Madre del Sur
	Rio San Juan (Mexico)			Papaloapan
	Llanos El Salado			Coatzacoalcos
	Lerma - Chapala			Chiapas - Fonseca
				Yucatan
				Quintana Roo - Motagua
Unknown: Grijalva - Usumacinta				

3.9. The Freshwater ecoregions according to the website FEOW

The data used to build these ecoregions dates back to 2008. We are still seeing a new approach to ecoregions in Mexico, which over the years are changing. Mexico in this alternative way of representing hydro ecoregions is divided into 24 ecoregions. These ecoregions are as follow:

Eleven of them belong to Xeric freshwaters and endorheic (closed) basins

- Colorado

"The Colorado River is a 1,450-foot-long river that begins in Colorado and flows through Utah, Arizona, Nevada, California and Mexico towards the sea." (« Facts About the Colorado River » s. d.). The Colorado River is easily the main river in the southwestern United States, draining some 242,000 square miles of land.
The ecoregion covers the north-eastern tip of Baja California in Mexico is one of the most arid ecoregions in North America. This ecoregion is not covering Mexico only but some states of

the United States of America too. Wyoming, Nevada, Arizona, Utah, Colorado states are part of this ecoregion too.
Freshwater habitats used to be dominated by warm rivers with highly variable flows. These rivers were themselves fed by cold mountain streams and springs. There were also swampy habitats and riparian forests.
Thus, alpine coniferous forests, shrubs and desert grasses can be found in this region.
Concerning the species inhabiting this ecoregion we find *Ptychocheilus lucius*, a carnivorous species and the largest cyprinid in North America. We also find as a species of fish almost endemic to this ecoregion

- Gila

This ecoregion covers a portion of southwestern New Mexico to north of Sonora. The Gila River, which represents the main watershed, is a tributary of the Colorado River and is one of the largest desert rivers in the world. It is now almost dry due to intensive irrigation and water detour. This watershed is characterized by other important rivers such as the San Pedro and Santa Cruz.
Among the endemic species of fish that can be found in this ecoregion is *Cyprinodon arcuatus, Gila intermedia, Meda fulgida, Oncorhynchus gilae* and *Rhinichthys cobitis.*

- Rio Conchos

The Rio Conchos is the main river of this ecoregion, itself a tributary of the Rio Grande. This region is partly located in Chihuahua and extends as far north as Durango. The freshwater habitats are the headwaters of the mountains, here in the Sierra Tarahumara, the middle and lower basin of the Rio Conchos mainly.
The Rio Conchos is still home to a significant number of species because its channel has not been anthropogenically modified. These spring habitats keep endemism high in this region. As previously stated, an incredible endemism is found in this region, with one third of the fish population having endemic character. We find as species Cyprinella panarcys, Cyprinodon macrolepis, C. pachycephalus, (C. salvadori, Etheostoma australe, E. pottsii, Gambusia alvarezi and G. hurtadoi. This region contains species that are essentially endemic to the Rio Grande/ Rio Bravo complex.

- Cuatro Cienegas

This small ecoregion is located in a valley of the Sierra Madre Oriental in the state of Coahuila. The freshwater habitats are geothermal springs (over 500), lakes and rivers. There are also marshes, lagoons and saltwater rivers and lakes. Because of the diversity of habitats, we can find thermal springs, fresh springs more or less turbid and saline. The fact that this ecoregion is geographically isolated, we find a strong endemism in fish. The species found are *Cichlasoma minckleyi, Cyprinella xanthicara, Cyprinodon atrorus, C. bifasciatus, Etheostoma lugoi, Gambusia longispinis, Lucania interioris* and *Xiphophorus gordoni.*

- Rio Salado

This ecoregion includes four rivers: Rio Salodo, Rio Sabinas, Rio San Juan in the north and Rio Salado de Nadadores in the south. It extends over the regions of Mexico which are the east of Coahuila, the north of Nuevo Leon and part of Tamaulipas.
Two tributary rivers of the Rio Salado allow us to characterize this ecoregion, we have first of all the Rio San Juan North whose waters are fresh and the Rio Salado de Nadadores South which is largely saline. Thus, we find the Rio Salado with a high salt content, muddy because with it has a low slope characterizing it. Only one species is considered totally endemic to this

region, which is Notropis saladonis. Otherwise, there are other species qualified as almost endemic.

- Rio San Juan

The main rivers of this ecoregion are the Río San Juan and the Río Álamo, which later flow into the Rio Grande/Río Bravo. This region extends from the southeast of Coahuila and the northwest of Tamaulipas to the Rio Grande. The different freshwater habitats that make up this ecoregion are springs, lagoons, plain rivers, and mountain creeks. This region is one of those with a high rate of endemism, the species that will be strictly endemic is the wanderer of Membras (Membras vagrans).

- Southern California Coastal Baja California

The entire Baja Peninsula, Channel Islands and Cedros Islands are also part of this ecoregion. Very few rivers are permanent, but there are mountain and plain creeks, springs and lagoons. Endemic species in this region are mostly found not in Mexico but in the California Basin. The species are the following: *Catostomus santaanae, Fundulus parvipinnis, Gobiesox juniperoserrai, F. lima, Gasterosteus aculeatus microcephalus et Onchorhynchus nelsoni*.

- Sonora

This ecoregion covers a large part of the state of Sonora, passing through the Sierra Madre Occidental in the east, the Rio del Fuerte in the south, the Rio Colorado and Gila in the north.
Its topography is varied between vast plains and very high altitudes. It includes a series of mountain ranges. This ecoregion also has the most extensive desert dune system in North America.
Freshwater habitats include streams and creeks in the high mountains, as well as endemic plant species. About endemic fish species we find Opata sucker and desert chub.

- Guzman – Samalayuca

This region is part of the Rio Grande complex, the rivers that make it up are: Rio Casas Grandes, Rio Santa Maria, Rio Ahumada, Laguna de Bavicora, Llanos de Samalayuca and Rio Carmen. This region will cover the majority of the state of Chihuahua to the southwest of New Mexico. It will also cover a small part of northern Sonora and southeastern Arizona. Creeks, rivers and springs punctuate the habitats of this region. Formerly the bed of an ancient lake, the Medanos Samalayuca is now a rugged area of dry sand dunes. This region is as rich in endemic species as most endorheic habitats, the following species are found here: *Cyprinella bocagrande, Cyprinodon fontinalis and Gila nigrescens.: Cyprinella bocagrande, Cyprinodon fontinalis* et *Gila nigrescens.*

- Mayran – Viesca

We are once again in a large endorheic basin in north-central Mexico, with as main rivers the Río Nazas-Laguna Mayrán, Río Aguanaval-Laguna Viesca, Laguna Tlahualilo, Parras, Río Mezquital Superior and Laguna de Santiaguillo. This region will cross 6 different states of Mexico which are the following: Chihuahua, Coahuila, Durango, Zacatecas, San Luis Potosí and Nuevo León.
Region with closed watershed rivers that increase the endemism of the region. Thus we find as endemic species the following species: *Catostomus nebuliferus, Characodon audax, Cyprinella alvarezdelvillari, C. garmani, Cyprinodon meeki, C. nazas, Gila conspersa, Notropis aulidion* and *N. nazas*. There is a fragmentation of species due to the isolation of the basins that cover the region.

- Lerma – Chapala

Composed of many endorheic basins, with as main bodies of water the Rio Lerma and the Lago de Chapala which is the largest lake in Mexico. Other crater lakes exist in this region such as Lago Alchichica, Lago Quechulac, Lago La Preciosa. The freshwater habitats of this region are mainly crater lakes and more rarely creeks. In the past there were many mountain creeks, springs and lagoons which are now dry. Each basin of this region is composed of different endemic species, we will find in the Rio basin Lerma *Algansea barbata, A. popoche, Alloophorus robustus, Allotoca dugesii, Chapalichthys encaustus, Chirostoma aculeatum, C. bartoni, C. chapalae, C. contrerasi, C. labarcae, C. riojai, Girardinichthys multiradiatus, Lampetra geminis.* Endemic species in the Mexico Valley include *Poblama ferdebueni, Girardinichthys* viviparous. On the Puebla Plateau we find *Poblama alchichica, P. letholepis* and *Chirostoma squamata*. Separate species are found because this basin has undergone fragmentation.

One of the regions belongs to Temperate upland rivers

- Upper Rio Grande – Bravo

The Rio Grande has as tributaries the Rio Chama, the Rio Puerco and the Rio Paraje, and the Alamosa. This region is in central-western New Mexico where more than 80% of the population lives along the Rio Grande River, better known as Rio Bravo del Norte. This region has only one endemic fish species which is *Cyprinodon tularosa.*
This region belongs to Temperate floodplain rivers and wetlands

- Lower Rio Grande – Bravo

One of the largest rivers in the world, the 5th largest in North America and the 22nd largest in the world. It forms the border between the United States and Mexico with a border length of 2004 km. This region is located where the Rio Grande flows from its confluence with the Rio Conchos to the Gulf of Mexico. Covering then the eastern part of Chihuahua, the north of Coahuila, the extreme north of Nuevo Leon and the north of Tamaulipas. Floodplains, streams and caves are found as freshwater habitat. One of the peculiarities of this region is its underground aquifer with which many springs and caves can be associated, this area is known as Zona Carbonifera. Suffering from the invasion of brackish water, the watershed is suffering from drying out and salinization, which causes the disappearance of freshwater species. However, endemic species such as the Dionda diaboli, Gambusia gaigei and Gambusia krumholzi can be found.

The last eleven region belong to Tropical and Subtropical coastal rivers

- Rio Santiago

Defined by the basins of Rio San Pedro, Rio Santiago, which drains Lake Chapala from another ecoregion that of Lerma - Chapala, but also includes the Río Mezquital, Río Grande de Santiago, Río BolaZos and Río Juchipila. This region is in the state of Durango, Jalisco, Nayarit, Guanajuato, Zacatecas, and Aguascalientes. It also includes the Marias Islands. Within this region is a warm aquifer hosting unique populations of aquatic invertebrates, especially rotifers. To complete this habitat, we also find rivers. Nevertheless, we will find few endemic fish species, there will be *Algansea avia, Algansea monticola, Ictalurus ochoterenai* and other species almost endemic.

- Panuco

This Panuco region has 4 main rivers which are the Río Pánuco, the Río Tamesí, the Río Soto la Marina and the Río Verde/La Media. It is found in the states of Tamaulipas, San Luis Potosí, Guanajuato, Querétaro, Hidalgo, Mexico City, Puebla, and Veracruz. Freshwater habitats include springs, creeks, freshwater or brackish lagoons and rivers. With a 60% endemic fish fauna, the ecoregion is composed of the following endemic species: *Prietella lundbergi, Dionda dichroma, Dionda mandibularis, Ataeniobius toweri* and *Cualac tessellatus.*

- Ameca – Manantlan

Located in the south of Nayarit, from Jalisco throughout the state of Colima and northwest of Michoacan, this ecoregion is mountainous. Its freshwater habitat includes floodplains and coastal rivers. More than half of this region has endemic fish such as *Allodontichthys hubbsi, A. polylepis, A. tamazulae, A. zonistius, Ameca splendens, Ilyodon furcidens, Skiffia francesae, Xenotaenia resolanae, Xenotoca melanosoma, Zoogoneticus tequilae* and many other species.

- Rio Balsas

This coastal region has the Rio Balsas as its main river and the largest lake is the Pres adel Infiernillo. It is in the states of Jalisco, Michoacan, Guerrero, Morelos, Tlaxala, Puebla and Oaxaca. It is a mountainous region bordered in the north by a volcanic belt. One of the longest rivers in Mexico, called the Balsas River, is in this region. There are many rapids, and 7 endemic fish are present in this region. *Ilyodon whitei, Allotoca catarinae, Poeciliopsis balsas, Poecilia maylandi, Atherinella balsana, Ictalurus balsanus,* and *Hybopsis boucardi*. The southern regions of Mexico are often rich in cichlid species, here we find only one, the *Cichlasoma istlanum*.

- Papaloapan

This coastal ecoregion covers much of the center of Veracruz, Puebla and Oaxaca. It includes the Rio Papaloapan basin and its tributaries that flow into the Gulf of Mexico. Ponds, rapids, waterfalls, lagoons, lakes, rivers and springs are part of the freshwater habitats. A volcanic crater lake, the Laguna de Catemaco is the particularity of this region located at an altitude of 335m. Region with a strong endemism within its ichthyofauna we find the following species: *(Priapella bonita), (P. olmecae), (Rhamdia reddelli)* and *(Bramocharax caballeroi).*

- Coatzacoalcos

Located in the states of Tehuantepec, Oaxaca and eastern Veracruz, this ecoregion is defined by the Rio Coatzacoalcos basin with the Jaltepec and Uspanapa rivers as its main tributaries. With varied freshwater habitats there is a high rate of endemism, especially with the presence of the species*: Heterophallus rachovii, Poeciliidae, Paraneetroplus bulleri, Almoloya Vieja regaini, Cichlidae* and *Atherinella ammophila.*

- Upper Usumacinta

Located in the states of Chiapas, Tabasco and northern Guatemala, the tributaries of the Usumacinta are the rivers of Lacanja, Pasion, Lacantun, Tzaconeja and Chixoy. Rivers, streams, wetlands, lagoons, cenotes and springs are part of the freshwater habitats of this region often surrounded by rainforest. *Lacantunia enigmatica* is the endemic species of this basin, other species are almost endemic and most of them are found in the tributaries of Guatemala.

- Chiapas – Fonseca

Consisting of many rivers and lagoons, this coastal ecoregion is located in the Golfo de Tehuantepec in Oaxaca, its many rivers flow into the Pacific Ocean. Freshwater habitats are

abundant between mangroves and tidal flats that dominate estuarine shores, salt marshes, mountain streams, canyon coves, coastal lagoons, and crater lakes. Many small coastal basins are found in this region such as the Rio Tehuantepec including the lagoon complex of Mar Muerto. Due to its many habitats this ecoregion includes many endemic species, among the endemic species are *Amphilophus macracanthus, Anableps dowei, Brachyrhaphis hartwegi, Dactyloscopus amnis, Poecilia marcellinoi, Rhamdia parryi, Vieja guttulata* and *V. zonata.*

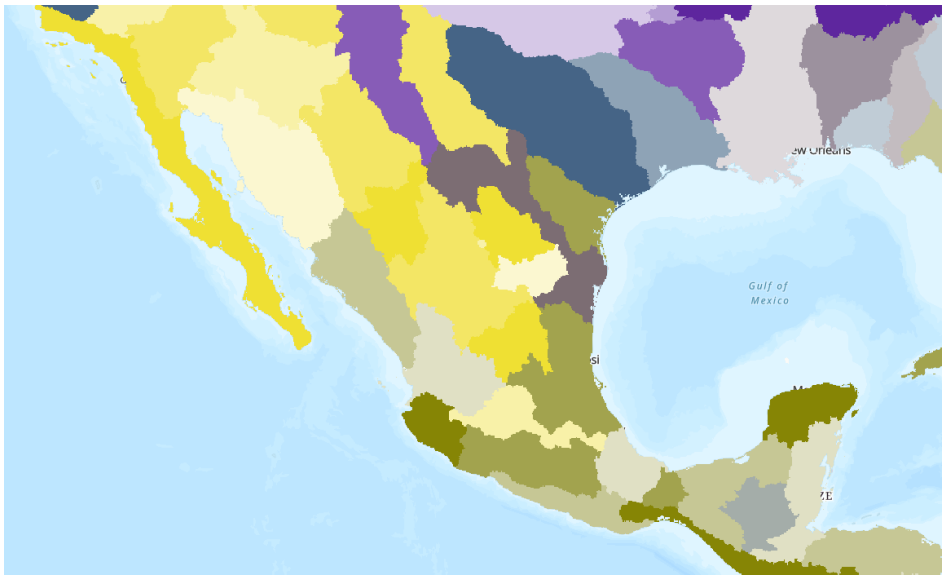
- Quintana Roo – Motagua

This ecoregion includes many small coastal basins, located on the Yucatan Peninsula, it also includes the Quintana, mainly the southern half and the Campeche. Different habitats are found between the cenote-rich northern regions and the small surface basins present in the south. The south also has many freshwater and marine lagoons. Some of the endemic species of this region are Cichlasoma bocourti, Poecilia teresae and Vieja godmanni. Underground habitats are home to unusual species such as *Ophisternon infernale, Sciaenidae, Cyprinodon artifrons, Floridichthys polyommus* and *Garmanella pulchra*. Part of the tropical fauna of this region has penetrated the Yucatan region.

- Yucatan

Comprising many coastal rivers, cenotes, aquadas and caves, this region is located in the states of Yucatan, Campeche and Quintana Roo. The island of Cozumel is part of this region. The peculiarity of this region is that it has almost no surface water. Nevertheless, the cenotes, aguadas and calderas connect the underground water to the surface. We find in these bodies of water fresh or brackish water often connected by underground rivers. The other peculiarity of this region is that it has rivers flowing from the sea to the interior of the land, rias. The Chichancanab Lagoon is a saline lagoon; therefore, few fish live there, only very small fish populate this habitat. This ecoregion will contain very few endemic fish species, we will find the following species: *Fundulus grandissimus, F. persimilis, Floridichthys polyommus* and Cyprinodontidae. Another endemic species that will be found particularly in caves and chasms is *Typhliasina pearsei*. In the underground habitats of this region, we find unusual species such as *Ophisternon infernale, Cyprinodon artifrons, Floridichthys polyommus* et *Garmanella pulchra*.

- Grijalva – Usumacinta [No specific data yet found about this region]



Here is a representation of these ecoregions that can be found at www.feow.org.

Figure 5- Map of the Freshwater Ecoregion of the World for Mexico (« Freshwater Ecoregions of the World » s. d.)

4. Discussion

Figure 6- Hydrological regions in Mexico

As previously mentioned, Mexico is not one of the geographical areas of the world that has collected the most data to be able to obtain an accurate map of the hydro ecoregions. There has been a lot of different representation that has evolved over the years with, among other things, the acquisition of new data.

Despite the fact that limnological knowledge of the entire Mexican territory is still very incomplete, CONAGUA (Comision Nacional del Agua) has still been able to divide Mexico into 37 hydrographic regions in 2016. These regions represent the natural limits of Mexico's major watersheds. (« AAM_2016.pdf » s. d.)

This map is the current representation of the hydro-ecoregions but it may not stay that way for long. This map dating from 2016 is already quite different from the representation made in 2008.

5. Conclusion

This research work on the hydro-eco-regions of Mexico, allowed us to get to know the information available to us on the subject. It has been possible to see that there are many representations of the hydro ecoregions. This is due to the fact that the data that can characterize them are not exhaustive, from year to year there are new discoveries, research, advances, which lead to see the representation of the hydro ecoregions change. Until there is more in-depth and centralized work on the hydro ecoregions, it will always be difficult to rely on a single map. It is also important to take into consideration all the characteristics of the environment that give clues as to the location of the hydro-ecoregions.

This work allowed me to get to know the research exercise. It is an exercise that I am doing for the first time and I did not find this work obvious. Nevertheless, it allowed me to discover this exercise, to become more aware of the expectations expected from a research work.

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Chaire UNESCO Fleuves et Patrimoine

MFUNDU KONDI Lorène

PFE/DAE5
IMA
2020-2021

Adaptation of a freshwater ecosystem zonation as a baseline for bioindication

Résumé : Il s'agit d'un travail de recherche concernant l'avancée des hydro-écorégions se trouvant au Mexique. Il fait état des lieux de ce que l'on peut trouver comme données scientifiques à ce sujet. On peut voir que même avec peu de données disponibles pouvant localiser les hydro-écorégions, plusieurs approches de celles-ci ont été proposé au cours des derniers années, avec une volonté de se rapprocher au plus près de la vérité.

It is a research work on the advancement of hydro-eco-regions in Mexico. It reports on what can be found as scientific data on this subject. Even with little data available that can locate the hydro-echo-regions, several approaches to them have been proposed in recent years, with a desire to get as close as possible to the truth.

Mots Clés: Hydro-ecoregion, freshwater of the world, Mexico, habitats, fishes, climate, hydrology.

Freshwater ecoregions in Mexico

Hydrological regions in Mexico

N

Legend

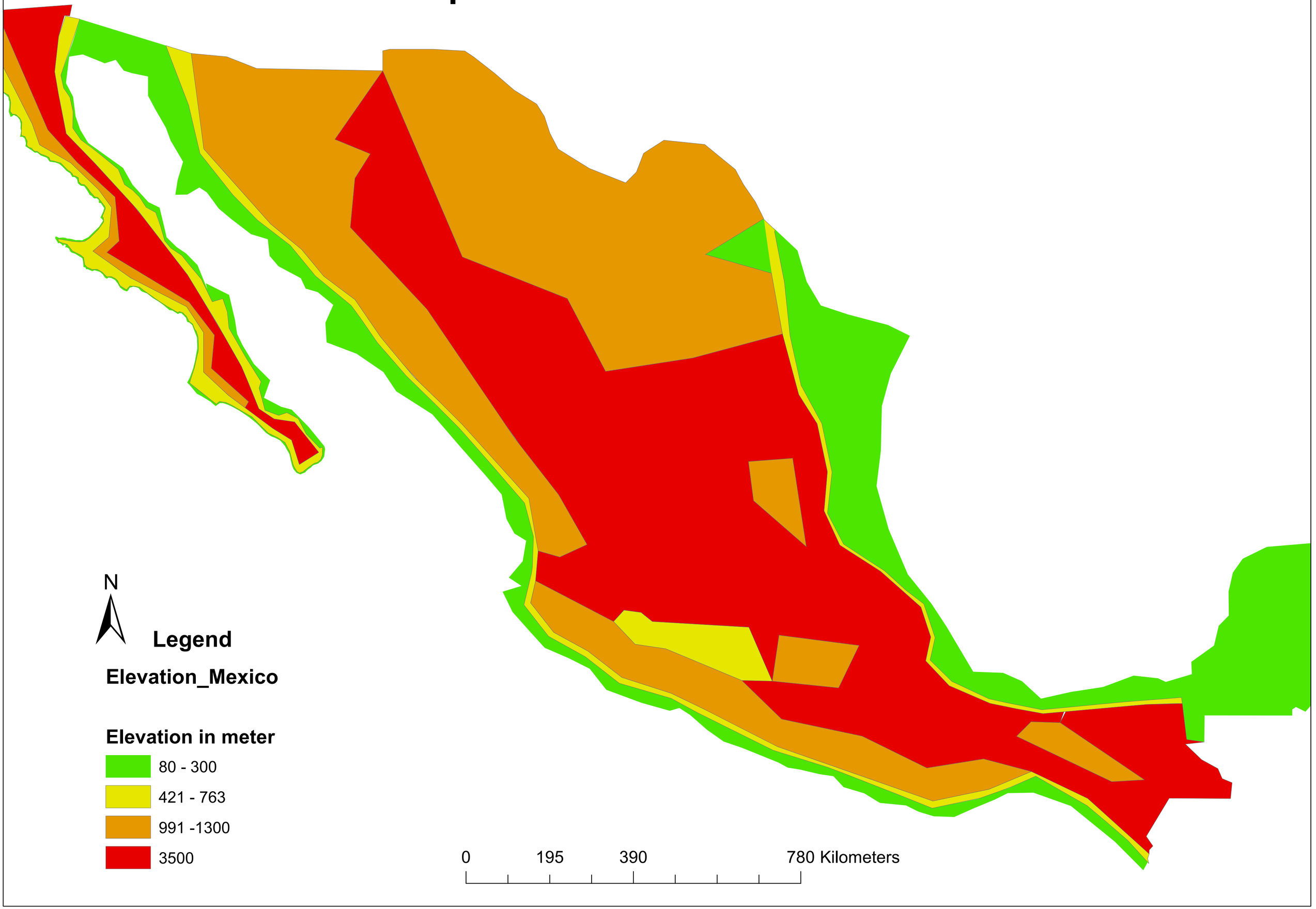
Hydrological_regions

Number - Name

- 1 - Northwest B.C
- 2 - Center-west B.C
- 3 - Southwest B.C
- 4 - Northeast B.C
- 5 - Center-east B.C
- 6 - Southeast B.C
- 7 - Colorado river
- 8 - North Sonora
- 9 - South Sonora
- 10 - Sinaloa
- 11 - Presidio
- 12 - Lerma-Santiago
- 13 - Huicicila river
- 14 - Ameca river
- 15 - Jalisco coast
- 16 - Armería-Coahuayana
- 17 - Michoacán
- 18 - Balsas
- 19 - Big coast of Guerrero
- 20 - Small coast of Guerrero
- 21 - Oaxaca coast
- 22 - Tehuantepec
- 23 - Chiapas coast
- 24 - Bravo-Conchos
- 25 - San Fernando- Soto la Marina
- 26 - Pánuco
- 27 - North of Veracruz
- 28 - Papaloapan
- 29 - Coatzacoalcos
- 30 - Grijalva-Usumacinta
- 31 - West Yucatán
- 32 - North Yucatán
- 33 - East Yucatán
- 34 - Northern closed basins
- 35 - Mapimí
- 36 - Nazas-Aguanaval
- 37 - El Salado

0 215 430 860 Kilometers

Map of elevation in Mexico



The different types of habitats in Mexico