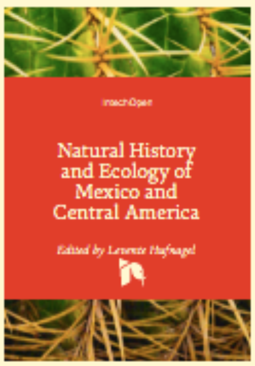
Natural History and Ecology of Mexico and Central America



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Chapter

Tropical Subterranean Ecosystems in Mexico, Guatemala and Belize: A Review of Aquatic Biodiversity and Their Ecological Aspects

Luis M. Mejía-Ortíz, Peter Sprouse, Juan C. Tejeda-Mazariegos, Jair Valladarez, Oscar Frausto-Martínez, Alejandro L. Collantes-Chavez-Costa, Guillermo Ruíz-Cancino and German Yáñez

Abstract

The subterranean ecosystems in tropical areas of Mexico, North of Guatemala & Belize are very abundant because the karstic soil that allow these formations are the main composition in the Yucatán Peninsula and several mountains systems in these countries; also, they have a strong relationship with tropical forest adjacent where the main energy into the caves have an alloctonous origin. In these three countries there are three different cave conditions: a) freshwater semi-dry caves, b) flooded freshwater systems and c) anchialine systems. Mainly crustaceans and freshwater fishes are the major representative group in the aquatic diversity in these systems because the anchialine members are restricted to Yucatán Peninsula and Islands adjacent. Around 5000 entries to subterranean world there are among these countries, where the Yucatan Peninsula is the area with major caves or cenotes in comparison with southern of Mexico, North of Guatemala and Belize. Into these systems are possible found crustaceans and fishes from different families. The objective of this paper is present a review of these systems according with each karstic areas and show the current map including the location of each systems; as well their subterranean aquatic biodiversity and, finally discuss the relationships among these different areas using their biological aquatic richness in consideration with ecological subterranean conditions.

Keywords: Mesoamerica, Subterranean Biodiversity, Cave environments

1. Introduction

The biodiversity in the tropical area among Mexico, Guatemala and Belize are good represented in several taxa since the tropical forest are the most representative biomass in this area, where there are a high species richness. The climatic conditions produce a great opportunity to maintain this diversity [1].

The geological history of Central America shows that this area is recently in comparison with the Mexican North portion, however the Peninsula Block has moved into the sea 165 Ma during the Jurassic Period, and emerge on Pleistocene; during these last period the opportunity of the migration species to colonised the mountain chains in Guatemala y Belize had origin from north to south [2].

This geological history include the karstic regions in the three countries, but the Yucatan Peninsula is the most recently portion in emerge from the sea in México [3], but the volcanic activities and emerged areas in the north of Guatemala and even Belize central portion involved the mountain formation and limestone soil, and of course the colonised caves and grootes from terrestrial and aquatic animals from surface involved species that in another times previously had occupied these epigeal environments [4, 5]. The geological conditions produce a different opportunities to be occupied for these animals mainly crustaceans and fishes [6, 7].

Has been reported the existence of different aquatic habitats in the cave environments: a) freshwater semi-dry caves, b) flooded freshwater systems and c) anchialine systems, only Guatemala have not the anchialine systems reported, but the three conditions are present in Mexico & Belize [8–16], to date is possible identify four main karstic areas: Chiapas Mountains, Yucatan Peninsula (Mexico), Alta VeraPaz karstic area, Peten Area (Guatemala), and Chiquibul area (Belize). Where fishes and crustaceans has been reported with several species. The aim of present chapter is show a review of the aquatic subterranean biodiversity in these two major taxa and their relationship with their ecological conditions that there are in each habitat type, to discuss the interrelationships that these five karstic areas.

2. Study area

The study area includes the karstic regions from Tehuantepec Isthmus, Yucatán Peninsula and Islands adjacent and Guatemala & Belize. In this area exist five karstic regions 1) Chiapas karstic Mountains, 2) Yucatán Peninsula, 3) Alta Verapaz, 4) Petén Area, and 5) Chiquibul area as is possible see in the **Figure 1**.

In each area has been recorded several entrance to subterranean environments in the all them the dissolution caves are the principal formation due the limestone soil. The Chiapas karstic mountains had diverse caves record mainly dry and semi-dry conditions but in there are the most origins of superficial springs that flow to Gulf of Mexico basin [8, 9, 17]. In the Yucatán Peninsula is where there are more entrance recorded due the special efforts that involve the anchihaline systems but also there are an important number of dry cave or semi-dry caves in there in special on the Riviera Maya Coast. Also show a sub-region called Cenotes Ring where the freshwater flooded caves is very well represented [18]. Also in the Island and coast as Cozumel Island there are anchialine caves with species fauna [12–14]. Alta Verapaz region had an important Mountain Chain that produce conditions to dissolution of limestone that is the main characteristic of soil to produce different cave types from Springs as Hunalye and semi-dry caves Lanquin area where some freshwater prawns, crabs, and fishes living [19]. The highlands have an estimation of 150 Ma of age. The Petén region is the Peninsula base where the limestone starts to be the main soil type and the cave formations are frequently from Quaternary times with marine sediments [5]. Finally the Chiquibul area in the Mountain Central part of Belize but as a continuum of these soil, show a unexplored area even to discover, however in the area at less there are some caves records with important fauna [11].

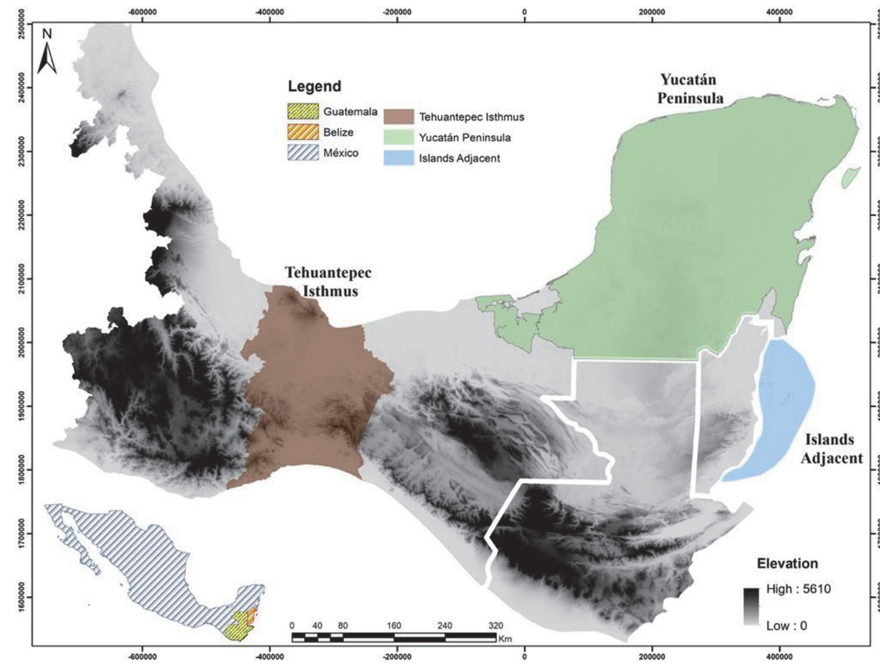

Figure 1.
AQ03 *Mesoamerican karstic region. Include the five study areas: a) isthmus and Chiapas Mountain systems, b) Yucatan peninsula, c) Alta Verapaz, d) Peten & e) Chiquibul and karst Main Mountain.*

3. Material & methods

Several explored trips where conducted on the last fifteen years around the study area, exploring caves and cenotes in each karstic region; according with the site was measured the abiotic data from the water (temperature, conductivity, salinity, pH, depth, dissolved oxygen and light) using the Hydrolab Data Sonde 5, applying SCUBA techniques; or the oximeter Oakton: dissolved oxygen (±0.01 mg/l), pH (±001 pH), salinity (±0.01%), and temperature of the water (±0.01°C). The altitude and the GPS values were recorded with a Garmin GPS [20–24]. With help to several speleological groups were record the GPS data from each entrance, and the photographic record of fauna has been registered. More than 100 caves were visited as representative from all regions were recorded fishes and crustaceans and preserved in alcohol to taxonomic identification, and compared with previous reports. The maps of entrance distribution to each region were done and the fauna richness relationship analysis was made according with the procedure reported for some subterranean systems [25], that "due the possibility to have a samples incomplete, some estimators have been derived to predict the true number of species based on rare species in a sample. This was calculate according with Chao [26], AQ02

$$S_1 = S_{obs} + \left(L^2/2M\right)$$

where S_{obs} is equal to the number of species observed in a sample, L is the number of observed species represented by a single individual (i.e., singletons), and M is the number of observed species represented by two individuals in the sample (i.e., doubletons).

Also the same authors recommend the application of Burnham and Overton's [27] jackknife estimators in order to reduce estimation bias in estimating species richness.

$$S_2 = S_{obs} + \left[(L(2n-3)/n) - \left(M(n-2)^2/n(n-1)\right)\right]$$

where n is the number of samples. No direct formula for the calculation of the variance is available".

4. Results

4.1 Karstic areas and their aquatic diversity

a. Chiapas Mountains (**Figure 2**)

The Chiapas Karstic area involve the Mountain Chain from Tehuantepec Isthmus to Guatemala border, in there these mountains have a karstic soil and the dissolution of limestone produce several caves. The altitude range is from 1700 to 100 meters above sea level (masl) and in these regions there are almost 150 caves reported. The drainage from aquifer that flow to Gulf of Mexico produce one connection with surface and many cave crustaceans had their origins from epigeal populations. The main fishes in this region are from *Rhamdia* genus with or without adaptation to cave life. In the crustaceans decapods species there are freshwater prawns *Macrobrachium sbordonii*, *Macrobrachium acherontium*, *Cryphiops sbordonii* and *Cryphiops luscus*; crayfishes *Procambarus mirandai*, *Procambarus* sp. (From La Lucha system)

Figure 2.
Caves location from isthmus and Chiapas region. The red points represent each entrance to subterranean systems.

crabs *Rodriguezia adani*, *Avotrichodactylus bidens*, and *Rodriguezia* spp. (From the Ocosingo Area) (**Table 1**). In this region only the freshwater crabs was recorder from literature the remain was confirmed with our fieldtrip work.

Crustaceans	Fishes
Procambarus mirandai	*Rhamdia guatemalensis* -Cosmopolitan species
Procambarus sp. (Itshmus)	*Rhamdia sbordonii*
Macrobrachium acherontium	
Macrobrachium sbordonii	
Macrobrachium sp. (Isthmus)	
Cryphiops sbordonii	
Cryphiops luscus	
Rodriguezia adani	
Avotrichodactylus bidens	
Typhlopseudothelphusa mocinoi	
Typhlopseudothelphusa hyba	
Rodriguezia villalobosi	
Rodriguezia mensabak	
Odontothelphusa monodontis	

Table 1.
Checklist of subterranean fauna taxa of the Tehuantepec isthmus and Chiapas region all from freshwater semi-dry caves.

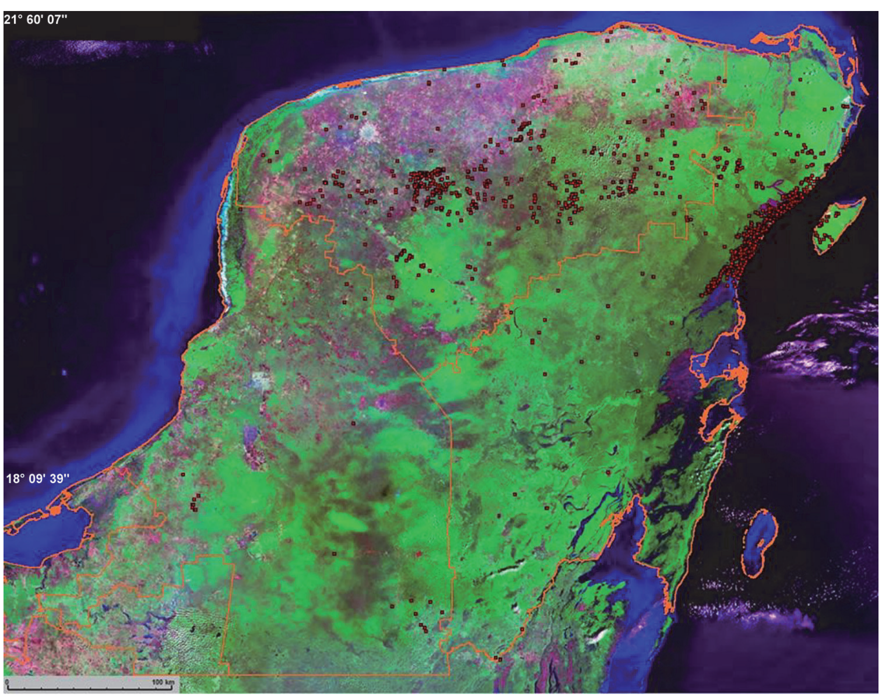

Figure 3.
Caves and cenotes from Yucatan peninsula. The red points represent each entrance to subterranean systems.

b. Yucatan Peninsula (**Figure 3**)

This area involve three Mexican states, is the longest area in the Southern of Mexico with a major caves formations involve the semi-dry, dry and flooded caves, in those closed to coast with sea water and freshwater subterranean interactions are called anchihaline systems, and their fauna is complete different to those with all freshwater. In the Yucatan Peninsula the maximum elevation is in Ticul Mountains, with 300 masl, However according with the different geological times that this Peninsula emerge there are at less five sub-regional areas, where the tropical forest are the most source of energy to maintenance the live in underground. The fishes more representative in the region are catfishes, *Rhamdia guatemalensis*, *Opisternon infernale* and *Ogilbia pearsei*, all them in freshwater, in the same conditions the crustaceans more abundant are *Creaseriella anops* (isopod), *Creaseria morleyi* and *Typhlatya mitchelli* and *Typhlatya pearsei*. Whilst, in anchialine systems there are *Barbouria cubensis, Agostocaris bozanici, Agostocaris zabaletai, Anchialocaris paulini, Procaris mexicana, Parhippolyte stereri, Yagerocaris cozumel, Xibalbanus tulumensis, Xibalbanus cozumelensis* and *Xibalbanus fuchscockborni,*

Freshwater habitats	
Crustaceans	**Fishes**
Creaseriella anops (Isopod) Cosmopolitan species	*Rhamdia guatemalensis* –Cosmopolitan species
Creaseria morleyi –Cosmopolitan species	*Opisternon infernale*
Typhlatya mitchelli –Cosmopolitan species	*Ogilbia pearsei*
Typhlatya campechae	
Procambarus sp.	
Anchialine habitats	
Barbouria cubensis	
Anchialocaris paulini	
Agostocaris bozanici	
Agostocaris zabaletai	
Yagerocaris cozumel	
Triacanthoneus akumalensis	
Parhippolyte sterreri	
Janicea antiguensis	
Calliasmata nohochi	
Procaris mexicana	
Typhlatya dzilamensis	
Typhlatya pearsei	
Xibalbanus cozumelensis	
Xibalbanus tulumensis	
Xibalbanus fuchscockborni	
Metacirolana mayana	

Table 2.
Checklist of subterranean fauna taxa of the Yucatan peninsula region.

Metacirolana mayana, Mayaweckelia cernua (**Table 2**). In this case all crustaceans was confirmed with our fieldtrip work.

c. Alta VeraPaz Region (**Figure 4**)

This area comprised the Mountains Chains that slope drainage to Gulf of Mexico, there are a continuum of Mountains from Chiapas, and they are formed mainly by karstic soil, and the elevations go to 2000 m from Río Salinas and Río Xcán, that drainage to Usumacinta river in Mexico and to Cahabon river that go to Izabal Lake. In they are the main cave formations are in the Lanquin Area, and the springs from different rivers such the Hunalye, Cahabon, Xcán and others. The species reported in there are: freshwater prawns *Macrobrachium vicconi* in the entrance of spring of Hunalye without cave adaptations, *Macrobrachium* spp. (in description process), blind crabs, from Pseudothelphusidae family, and catfishes from *Rhamdia* genus. The tropical forest is the most common adjacent ecosystems and the bat activity to carried energy inside the caves is the principal source to maintenance the ecological function from these underground ecosystems. In this case all species was collected by authors.

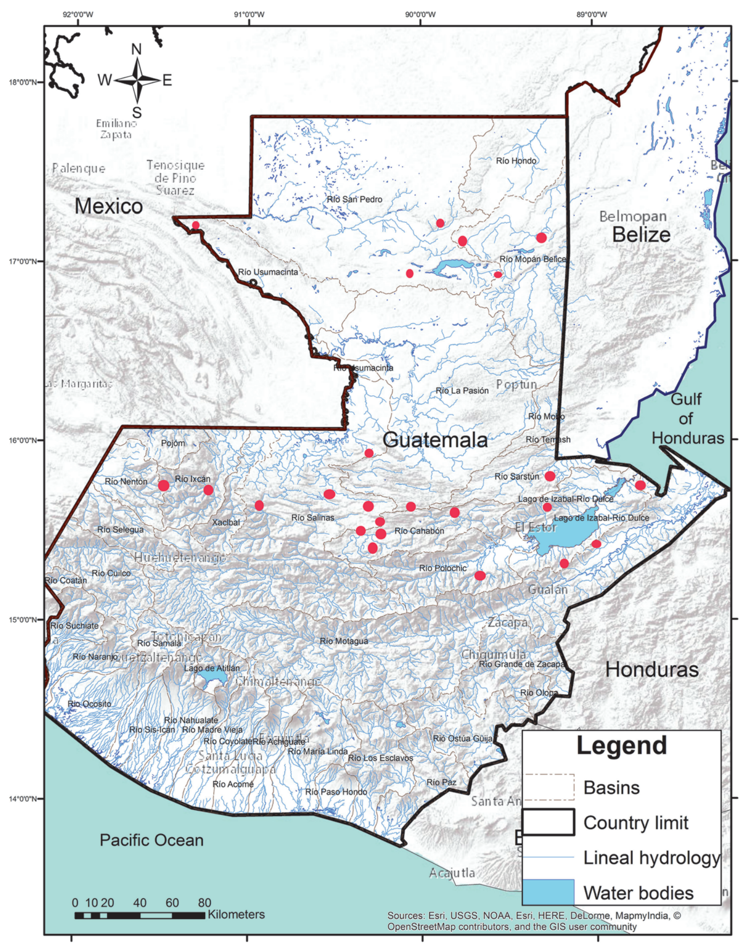

Figure 4.
Caves from Alta Verapaz and Peten regions in Guatemala.- the red points represent each entrance to subterranean systems.

d. Petén Region (**Figure 4**)

This area is part of the Yucatan Peninsula base, where the elevations are less evident, from 350 to 50 masl, and the drainage to underground by karstic soil of water is more representative, here the caves are on floor level, and local people as water source use them. In this area the principal species are freshwater prawns *Macrobrachium* and crabs from Pseudothelphusidae family. They are not showed cave life adaptations. In this region all animals was confirmed by fieldwork from authors.

e. Chiquibul Region (**Figure 5**)

In Belize, there are several areas with karstic composition in the soil but only around of Mountains Systems has been recorded caves with long formations. Is important mentioned that close to Mexican border the soils is too similar to rest of Yucatan Peninsula and the potential to found caves or even cenotes is high. However, the caves recorded in Belize are mainly in Chiquibul region among 150 to 800 msal and in Islands and Cays where has been recorded anchialine systems. In there some crustaceans could be found as *Macrobrachium catonium*,*Typhopseudothelphusa acanthochela* and fishes from *Rhamdia laticauda*, however there are in description two new species of *Macrobrachium* species and one crab from the same family. In the anchialine systems has been reported *Xibalbanus cockei.* Jill Yager author that described it confirmed only this last species.

4.2 Ecological conditions to freshwater and anchialine habitats

The geological history of this region has two main sections in first instance the Mountain Systems Development in the different geological times was producing a new subterranean habitats to some freshwater groups invaded these sites with a consequently a new opportunity to speciation but they could be seen as a biological subterranean corridor, because these species have the same selection pressures and the changes among them are so closed. However, as has been reported each cave is a new chance to produce some changes in the adaptation as outcome of isolation procedure that considering this the different species of freshwater prawns, crayfish, or crabs, in these places in average the oxygen are lower between 2 to 3 mg/l with a saturation of 60%; at same time the pH is around the neutral values with some peaks to alkalinity, normally all with freshwater conditions and values of temperature around the 18 to 22°C, in all these places the measures were taken with low depth.

However, the Yucatan Peninsula have a different origin and the different ways to colonised this subterranean habitats, our results show that in the enormous plate the species are cosmopolitan but exclusively in they are as *Creaseria morleyi, Typhlatya mitchelli*. Another big faunistic group is from anchialine group that their marine habitats conditions there are species so very primitive as Remipedia with at less three species around the coastal caves, or different decapod species that has been reported with different origins, as *Procaris mexicana, Anchialocaris paulini*, *Agostocaris bozanici, A. zabaletai, Typhlatya dzilamensis, Barbouria cubensis*, or even *Calliasmata nohochi* and *Yagerocaris cozumel*. In this places where the anchialine habitats are present the salinity is closed to marine conditions 36 ups, with pH values clearly to alkalinity between 8 and 9, the oxygen dissolved are close to hypoxic conditions 0.15 to 0.3 mg/l, with 5 or 10% of saturation. The temperature is

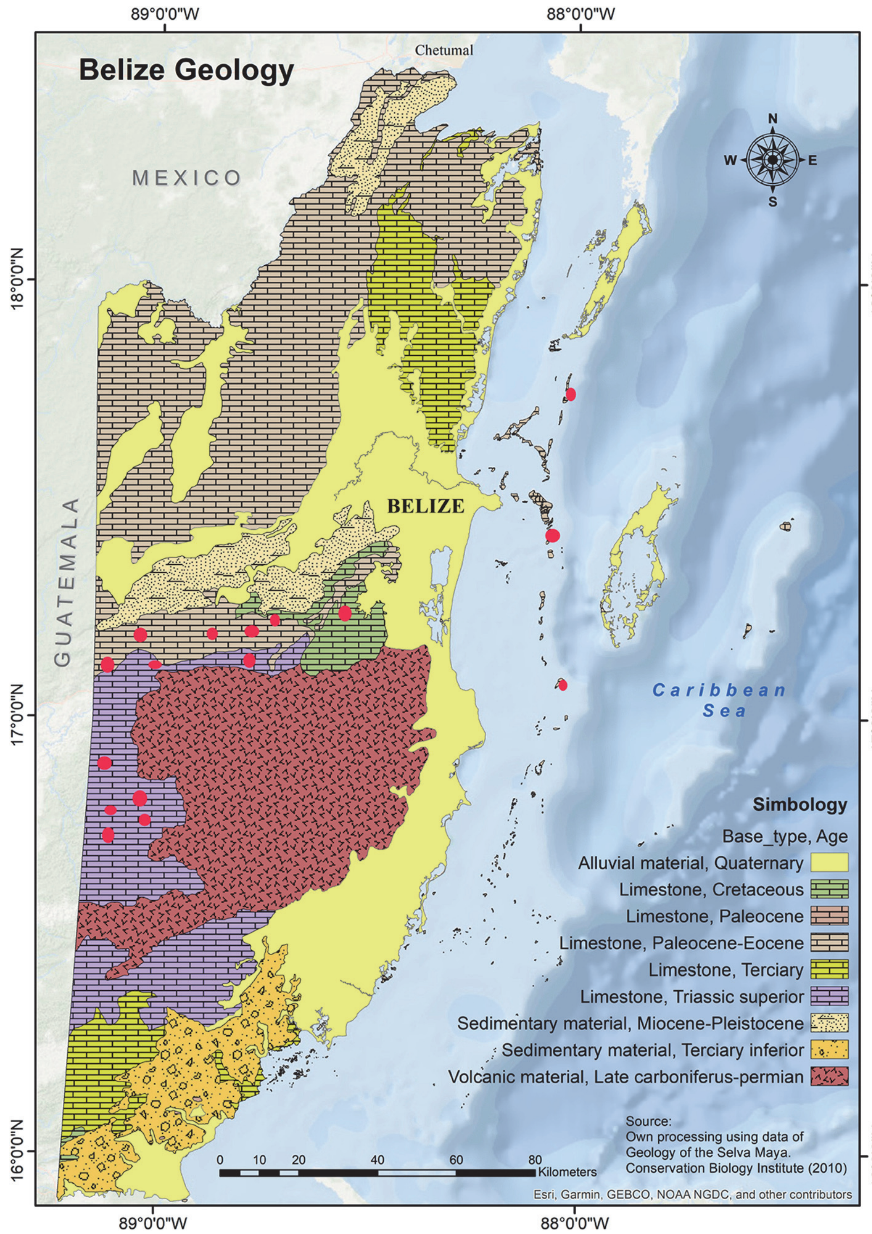

Figure 5.
Caves from Belize karst regions. The red points represent each entrance to subterranean systems.

around the 24°C [28] an example of these behaviour is showed in the **Figure 6** to Cenote Chempita.

4.3 Interrelationships among the karstic areas (richness analysis and biological subterranean corridor)

The five karstic areas involved, show a differences in the species composition and their numbers, in some places only one specimens are located, whilst another

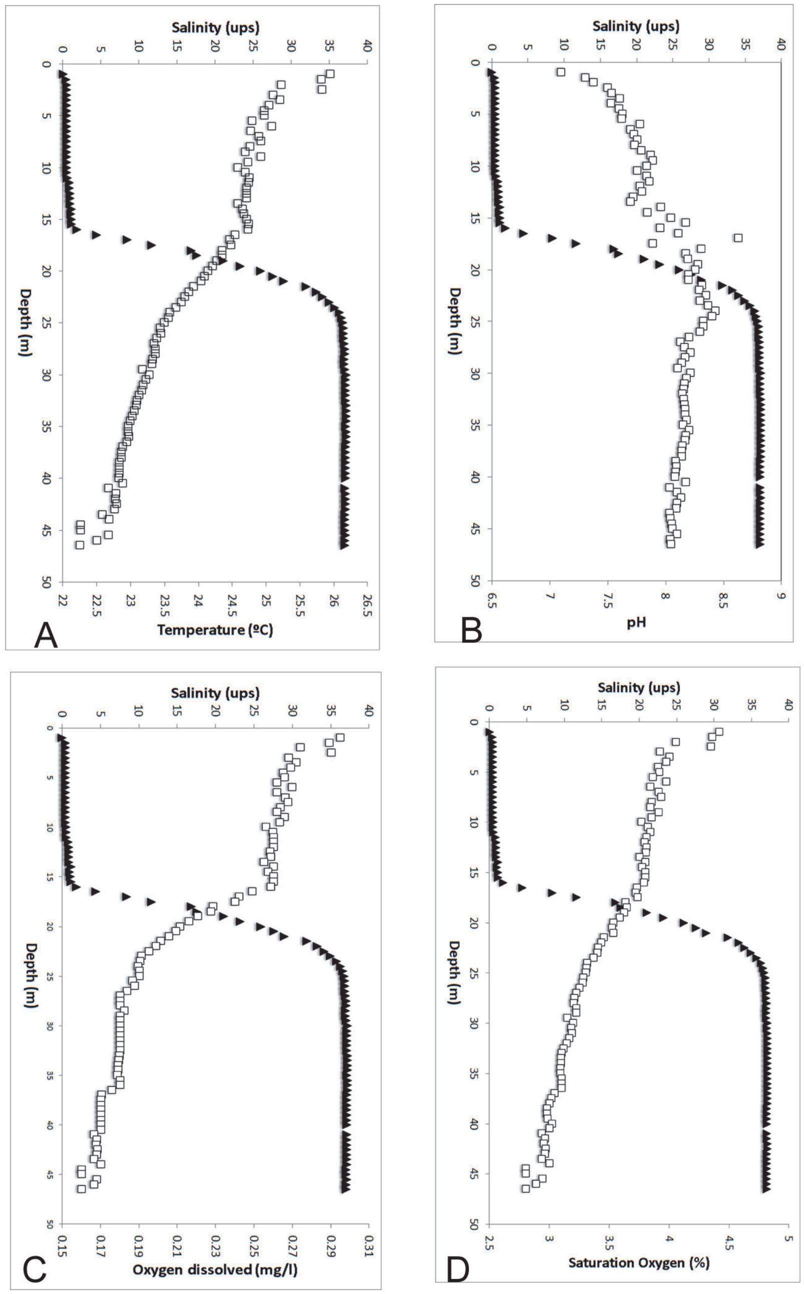

Figure 6.
Profile of Anchialine deep ecosystems. The cenote Chemita located in Cozumel Island, have a representative of three water layers i) freshwater 0-16 m; brackish water 16—24 m, and marine water 24–60 m.

there are hundred or even miles (**Table 3**). However, in the first view or richness the Yucatan Peninsula is more diversity in the crustaceans but have two different habitats and in the freshwater the *Creaseria morleyi* and *Creaseriella anops* are too cosmopolitan; whilst in the coastal areas the anchialine habitats allow that species with more relationships with another Caribbean Islands species live, and normally these species have a microdistribution and marine origin recent. Is evident that this region the species that inhabiting, not share with another region.

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Karstic Regions	Species number	Cave number	Specimens recorded	Richness (Cave/sp)	Chao's S_1	Burham & Overton S_2
Tehuantepec Isthmus & Chiapas	16	150	60–90	9.3	16	18.336
Yucatan Peninsula	24	4500	>5000	180	24	25.193
Alta Verapaz	4	18	>1000	4.5	4.5	4.5
Peten	2	5	>500	2.5	2	2
Chiquibul	6	16	>500	2.6	6	6.3

Table 3.
Comparison of richness among karstic regions.

In contrast in the Isthmus and Chiapas region the crustaceans have a freshwater origin and their microdistribution are mainly in the locality type for several freshwater shrimp and crabs. However according with the geological development from all these regions and this report of species distribution the subterranean corridor existed in this case among Tehuantepec Itsthmus and Chiapas, Alta Verapaz and Chiquibul region for *Macrobrachium* genus, because the all these regions this genus inhabiting the different cave options producing several species that have phylogenetics relationships, at the same situations occurs with Pseudothelphusidae crab family, and of course fishes species. Currently this corridor is not working to gene flow because the caves working like a barrier among populations and the distance are very significative which not happened in the Yucatan Peninsula where the existence of subterranean rivers has been reported.

5. Discussion

The tropical subterranean aquatic biodiversity in Central America (Mexico, Guatemala & Belize) is higher in comparison with those temperate zones in Mexico even, because how has been described previously there are more taxa (**Figures 7** and **8**) [10, 21, 22, 29]. Although as well had been described, in other continents are described with more detail the taxa numbers by example Europe where the main factor to produce these numbers are the efforts occupied in exploring and registered these taxa [30]. Therefore, the diversity comparison among these regions are too difficult, because depends in first instance of the correct reports and the effort to exploring the areas, all these data are an approximately about that the current status of biodiversity [31], showed the status among this subterranean diversity in the tropics using some cave as examples but is not determinant but in the aquatic habitats the crustaceans are reported as main taxa. However, is evident that the freshwater groups colonised in first instance those habitats close the mountains in this biological subterranean corridor, there are another group that cluster the Yucatan Peninsula Region and due the different origin from the Mountain Systems allow that these species are cosmopolitan distribution [6]. Finally the anchialine species group are totally different and their relationships are more closely with Antilles fauna [32–35]. Even among the regions there are important differences in the diversity not only in the composition of genus or families, too in the number of species and in the specimens registered, by example due that the regions are big land extension is few possible that only one or two specimens were registered, is we check the numbers of index as Chao's or Burman & Overton the diversity estimated increase few because the taxa included in the analysis had a good representation in the area, someone are cosmopolitans in the same region.

Figure 7.
Representative cave crustaceans species in the Mesoamerican region. a) Procambarus *sp.; c)* Typhlopseudothelphusa acanthochela*; d)* Macrobrachium catonium*; e)* Creaseria morleyi *(courtesy by* AQ05 *Erick Sosa); e)* Procaris mexicana*; f)* Anchialocaris paulini*; g)* Typhlatya *sp.; h)* Agostocaris zabaletai*; i)* Calliasmata nohochi*; j)* Barbouria cubensis*.*

By another aspect is the subterranean environments that in first instance was classified in dry, semi-dry, freshwater flooded, and anchialine caves as has been reported in several opportunities [36], but in recently studies has been reported that

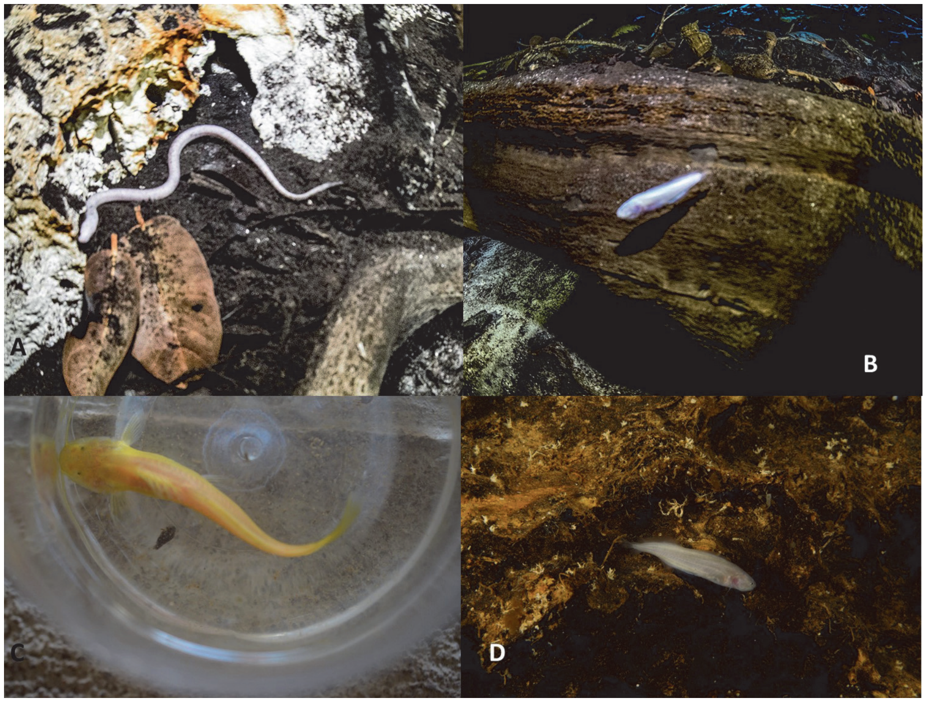

Figure 8.
Representative cave fish species in the Mesoamerican region a) Opisternon infernale*; b)* Ogilbia pearsei *(photo courtesy of Juan Carmona; c)* Rhamdia laticauda*; d) fish from Bithynidae family in anchialine ecosystems.*

even in the tropical dry caves there are some different according with the temperature and humidity that produce a major heterogeneity because these features are changing in relation with outside [37, 38], and in semi-dry caves these features have a relation with the oxygen inputs in the subterranean aquatic habitats. In the Anchialine caves the size of freshwater lenses are the main changes to energy entrance and the environmental stability [28]. Their ecological relation in these subterranean systems all in tropical conditions depends of course of their energy support and in this region there are two main ways, the alloctonous way using the biological and hydrological process [36] and for autochthonous way producing by chemolitotrophic procedures the energy using the chemosynthetic bacteria and support by use of methane and dissolved organic carbon [39–41]. In the first option the biological process involve bats that carry several seeds or insect debris, even they self when died; some trogloxene animals that sometimes entrance to these environments and died; but also by there are an important energy sources in cave entrance by the sun effects, where several plants growth and some cave insects go to entrance to feed and back to dark zones. In the second option the chemolitotrophic organisms has been reported on the walls or ceiling as Cueva de Villa Luz in Tabasco and even in some symbiosis with another animals using the electrons from sulphur origin or chemoorganotrophic as the methane decomposition to produce energy as been reported for some crustaceans [42, 43]. This energy source still are working in the different research groups to understand in first instance how is support the life, and the organic matter available could be the main evolutionary forces to different process how as been reported by [15, 21, 44, 45].

6. Conclusions

a. The subterranean diversity in fish and crustaceans species is high in relation with the tropical surrounded environments.

b. The cave decapods is the taxa with major diversity in subterranean Mesoamerican ecosystems

c. The energy to support this diversity had a main source from outside through the carry of organic matter by bats or hydrological r egimens.

d. These ecosystems are strong relationship with outside tropical environments.

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Conflict of interest

The authors declare no conflict of interest.

Author details

Luis M. Mejía-Ortíz[1,6]*, Peter Sprouse[2,5], Juan C. Tejeda-Mazariegos[1], Jair Valladarez[3], Oscar Frausto-Martínez[4], Alejandro L. Collantes-Chavez-Costa[5], Guillermo Ruíz-Cancino[1] and German Yáñez[6]

1 Biospeleology and Carcinology Lab, Sustainability Development Division, University of Quintana Roo, Cozumel, Mexico

2 Zara Environmental LLC, Manchaca, TX, USA

3 University of Belize

4 Spatial Observation Lab, Sustainability Development Division, University of Quintana Roo, Cozumel, Mexico

5 Sustainability Development Division, University of Quintana Roo, Cozumel, Mexico

6 Speleological Circle of Mayab, Cozumel, Mexico

*Address all correspondence to: luismejia@uqroo.edu.mx

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