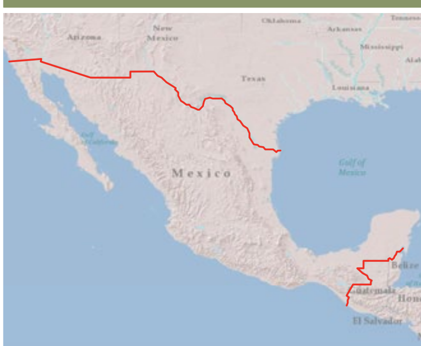
IUCN RED LIST

The status and distribution of freshwater fishes in Mexico

Edited by Timothy Lyons, Laura Máiz-Tomé, Marcelo Tognelli, Adam Daniels,
Clayton Meredith, Robert Bullock and Ian Harrison
IUCN Freshwater Biodiversity Unit, Global Species Programme and the ABQ BioPark

MEXICO



The IUCN Red List of Threatened Species™

SSC
Species Survival Commission

ABQ BIOPARK

TOYOTA

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Project management

Coordination of the Mexican freshwater fish Red List assessment was carried out by Laura Máiz-Tomé (IUCN Global Species Programme, Freshwater Biodiversity Unit), with support from Adam Daniels (IUCN Global Species Programme, Freshwater Biodiversity Unit) and Tim Lyons (New Mexico BioPark Society).

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Red List species assessors , evaluators, and workshop participants

All of IUCN's Red Listing processes rely on the willingness of scientists to contribute and pool their collective knowledge to make the most reliable estimates of species' status. Without their enthusiastic commitment to species conservation, this work would not be possible.

We would therefore like to acknowledge the committed work of all the Mexican and international ichthyologists who have provided information and expertise to this project: Arcadio Valdés González; Claudia Patricia Ornelas García; Dean Hendrickson; Eduardo Soto-Galera; Héctor Espinosa Pérez; Héctor Omar Mejía Guerrero; Jairo Arrojave; Juan Jacobo Schmitter-Soto; Juan Manuel Rivas González; María Antonieta Gómez Balandra; María Eugenia Vega; Michael Köck; Norman Mercado Silva; Omar Domínguez Domínguez; Steven Norris; Topiltzin Contreras-MacBeath; Wilfredo Matamoros.

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Executive summary

The inland waters of Mexico support a highly diverse group of freshwater fishes with high levels of endemism that occur across a broad range of aquatic habitat types. These aquatic ecosystems provide many direct (e.g., fisheries) and indirect (e.g., agricultural irrigation) benefits to people, and support local livelihoods and economies across Mexico. Freshwater ecosystems are undervalued and receive insufficient funding, political attention and protection. Developing interests and funding for freshwater species conservation is crucial for "bending the curve" to reduce and ultimately reverse freshwater biodiversity declines. Historical disregard for the health and sustainable use of freshwater ecosystems has resulted in alarming rates of loss in the quality and availability of aquatic habitat. This report presents the most recent information on the conservation status and distribution of freshwater fishes in Mexico, and examines the stressors that are driving their declining conservation status. Important conservation actions and considerations are also presented.

Five hundred and thirty-six species of freshwater fishes were assessed against the IUCN Red List Categories and Criteria, representing the most comprehensive assessment of freshwater biodiversity in Mexico to date. This assessment seeks to address the insufficient information available on freshwater fish conservation status, which has resulted in their inadequate representation in environmental planning and management. The full data set, including all species distribution maps, is freely available through the IUCN Red List website (www.iucnredlist.org).

Forty percent of all extant species assessed are threatened with extinction, assuming all Data Deficient species are threatened in the same proportion as those for which enough information was available. The most pervasive threats are related to habitat loss and degradation, which is driven primarily by unsustainable water use and widespread agricultural activity. Excessive extraction of groundwater and diversion of surface water for human consumption, industrial processes, and plantation agriculture has led to widespread flow reductions, reduced water tables, and subsequent drying of aquatic habitat, which is especially prevalent in the arid, endorheic spring systems of northern and central Mexico. Mexico's vast hydroelectric infrastructure has altered the historical flow regime of many major rivers, blocking natural migration routes and fragmenting subpopulations of native fishes. Agricultural runoff, inadequate wastewater treatment, and industrial discharges have also resulted in increased levels of pollution. A number of non-native fish species have been introduced both intentionally and unintentionally throughout many of Mexico's natural and artificial surface waters, with profound impacts on native species distribution and abundance.

Given the high connectivity of riverine surface waters and underlying aquifers, the impacts of these threats spread rapidly throughout freshwater ecosystems. Future conservation efforts must place greater emphasis on upstream, downstream, and lateral connectivity within water catchments. Systematic conservation planning approaches should be implemented to develop an integrated conservation action plan for freshwater fishes in Mexico, including broad stakeholder participation, environmental monitoring schemes, and the development of protected areas designed to maintain high levels of aquatic connectivity.

Another priority is to direct additional research effort towards the high proportion of species assessed as Data Deficient due to insufficient information on their conservation status and distributions. This lack of information presents a significant bottleneck to the effective management and conservation of Mexico's freshwater habitats and ichthyofauna.

From a policy perspective, the information presented in this report will help support the implementation of multilateral environmental agreements in Mexico, guide conservation planning and priority setting at the national and international level, and provide a baseline of conservation success in subsequent assessments of extinction risk. In addition, this new information will help efforts to achieve the targets of the UN Sustainable Development Goals (SDGs), such as: Target 6.6 for protecting and restoring water-related ecosystems; Target 6.5 on implementing integrated water resources management at all levels; Target 15.1 for conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services; and Target 15.5 focused on urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity and, protect and prevent the extinction of threatened species.

The IUCN Red List is one of the most authoritative global standards supporting policy and action to conserve biodiversity. The analysis presented in this report, based on an assessment of species Red List status, will provide new information to help guide conservation actions and development planning to safeguard the diversity of freshwater ichthyofauna in Mexico. Periodic update of IUCN Red List species assessments will enable calculation of a Red List Index of change in freshwater species extinction risk over time, which will inform managers on the conservation effectiveness of any management interventions.

Chapter 1

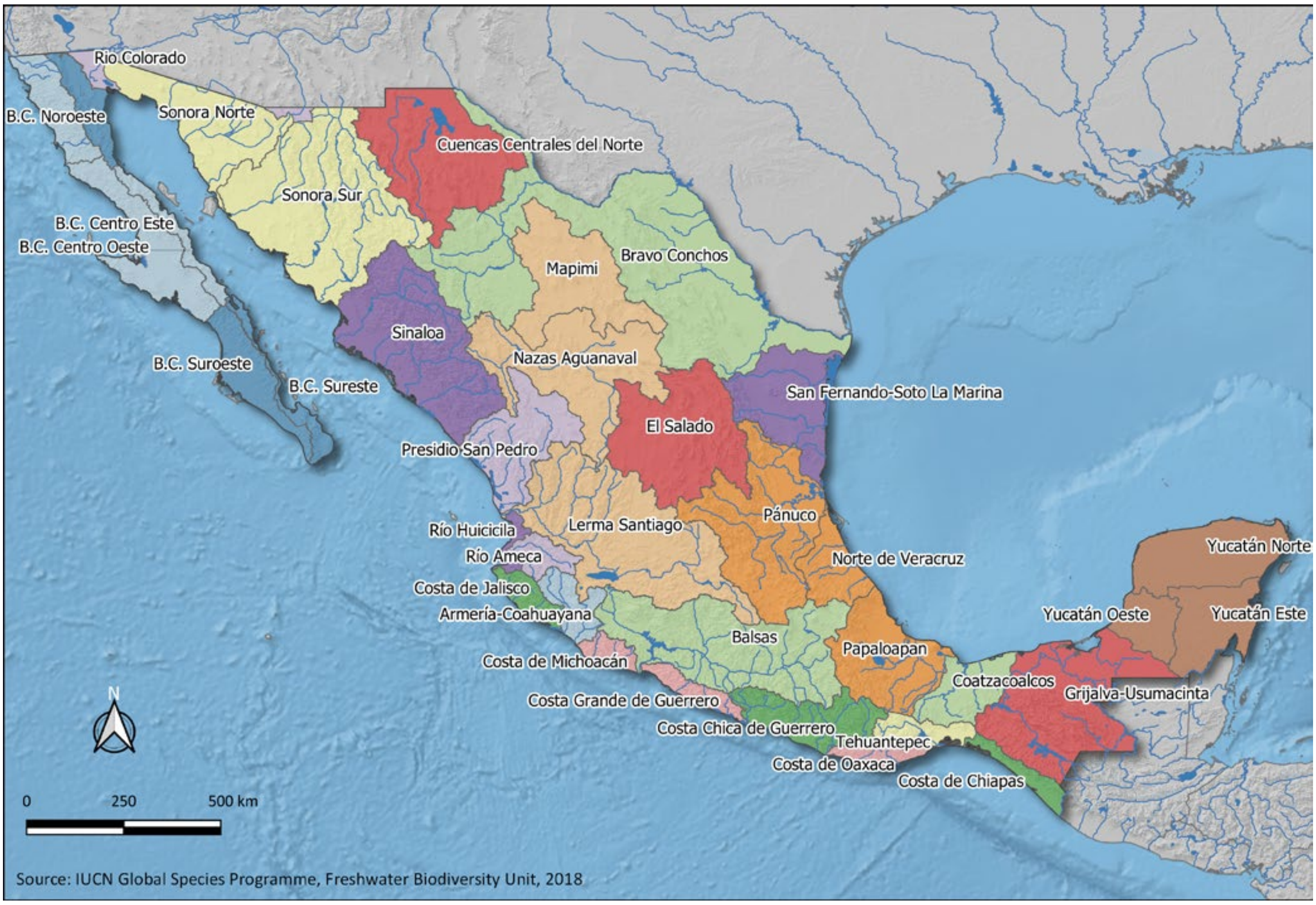
Background

Contents

1.1 Mexican freshwater resources

Mexico is the southernmost country in North America, extending into Central America south of the Isthmus of Tehuantepec. It has a territorial extension of 1,964,375 km^2, 1,959,248 km^2 (99.74%) being continental, plus islands totaling 5,127 km^2 (0.26%). Its coastlines extend for 7,828 km along the Pacific Ocean and 3,294 km along the Gulf of Mexico and Caribbean (CONAGUA, 2018). About 65% of the country is characterized by mountain ranges; from the north, the Sierra Madre Oriental and the Sierra Madre Occidental extend along north-south axes. They are then merged in central Mexico via the Trans-Mexican Volcanic Belt; extending further south towards Central America is the Sierra Madre del Sur. These mountain ranges result in a complex geography and climate, with high mountains, deep valleys, plateaus, and coastal plains, as well as large and small drainages (Contreras-Balderas et al., 2008). In terms of temperature and rainfall, 32% of the country is arid desert, 36% semiarid, and 32% sub-humid and humid.

Figure 1.1: Major catchments and rivers of Mexico (CONABIO, 2016).



These geographic features produce a great variety of habitats, including high mountains close to the equator exhibiting ecosystems characteristic of higher latitudes. As such, Mexico serves as a dispersal corridor for Nearctic and Neotropical biota and represents a transition zone between these realms (Pielou, 1979). Consequently, Mexico supports a vast number of species and is regarded as a megadiverse country that contains at least 10% of the terrestrial diversity of the planet (Espinosa & Ocegueda, 2008).

Mexican aquatic systems support highly diverse assemblages of freshwater species, including fishes, reptiles, amphibians, molluscs, gastropods, odonates, and other aquatic invertebrates (Huidobro et al., 2006; Kalkman et al., 2008; Thompson, 2011; Mercado-Salas et al., 2013; Contreras-MacBeath et al., 2014; Cumberlidge et al., 2014; Macip-Ríos et al., 2015). Mexico contains 37 major river basins, 12 of which drain to the Gulf of Mexico and the Caribbean, 19 to the Pacific Ocean and Gulf of California, and six which are endorheic. The largest basins include the Yaqui, Fuerte, Nazas-Aguanaval, Mezquital, Lerma-Santiago, and the Balsas on the Pacific slope, and the Bravo, Pánuco, Papaloapan, Coatzacoalcos, and Grijalva-Usumacinta on the Atlantic slope (Miller et al. 2005, Lara-Lara et al., 2008).

With respect to lentic environments, Mexico contains 70 major lakes that range between 1,000 and 10,000 hectares in area, and together cover 370,000 ha. The largest is Lake Chapala in Jalisco, followed by Cuitzeo and Pátzcuaro in Michoacán, Catazajá in Chiapas, del Corte in Campeche, Bavicora and Bustillos in Chihuahua, and Lake Catemaco in Veracruz. There are also some 14,000 man-made reservoirs, most with surface areas smaller than 10 hectares, whereas those with larger areas represent two thirds of the country's total reservoir surface area. The largest dams are Nezahualcóyotl, Belisario Domínguez, La Amistad, Falcón, Vicente Guerrero, Álvaro Obregón, El Infiernillo, Cerro de Oro, Temascal, Caracol, Requena, and Venustiano Carranza (Aguilar, 2003), comprising a cumulative storage capacity of approximately 150 km^3 (CONAGUA, 2018). Mexico's vast hydroelectric infrastructure currently supplies 12% of all electricity generation in Mexico. Additional development is expected to continue into the future to meet a 2024 national objective to provide 35% of power generation through clean energy, a target that could increase to 50% by 2050 (IHA, 2018), though the actual rate of growth may be lower (Mercado-Silva et al., 2018; G. Balandra 2019, pers. comm.).

1.2 Mexican Ichthyological history, diversity, and endemism

Mexico's ichthyofauna is highly diverse and relatively well-studied, with the first formal investigations beginning some 250 years ago (Miller et al., 2005), and the first five descriptions of its freshwater species dating back to Linnaeus' (1758). Other early works are those of Cuvier and Valenciennes (1835), which recognises 14 species, Baird and Girard (1822-1895), which recognizes 50 species, and Günther (1859-70), which recognises 30. The first contribution of a Mexican ichthyologist dates back to 1837, when Miguel Bustamante and Septién described *Girardinichthys viviparus*. Some other early relevant publications are *Fishes of North and Middle America*, by David S. Jordan and Barton W. Evermann (1898), *The Freshwater Fishes of Mexico North of the Isthmus of Tehuantepec*, by Seth E. Meek (1904), and *Biologia Centrali-Americana*, by Charles T. Regan (1906–1908).

The first published list of the freshwater fishes of Mexico was produced by De Buen (1940), and consisted of 321 species in 136 genera. Building on this collective knowledge, the many important and progressive contributions to our understanding of Mexican freshwater fishes begin with the work of José Álvarez del Villar, who started his productive career in 1945. He described 35 species, and founded the first school of Mexican ichthyologists (Guerra, 2000). The second, and most cited list is that of Espinosa et al. (1993), which recognises 506 species. More recent publications report similar species estimates, such as Miller et al. (2005), with 495 species (updated to 589 species in a more recent Spanish translation; Miller et al. 2009), Froese & Pauly (2006) with 493, and Contreras-Balderas et al. (2008) with 545. Inconsistencies between these sources are primarily due to

Robert R. Miller, Carl L. Hubbs, and Salvador Contreras-Balderas (left to right) directing a 1973 meeting of the Desert Fishes Council in Tempe, Arizona. © Edwin P. Pister

Xiphophorus clemenciae **(DD), a species currently known only from the confluence of the Coatzacoalcos and Sarabia rivers in Oaxaca and Veracruz, Mexico.** © Juan Carlos Merino

the generation of new knowledge from one survey to another, differences in data interpretation by the specialists involved, and the use of modern molecular techniques in biodiversity assessments (Hulsey et al., 2004; Concheiro et al., 2007).

Unfortunately, Mexico suffers from many of the globally common environmental problems associated with unsustainable human development, including freshwater overexploitation, pollution, and biodiversity loss (OCDE, 1998; INEGI, 2000; Lira-Noriega et al., 2015). Aquatic ecosystems are among the most vulnerable to destructive human activities. Rivers, lakes, lagoons, seas, and other surface waters receive the vast majority of contaminants and other impacts from large cities, industrial parks, and from livestock production and agricultural activities. These stressors have had measurable impacts on freshwater species (Dirzo et al., 2009), and more specifically on freshwater fishes (Contreras-Balderas et al., 2008; Díaz-Pardo et al., 2016). However, environmental impact assessment studies that address the impacts of hydraulic infrastructure and water allocation typically only consider biodiversity in the context of species that are federally protected, and do not consider impacts on habitat connectivity, abundance, or overall biodiversity. Following the classification of Salafsky et al. (2008), the main threats to freshwater fish biodiversity are those from dams, natural systems modifications and water management/use, pollution, invasive species, and overfishing (see 3.4.1-3.4.4).

1.3 Global Freshwater Fish Assessment

In 2016, The International Union for Conservation of Nature (IUCN) and Toyota Motor Corporation (Toyota) announced a five-year partnership to provide funding to broaden the scope of The IUCN Red List of Threatened Species™ and significantly increase knowledge on the extinction risk of more than 28,000 species.

This partnership is driven by the **Toyota Environmental Challenge 2050,** which aims to reduce the negative impacts associated with automobiles to zero and beyond, whilst simultaneously making positive impacts on nature and society. As part of this partnership, the IUCN Freshwater Biodiversity Unit received funds to complete a comprehensive assessment of freshwater fishes by 2021 – including the assessment of 536 native freshwater Mexican fishes.

This is vitally important, given that as much as 75% of the world's inland wetlands may have been lost during the 20th century (Ramsar Convention on Wetlands, 2018), and **freshwater populations have declined by 83% on average between 1970 and 2014,** equivalent to 4% per year, according to the latest Living Planet Report (WWF, 2018).

Since 2018, the IUCN Freshwater Biodiversity Unit has collaborated with the ABQ BioPark, located along the Rio Grande River in New Mexico, USA. The ABQ BioPark has become an IUCN Species Survival Commission Red List hub, with the addition of three Species Survival Officers, who helped to organise and facilitate a Red List review workshop attended by regional and international experts. Financial contributions made by the New Mexico BioPark Society funded significant portions of this project including some species assessments and portions of the Red List review workshop.

The data presented in recognised and respected formats such as the IUCN Red List provide important tools to: a) raise awareness of freshwater species in need of protection; and b) inform decision-making in relation to conservation and development planning to minimize and where possible prevent anthropogenic impacts on freshwater ecosystems.

The information presented in this project report provides the most up-to-date information on the conservation status and distribution of freshwater fishes for Mexico. Combined with political will and subsequent action it can help to ensure the long-term survival of freshwater fishes and associated dependent local livelihoods in Mexico.

Periodic update and monitoring of this baseline of IUCN species Red List assessments will enable tracking of trends in the status of freshwater fishes through calculation of the Red List Index. This index will in turn, inform managers on the effectiveness of their management interventions.

Participants at the Red List review workshop held in Albuquerque, New Mexico in December 2018. © Baird Fleming

Chapter 2

Red List Assessment Methodology

Contents

2.1 Data collection and quality control

The biodiversity assessment required sourcing and collating the best information on all known, described Mexican freshwater fish species. As the primary source for this information, regional and international experts for these taxa were first identified through consultation with the IUCN Species Survival Commission (SSC) Freshwater Fish Specialist Group (FFSG). These experts collated the relevant information within the IUCN Species Information Service database (https://sis.iucnsis.org) and applied the IUCN Red List Categories and Criteria (IUCN, 2012), to assess the species risk of extinction in the wild.

Species range distributions were also mapped (see below). All information was then peer reviewed at a workshop held at the Albuquerque BioPark in December 2018. At the workshop, each species assessment was evaluated by at least two independent experts to ensure that the information presented for each Red List assessment was both complete and correct, and that the Red List Category and Criteria assigned to each species were supported by the information provided within the assessment text.

For the purposes of this assessment, freshwater fishes are defined as those species that spend all or a critical part of their life cycle in freshwaters. There are approximately 13,000 freshwater fish species in the world, or approximately 15,000 if brackish water species are included (Lévêque et al., 2008). Five hundred and thirty-six freshwater fish species native to Mexico were mapped and assessed for their risk of extinction using the IUCN Red List Categories and Criteria (IUCN, 2012). Two hundred and fifty-six of these species were reassessed as part of this project. Therefore, many of the Red List assessment results presented here reflect reassessments, building on and updating the previous assessments. Two hundred and eighty species were assessed for the first time.

2.2 Nomenclature

Taxonomic schemes are constantly changing as science advances, and in particular, following the introduction of molecular techniques. Taxonomy is also a somewhat controversial field, and in many cases, it is difficult to find a universally accepted taxonomic hierarchy. In this project, the taxonomy followed is that adopted by the IUCN Red List, which, where possible, employs existing published world checklists. For this project, classification generally follows the California Academy of Sciences' Eschmeyer's Catalog of Fishes (Fricke et al., 2019).

For more information on the taxonomic standards of the IUCN Red List, please visit https://www.iucnredlist.org/resources/supporting-information-guidelines

2.3 Species Mapping

Using ArcMap 10.6 software (ESRI, 2018) all species distributions were mapped to river and lake sub-basins as delineated by HydroBASINS Level 08 (Lehner & Grill, 2013) a global standardized hydrological framework that delineates catchments at 12 resolutions and includes information on network hydrological connectivity. Where spatial data were of sufficiently high detail, species were mapped to smaller sub-basins (HydroBASINS Level 12). River basins were selected as the spatial unit for mapping and analysing species distributions, as it is generally accepted that the river/lake basin or catchment is the most appropriate management unit for inland waters.

Using sub-basins to delineate freshwater species distributions provides clear benefits, as they represent well-defined and ecologically meaningful management units, they facilitate ease of data storage, search, and management (tabular format), account for hydrological connectivity, facilitate input to conservation planning software such as Marxan, and can be flexibly applied at 12 different grain sizes, the smallest being approximately 10 km^2.

Where data were available, point localities (the latitude and longitude for a species collection) were used to identify which sub-basins are known to contain the species. Point localities are based on museum records from all major collections and supplemented by expert knowledge of presence at sites where no voucher specimens were collected. The preliminary species distribution maps were digitized and then further edited at the review workshop where errors and dubious records were deleted from the maps.

Connected sub basins where a species is expected to occur, although presence is not yet confirmed, are known as 'inferred basins'. Inferred distributions, coded as "Possibly Extant", were determined through a combination of expert knowledge, coarse-scale distribution records and unpublished information.

2.4 Assessment of species threatened status

The risk of extinction for each species was assessed according to the IUCN Red List Categories and Criteria: Version 3.1 on a global scale (IUCN 2012). The IUCN Red List of Threatened Species™ is the world's most comprehensive information source on the global conservation status of plant and animal species, and is widely used to help inform conservation priority setting.

The nine Red List Categories at the global level are shown in Figure 2.1. A species is assessed as **Extinct (EX)** when there is no reasonable doubt that the last individual has died. A species is assessed as **Extinct in the Wild (EW)** when it is known only to survive in cultivation, captivity or as a naturalised population well outside its native range. A species assessed as **Critically Endangered (CR)** is considered to be facing an extremely high risk of extinction in the wild. A species assessed as **Endangered (EN)** is considered to be facing a very high risk of extinction in the wild. A species assessed as **Vulnerable (VU)** is considered to be facing a high risk of extinction in the wild. All species listed as Critically Endangered, Endangered or Vulnerable are described as **threatened**. A species is assessed as **Near Threatened (NT)** when it is close to qualifying for a threatened category, or if it is the focus of a specific and targeted conservation programme, the cessation of which would result in the species soon qualifying as threatened. A species is assessed as **Least Concern (LC)** if it does not qualify (and is not close to qualifying) as threatened or Near Threatened. Least Concern species are generally common and widespread. A species is assessed as **Data Deficient (DD)** if there is insufficient information to make a direct or indirect assessment of its risk of extinction. Data Deficient is therefore not a category of threat and instead indicates that further information on the species is required. Species assessed as Data Deficient are priorities for additional research and should be acknowledged as potentially threatened.

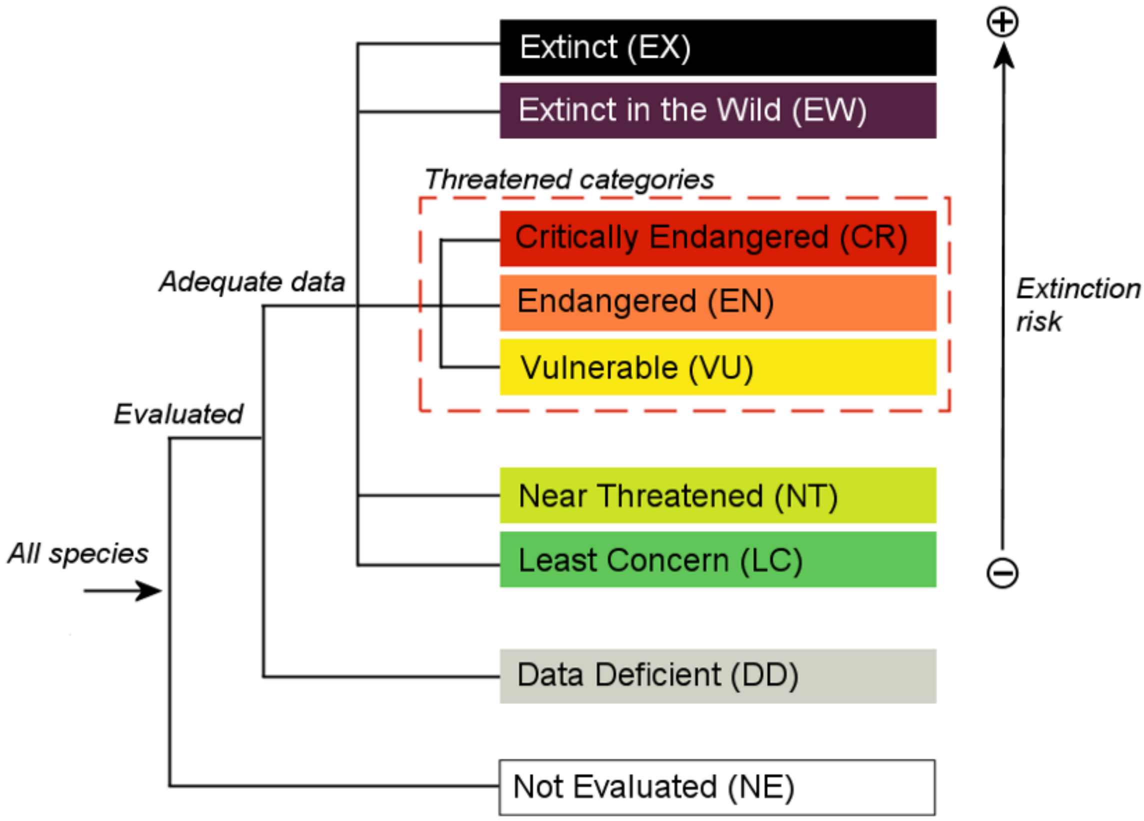
To determine whether a species should be assigned to one of the three threatened categories, there are five criteria with quantitative thresholds (Figure 2.2), reflecting biological indicators of populations threatened with extinction.

For a detailed explanation of the categories and of the criteria that must be met for a species to qualify under each category, please refer to *The IUCN Red List Categories and Criteria: Version 3.1*:

http://cmsdocs.s3.amazonaws.com/keydocuments/Categories_and_Criteria_en_web%2Bcover%2Bbckcover.pdf.

Red List assessments are published online on the IUCN Red List website (www.iucnredlist.org) where they are freely available to the public.

Figure 2.1: IUCN Red List Categories Version 3.1 Second Edition on a global scale (IUCN 2012).



Reporting the proportion of species in a taxonomic grouping that are threatened requires a standardised approach as some species have so little information available that they can only be assessed as Data Deficient (DD). The reported percentage of threatened species for each group is presented as a **best estimate** within a range of possible values bounded by lower and upper estimates:

- **Lower estimate** = % threatened extant species if all DD species are not threatened, i.e., (CR + EN + VU) / (total assessed - EX)

- **Best estimate** = % threatened extant species if DD species are equally threatened as data sufficient species, i.e., (CR + EN + VU) / (total assessed - EX - DD)

- **Upper estimate** = % threatened extant species if all DD species are threatened, i.e., (CR + EN + VU + DD) / (total assessed - EX)

Figure 2.2: Summary of the five criteria (A-E) used to evaluate if a species belongs in an IUCN Red List threatened category: Critically Endangered, Endangered or Vulnerable.

A. Population size reduction. Population reduction (measured over the longer of 10 years or 3 generations) based on any of A1 to A4

	Critically Endangered	Endangered	Vulnerable
A1	≥ 90%	≥ 70%	≥ 50%
A2, A3 & A4	≥ 80%	≥ 50%	≥ 30%

A1 Population reduction observed, estimated, inferred, or suspected in the past where the causes of the reduction are clearly reversible AND understood AND have ceased.

A2 Population reduction observed, estimated, inferred, or suspected in the past where the causes of reduction may not have ceased OR may not be understood OR may not be reversible.

A3 Population reduction projected, inferred or suspected to be met in the future (up to a maximum of 100 years) *[(a) cannot be used for A3]*.

A4 An observed, estimated, inferred, projected or suspected population reduction where the time period must include both the past and the future (up to a max. of 100 years in future), and where the causes of reduction may not have ceased OR may not be understood OR may not be reversible.

based on any of the following:

- **(a)** direct observation *[except A3]*
- **(b)** an index of abundance appropriate to the taxon
- **(c)** a decline in area of occupancy (AOO), extent of occurrence (EOO) and/or habitat quality
- **(d)** actual or potential levels of exploitation
- **(e)** effects of introduced taxa, hybridization, pathogens, pollutants, competitors or parasites.

B. Geographic range in the form of either B1 (extent of occurrence) AND/OR B2 (area of occupancy)

	Critically Endangered	Endangered	Vulnerable
B1. Extent of occurrence (EOO)	< 100 km^2	< 5,000 km^2	< 20,000 km^2
B2. Area of occupancy (AOO)	< 10 km^2	< 500 km^2	< 2,000 km^2
AND at least 2 of the following 3 conditions:			
(a) Severely fragmented **OR** Number of locations	= 1	≤ 5	≤ 10
(b) Continuing decline observed, estimated, inferred or projected in any of: **(i)** extent of occurrence; **(ii)** area of occupancy; **(iii)** area, extent and/or quality of habitat; **(iv)** number of locations or subpopulations; **(v)** number of mature individuals			
(c) Extreme fluctuations in any of: **(i)** extent of occurrence; **(ii)** area of occupancy; **(iii)** number of locations or subpopulations; **(iv)** number of mature individuals			

C. Small population size and decline

	Critically Endangered	Endangered	Vulnerable
Number of mature individuals	< 250	< 2,500	< 10,000
AND at least one of C1 or C2			
C1. An observed, estimated or projected continuing decline of at least (up to a max. of 100 years in future):	25% in 3 years or 1 generation (whichever is longer)	20% in 5 years or 2 generations (whichever is longer)	10% in 10 years or 3 generations (whichever is longer)
C2. An observed, estimated, projected or inferred continuing decline AND at least 1 of the following 3 conditions:			
(a) **(i)** Number of mature individuals in each subpopulation	≤ 50	≤ 250	≤ 1,000
(a) **(ii)** % of mature individuals in one subpopulation =	90–100%	95–100%	100%
(b) Extreme fluctuations in the number of mature individuals			

D. Very small or restricted population

	Critically Endangered	Endangered	Vulnerable
D. Number of mature individuals	< 50	< 250	**D1.** < 1,000
D2. *Only applies to the VU category* Restricted area of occupancy or number of locations with a plausible future threat that could drive the taxon to CR or EX in a very short time.	-	-	**D2.** typically: AOO < 20 km^2 or number of locations ≤ 5

E. Quantitative Analysis

	Critically Endangered	Endangered	Vulnerable
Indicating the probability of extinction in the wild to be:	≥ 50% in 10 years or 3 generations, whichever is longer (100 years max.)	≥ 20% in 20 years or 5 generations, whichever is longer (100 years max.)	≥ 10% in 100 years

1 Use of this summary sheet requires full understanding of the *IUCN Red List Categories and Criteria* and *Guidelines for Using the IUCN Red List Categories and Criteria*. Please refer to both documents for explanations of terms and concepts used here.

2.5 Reassessment methodology

In order to monitor the changing status of biodiversity over time, it is important to periodically reassess the extinction risk of species. Category transitions can result from non-genuine or genuine changes (IUCN, 2013).

Non-genuine changes typically result from information that has become available after the most recent assessment (e.g., more recent data are available on population sizes, threatening processes, rates of decline or recovery), taxonomic revision that results in a new species concept (e.g., the species is not split into several species, each with smaller ranges and population sizes; or it has been merged with other species so that range and population size are larger), errors discovered in the previous assessment (e.g., incorrect information was used, or the IUCN Red List Categories and Criteria were incorrectly applied), or the previous assessment used an older version of the IUCN Red List Categories and Criteria and the current reassessment uses criteria with slightly different thresholds.

Genuine improvements in conservation status occur when the main threats to the species are no longer present, or when conservation measures (e.g., reintroduction, habitat protection or restoration, legal protection, harvest management) have successfully improved the status of the species enough to move it into a lower category of threat. **Genuine declines** in conservation status are typically the result of threats that have continued unabated or increased, or the development of new threats that have caused the status of the species to deteriorate enough to move it into a higher category of threat.

Ik-Kil cenote outside of Chichén Itzá in Yucatan, Mexico, is a popular swimming destination for tourists, and is a suitable habitat for *Rhamdia guatemalensis*. © Omar Domínguez Domínguez

Chapter 3

Results and Discussion

Contents

3.1 Conservation status of freshwater fishes

At the global level, 165 species of Mexican freshwater fishes are threatened with extinction, representing 39.9% of all species assessed – assuming all Data Deficient species are threatened in the same proportion as those for which enough information was available.

Threatened species are divided into the categories 'Vulnerable', which includes 9.3% of all species assessed, 'Endangered', comprising 13.2% of all species assessed, and 'Critically Endangered', comprising 8.2% of all species assessed. A further 3.4% of species are classified as Near Threatened (Table 3.1, Figure 3.1).

An additional 12 (2.2%) species of Mexican freshwater fishes are globally Extinct, and eight (1.5%) species are Extinct in the Wild. Of these, all were endemic to Mexico, and all but one belong to the order Cyprinodontiformes.

These numbers are, however, likely an underestimate of the true extinction rate, given that several Critically Endangered species have not been recorded from Mexican freshwaters in the recent past (Miller, 1964; Miller et al., 2005; Bloom et al., 2009; Burkhead, 2012).

The threat of freshwater fish extinction in Mexico is comparable to other biodiversity hotspots around the world, including Madagascar and the Indian Ocean Islands (Máiz-Tomé et al., 2018), the Eastern Mediterranean (Smith et al., 2014), and others. The percentage of threatened species identified in this report is consistent with an observed increasing trend in the extinction risk of Mexican freshwater

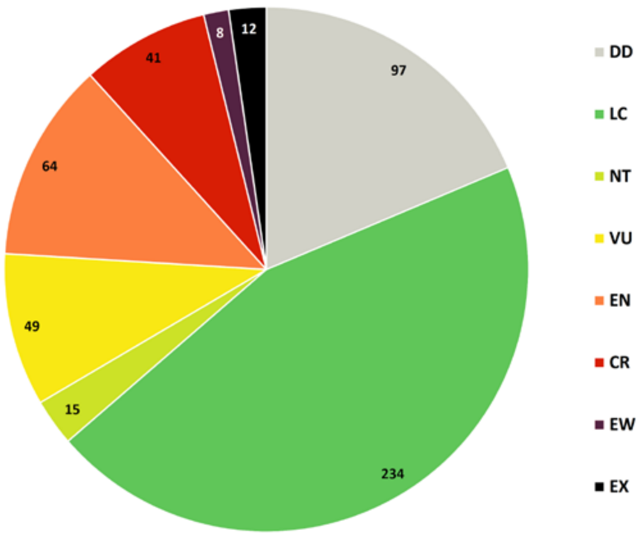
Table 3.1: The number of Mexican freshwater fishes in each global IUCN Red List Category

IUCN Red List Category	Number of species	Number of endemic species
Extinct	12	12
Extinct in the Wild	8	8
Critically Endangered	44	44
Endangered	71	64
Vulnerable	50	38
Near Threatened	18	17
Least Concern	234	37
Data Deficient	99	71
Total species	**536**	**291**

fishes over the last 50 years (Contreras-Balderas et al., 2003). The extinction risk of Mexican freshwater fishes is considerably higher than that reported for Pan-African freshwater biodiversity, where 21% of fish species were assessed as threatened (Darwall et al., 2011).

Approximately 18.5% of species are Data Deficient. It is important to note, however, that many of these species are likely to meet the threshold for a threatened category when more data become available. The broad range of potential extinction risk clearly illustrates the need to direct additional research effort towards these priority species that are currently lacking the necessary data to accurately assess their extinction risk, particularly in the form of additional sampling surveys to clarify geographic ranges, abundances, and recent population trends.

Figure 3.1: The proportion (%) of Mexican freshwater fish species in each global IUCN Red List Category.



3.2 Reassessment trends

Of the 536 species included in this project, 256 (47.8%) species were re-assessments. Of the species that were reassessed, 62 experienced a non-genuine category change and seven experienced a genuine category change. In total, 21 species were uplisted to a higher threatened category, and 29 species were downlisted to a lower threatened category. Four species moved from Data Deficient to Least Concern, three species moved from Data Deficient into a threatened category, and six species moved from a threatened category into a Data Deficient category.

All genuine category changes showed marked declines in the conservation status of the species, including three threatened category uplistings (*Characodon audax* and *C. lateralis*, and *Girardinichthys multiradiatus*), three extinctions in the wild (*Cyprinodon veronicae*, *Xiphophorus couchianus* and *X. meyeri*), and one extinction (*Megupsilon aporus*) resulting from the loss of the last known captive population. Two species (*Ameca splendens* and *Notropis amecae*) that were previously assessed as Extinct in the Wild and Extinct, respectively, were rediscovered in wild populations following the most recent historical assessment.

Reassessment trends highlight the need for effective conservation action for threatened taxa, particularly those that are Extinct in the Wild and Critically Endangered. The transition of species from Data Deficient to Least Concern and threatened categories represents progress in research and an understanding of conservation status. However, most changes during reassessment were non-genuine, which suggests that most of these changes are the result of taxonomic changes, new information, or a prior mischaracterization of extinction risk.

3.3 Status by taxonomic group

The Mexican freshwater ichthyofauna includes 48 families which vary widely in the number of species they contain, and the relative threat status of their species (Table 3.3). The largest and most threatened groups include Goodeidae (83%), Cyprinodontidae (48%), Atherinopsidae (45%), and Cyprinidae (40%) (Table 3.3). These species are often highly restricted endemics that are experiencing major declines in habitat quality due to a variety of water and land use changes. Atherinidae includes four Mexican endemics, all of which are threatened by habitat loss due to groundwater over-extraction, industrial pollution, solid waste, expanding tourism, and the introduction of non-native species. Mexico also contains two endemic lamprey species in the family Petromyzontidae, both of which are severely threatened by habitat fragmentation resulting largely from dam construction.

Table 3.3: Global IUCN Red List Status of Mexican freshwater fishes by taxonomic family.

Family	Total	EX	EW	CR	EN	VU	NT	LC	DD	% Threatened
Atherinidae	4			4						100%
Gobiesocidae	3			1		2				100%
Lacantuniidae	1					1				100%
Megalopidae	1					1				100%
Petromyzontidae	2			1	1					100%
Goodeidae	40	1	2	13	14	6		4		83%
Ictaluridae	6				1	3			2	67%
Percidae	6			2	1	1		2		67%
Salmonidae	12			3	5		3		1	67%
Fundulidae	10			1	3	1		5		50%
Cyprinodontidae	33	3	3	2	5	9	3	7	1	48%
Atherinopsidae	38	1		6	8	3		9	11	45%
Cyprinidae	77	7	1	7	17	7	6	23	9	40%
Heptapteridae	8			1		2	1	4		38%
Characidae	18			1	1	4	1	9	2	33%
Rivulidae	3				1			1	1	33%
Synbranchidae	3				1			2		33%
Profundulidae	8				1	1		2	4	25%
Catostomidae	18					3		9	6	17%
Cichlidae	50				5	2	1	27	15	14%
Poeciliidae	86		2	2	7	3	2	32	38	14%
Gobiidae	21					1		19	1	5%
Achiridae	5							5		0%
Anablepidae	1							1		0%
Ariidae	5							3	2	0%
Batrachoididae	4							4		0%
Belonidae	4							4		0%
Blenniidae	1							1		0%
Bryconidae	1							1		0%
Carangidae	5							5		0%
Centrarchidae	5							5		0%

Table 3.3 (continued): Global IUCN Red List Status of Mexican freshwater fishes by taxonomic family.

Family	Total	EX	EW	CR	EN	VU	NT	LC	DD	% Threatened
Centropomidae	11							11		0%
Clupeidae	7							7		0%
Dactyloscopidae	1							1		0%
Dinematichthyidae	1						1			0%
Eleotridae	9							8	1	0%
Elopidae	1								1	0%
Embiotocidae	1							1		0%
Gasterosteidae	1							1		0%
Gymnotidae	2							2		0%
Haemulidae	1								1	0%
Hemiramphidae	7							5	2	0%
Lepisosteidae	4							4		0%
Moronidae	1							1		0%
Mugilidae	7							6	1	0%
Paralichthyidae	1							1		0%
Sciaenidae	1							1		0%
Syngnathidae	1							1		0%
Total species	**536**	**12**	**8**	**44**	**71**	**50**	**18**	**234**	**99**	**31%**

IUCN Red List Status: EX – Extinct, EW – Extinct in the Wild, CR – Critically Endangered, EN – Endangered, VU – Vulnerable, NT – Near Threatened, LC – Least Concern, DD – Data Deficient

3.4 Spatial distribution of species

3.4.1 Species richness

Species richness is a count of the number of species represented within sub-catchments and does not account for the relative abundance of species within those communities. The results of this project agree with earlier spatial analysis and broadly identify four major centers of richness (Contreras-MacBeath et al., 2014). The first center is located in southeastern Mexico, particularly within the Grijalva-Usumacinta, Coatzacoalcos, and Papaloapan river drainages, and including karst systems in the Yucatan Peninsula. This region contains a high diversity of fishes in the families Cichlidae and Poeciliidae.

The second center of richness occurs on the Pacific slope of central Mexico, primarily within the Lerma-Santiago river drainage. This center also includes lakes Pátzcuaro, Cuitzeo, and Chapala, which contain a high number of endemic freshwater fishes (Mercado-Silva et al., 2006). The family Goodeidae is the most diverse group of freshwater fishes here, with approximately 25 reported species (Domínguez-Domínguez et al., 2006).

Northern Mexico exhibits high species richness throughout the Bravo and Conchos river drainages. Richness is especially high in the Bravo River delta and the Laguna Madre, where coastal ecosystems and oftentimes brackish conditions provide suitable habitat for a number of peripheral fish species (Contreras-MacBeath et al., 2014). The families Cichlidae and Poeciliidae contain the highest diversity of freshwater fishes in this region (Contreras-MacBeath et al., 2014).

3.4.2 Distribution of threatened species

The highest concentrations of threatened freshwater fishes are found (1) within the Lerma and Santiago River drainages in Central Mexico, including species that occur within lakes Pátzcuaro, Cuitzeo, and Chapala, (2) in coastal regions along

Figure 3.4.1: The distribution of freshwater fish species across Mexico

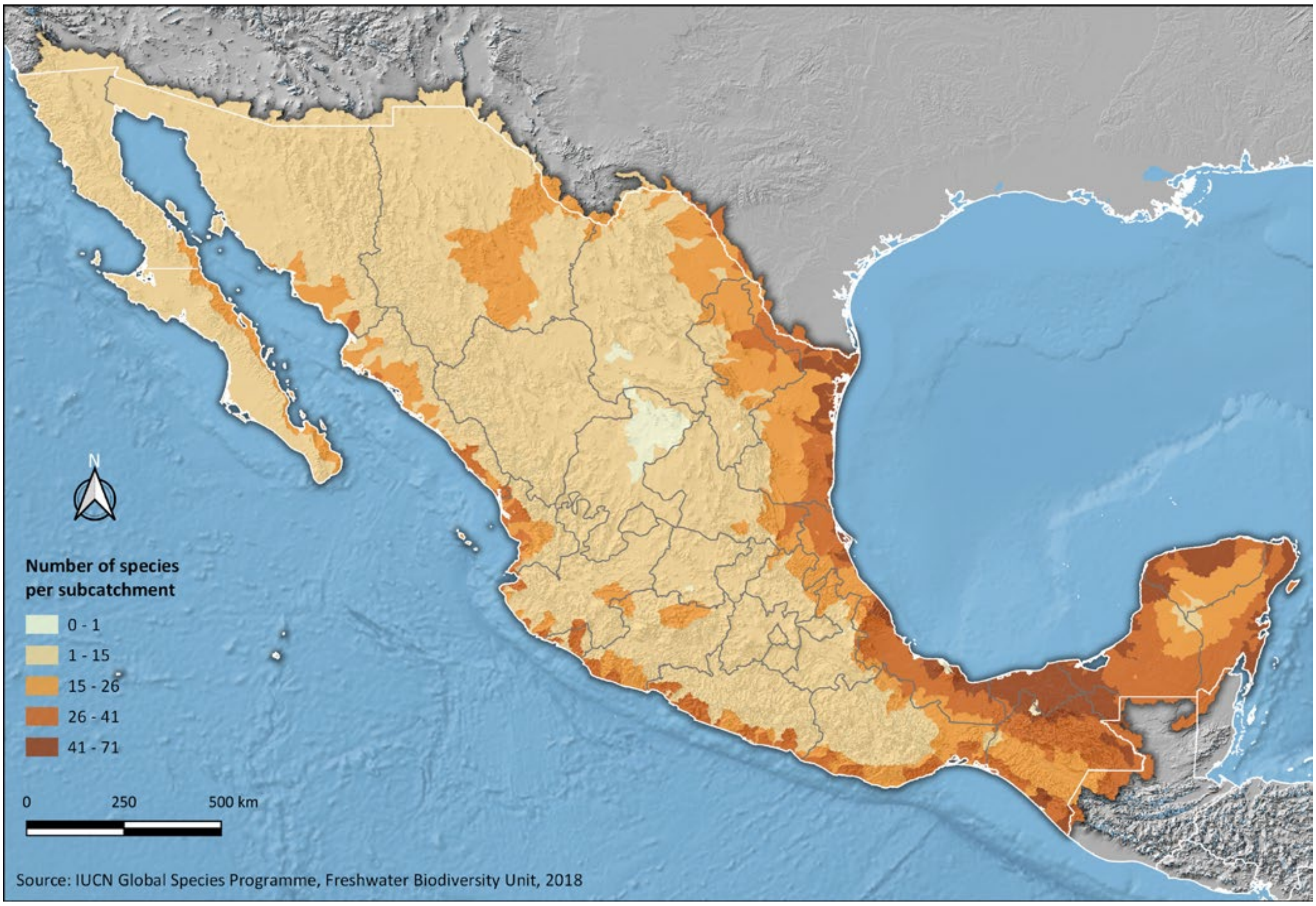
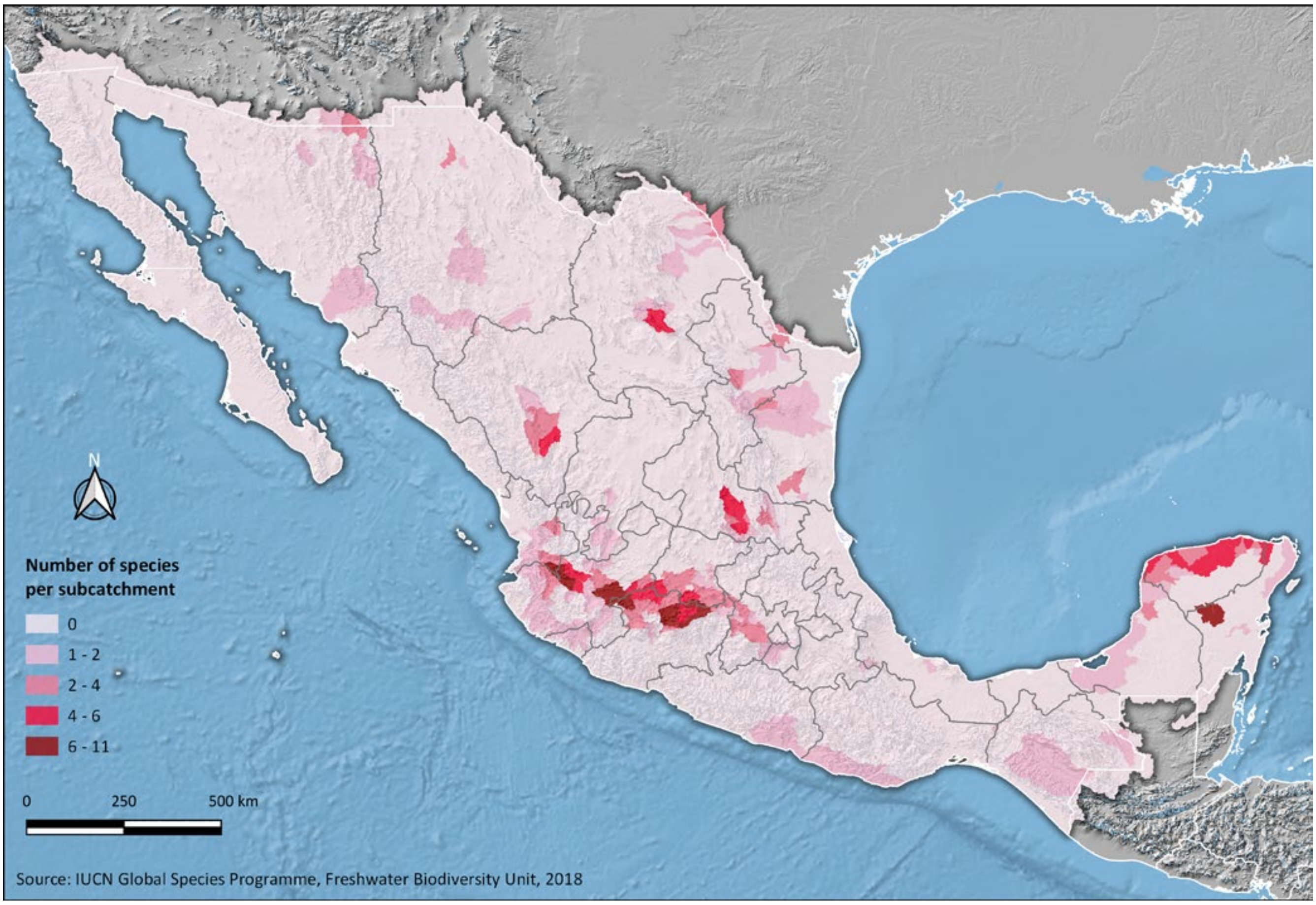


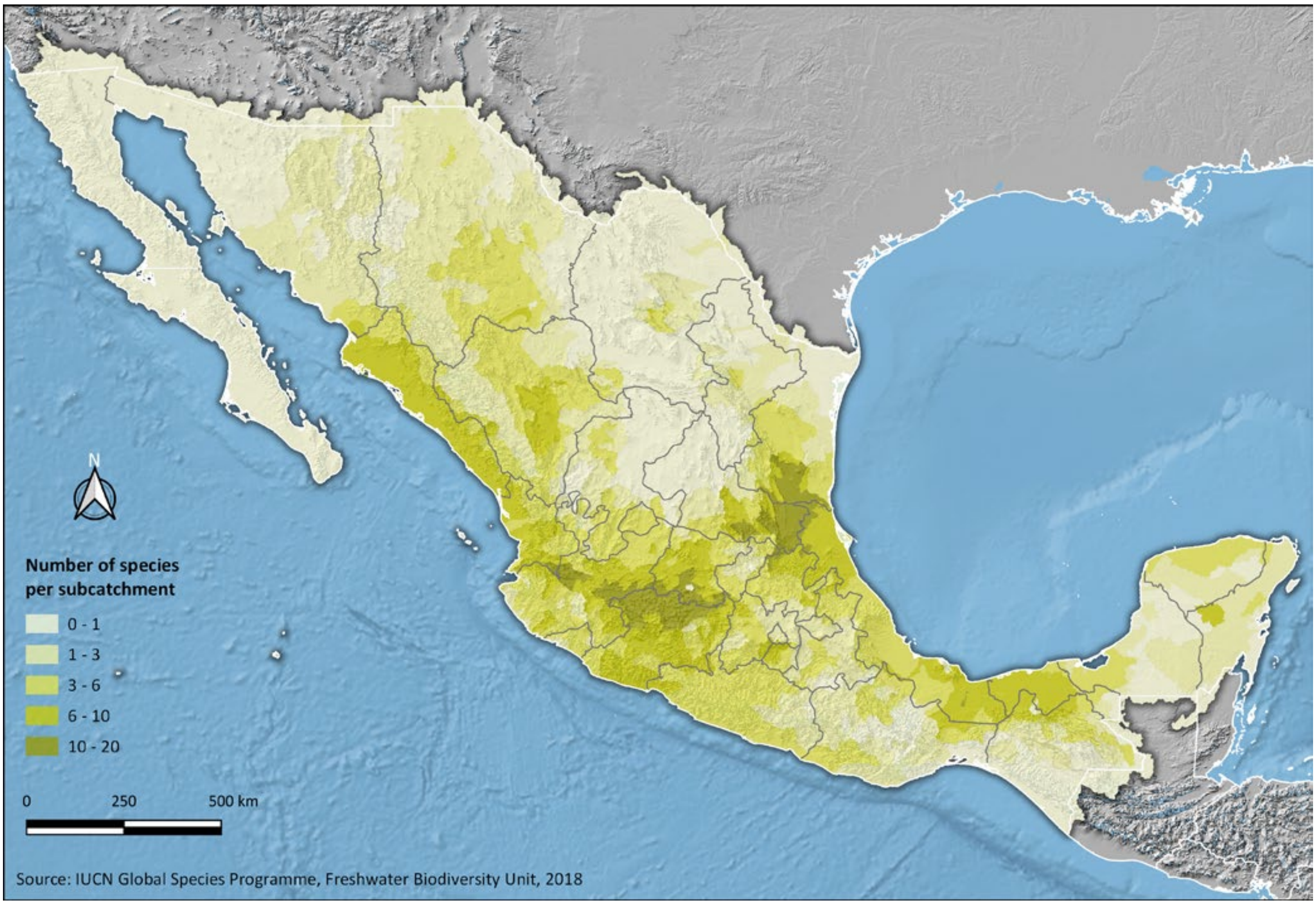
Figure 3.4.2: The number of threatened freshwater fish species within each sub-catchment across Mexico.



the Yucatan Peninsula, with a particularly high number of threatened species on the northern coast of the State of Yucatan and in Lake Chichancanab in the central Yucatan Peninsula, (3) in endorheic watersheds in northern Mexico, with specific mention of Cuatro Ciénegas in the State of Coahuila, (4) in headwaters of the Pánuco River drainage, including the upper Verde River and La Media Luna in the State of San Luis Potosí, and (5) in the headwaters of the Mezquital River in Central Durango.

In the Lerma and Santiago River drainages, pollution from agricultural runoff is a major pervasive threat that has resulted in decreases in the quality and availability of aquatic habitat (Sedeño-Díaz & López-López, 2007; Carrera-Hernández, 2017) and ultimately the collapse of several commercially important fisheries (Moncayo-Estrada et al., 2012). In the Yucatan Peninsula, the primary drivers of extinction risk include urbanization, excessive groundwater abstraction, and pollution from municipal and agricultural sources (Kane, 2016; Deng et al., 2017). Endorheic watersheds in northern Mexico are experiencing considerable habitat loss resulting from groundwater abstraction (Torres-Vera et al., 2012). Groundwater extraction and surface water diversion associated with agricultural activities in the headwaters of the Pánuco and Mezquital river drainages are primary stressors on threatened freshwater fishes in these regions (Dinerstein et al., 2001).

Figure 3.4.3: The number of endemic freshwater fish species within each sub-catchment across Mexico.



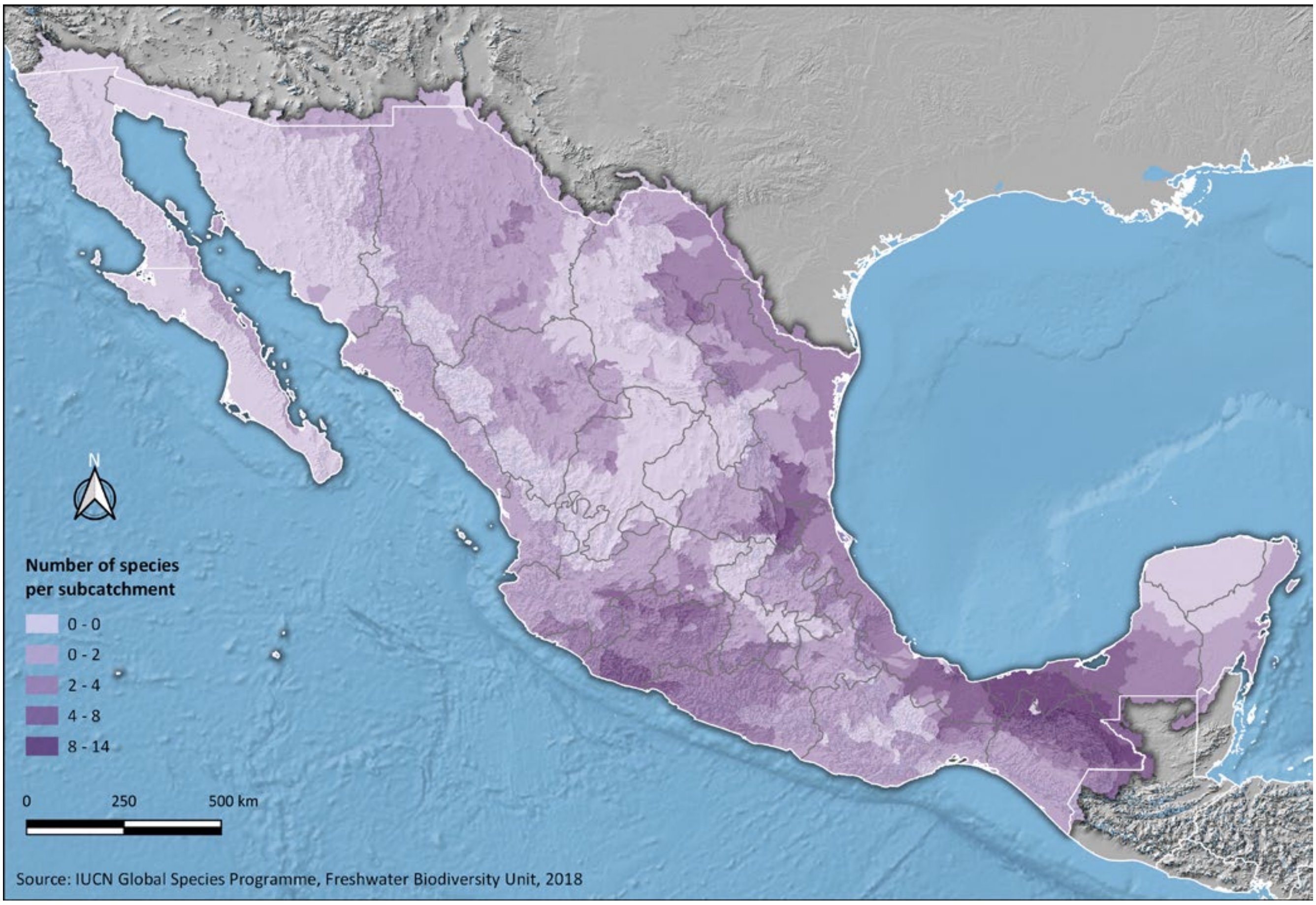
3.4.3 Endemic species richness

Endemism refers to species that only occur in Mexico. Moderately strong regions of endemism occur in the Lerma-Santiago River drainage on the Pacific versant, and the Pánuco and Grijlava-Usumacinta river drainages on the Atlantic versant. Specific mention is given to Cuatro Ciénegas in central Coahuila, a complex series of marshes, lakes, streams, and geothermal features that contains one of the highest numbers of endemic species in North America (Souza et al., 2006). Many freshwater fishes in Mexico are characterized by highly restricted, single site distributions (Contreras-MacBeath et al., 2014).

3.4.4 Distribution of Data Deficient species

The highest number of Data Deficient freshwater fish species (e.g., those species for which there is not enough data to assess them against the IUCN Red List Categories and Criteria) occur on the northern Atlantic border of Mexico, in the Lerma and Santiago drainage basins on the central Pacific versant, in the Pánuco drainage basin on the central Atlantic versant, and in the Grijalva-Usumacinta river drainages in southern Mexico. With regard to the north Atlantic coast and the Pánuco drainage basin, ichthyological study is typically cost-prohibitive and logistically challenging, given their remoteness, lack of major roads, and potential danger to scientists. High levels of data deficiency in the Lerma and Grijalva-Usumacinta drainages are likely an artifact of the sheer richness of their ichthyofaunas. Considering the relative proportions of threatened taxa in Mexico, many of the species that are currently assessed as Data Deficient are likely to fall into a threatened category. The high levels of uncertainty regarding these species clearly represent important and timely areas of further study.

Figure 3.4.4: The number of Data Deficient freshwater fish species in each sub-catchment across Mexico. Map includes only those species with distribution information that could be mapped.



3.5 Major threats to freshwater fishes in Mexico

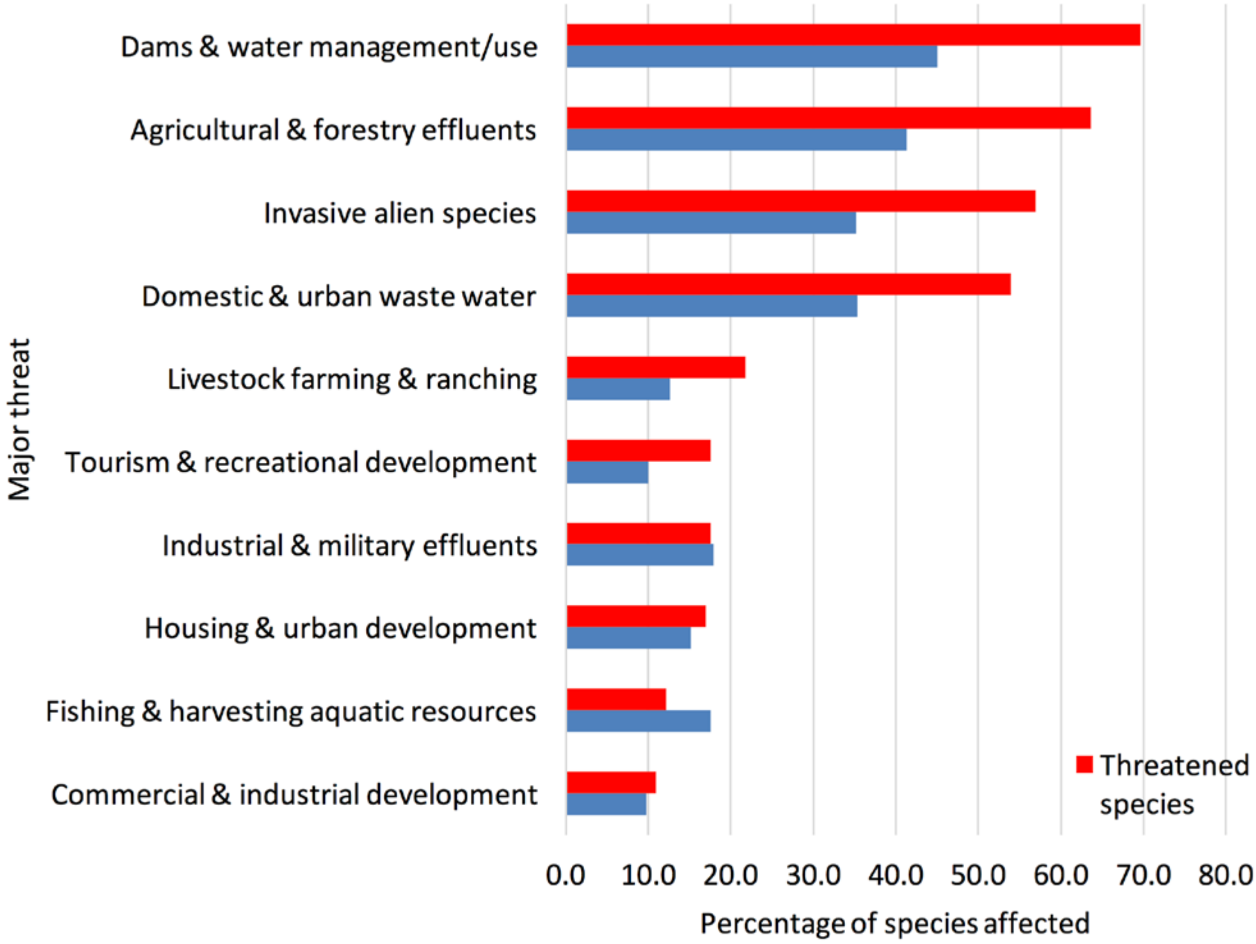
The major threats affecting each species were coded using the IUCN Threats Classification Scheme (Salafsky et al., 2008) (https://www.iucnredlist.org/resources/classification-schemes).

Natural system modification, including the development of hydraulic and hydropower infrastructure, diversion of surface water, and abstraction of groundwater to supply domestic, industrial, and agricultural activities is a threat to nearly half (45.0%) of all freshwater fishes in Mexico, and is a major threat to 69.7% of threatened species. A number of major dams have been constructed throughout Mexico's water courses (CONAGUA, 2018). Unsustainable agricultural practices (Bunge, 2010a), increased water demand resulting from expanding human development, and the associated depletion of underground aquifers have had severe impacts on the integrity of natural hydrological regimes in Mexico. Such changes often have profound consequences on freshwater habitat availability, sustainability, and quality (Small et al., 2009), and on species reproductive success (Olden et al., 2006).

Pollution is a major contributing threat to many species, and occurs widely throughout much of Mexico. The effects of pollution are particularly evident in the Lerma-Chapala basin (IMTA, 2009; Carrera-Hernández, 2017), which feeds Lake Chapala, the largest freshwater body in Mexico (Moncayo-Estrada et al., 2012). Agricultural and forestry effluents affect 41.3% of all species and 63.6% of threatened species, domestic and urban wastewater affects 35.4% of all species and 53.9% of threatened species, and industrial effluents affect 18.0% of all species and 17.6% of threatened species. Solid waste pollution is a major threat to just 3.3% of all species and just 4.8% of threatened species, though this is suspected to be more severe in habitats near urban and rural development (Sedeño-Díaz & López-López, 2007; Medina, 2011; Durán Moreno et al., 2013).

The introduction, establishment, and spread of non-native species is a primary driver of global biodiversity loss (Simberloff et al., 2013), and freshwater aquatic ecosystems

Figure 3.5: Major threats to freshwater fish species in Mexico.



are no exception (Gozlan et al., 2010; Vörösmarty et al., 2010). There are documented instances of 115 non-native fishes in Mexico (Contreras-Balderas et al., 2008). When introduced species establish outside of their range and begin to negatively impact native species assemblages, the term 'invasive' is used (Simberloff et al., 2009). Invasive species threaten 35.2% of all Mexican freshwater fishes, and are one of the main factors contributing to the decline of 57% of native threatened species.

Many species of freshwater fishes are targeted in artisanal and commercial food fisheries, which serve as major sources of protein for local communities and generate revenue that supports the livelihoods of local fishermen (Lyons et al., 1998; Inda-Díaz et al., 2009; Mendoza-Carranza et al., 2013). However, many fisheries employ gillnets, trawls, and other fishing gear types that do not select at the species level, resulting in major fisheries that include groups of species (Lyons et al., 1998) which are managed as a combined fishery (SAGARPA, 2015). Based on data compiled on the species assessed during this project, at least 76 individual species are targeted by the ornamental aquarium industry, but total

Plantation agriculture, including that for pineapple and sugar production, presents additional stressors to aquatic habitat and water availability. © Adalberto Ríos Szalay offtake is difficult to estimate because collection is largely unregulated. At least 23.9% of Mexican freshwater fishes are included in subsistence fisheries, 18.3% are included in local commercial fisheries, 26.5% are nationally important, and 14.6% are internationally important. Approximately 17.6% of all species assessed and 12.1% of threatened species assessed are affected by fishing and harvesting of aquatic resources.

Purépecha fishermen on Lake Pátzcuaro in Michoacán use artisanal canoes and traditional fishing nets to target pescados blancos (Atherinopsidae). © Adalberto Rios Szalay

A number of additional, less pervasive threats have been identified by assessors as having negative effects of freshwater fishes, including urban development (15.2% of all species and 17.0% of threatened species), livestock farming and ranching (12.6% of all species and 21.8% of threatened species), tourism and recreational development (10.0% of all species and 17.6% of threatened species), commercial and industrial development (9.8% of all species and 10.9% of threatened species), recreational activities (9.1% of all species and 23% of threatened species), and agriculture of non-timber crops (7.6% of all species and 15.8% of threatened species). These widely varied threats act on local and regional scales, and their impacts on native freshwater fish biodiversity vary in magnitude.

Overall, it is clear that Mexico's native and largely endemic freshwater fish fauna has been dramatically impacted by humans. Pronounced, concerted efforts from a broad range of stakeholders will be required to reverse this trend amidst an ever-expanding human population, rapid urbanization, and an increasingly intense reliance on the land-freshwater interface for food, energy, transportation, and industry.

3.5.1 Dams and other natural system modifications relating to water management/use

Dam construction and natural system modifications for irrigation purposes are two of the main threats to the freshwater fishes of Mexico. According to the International Commission on Large Dams, Mexico contains approximately 5,000 dams and water retention berms, 180 of which are classified as large (with a height of 15 metres or greater from the lowest foundation to the crest or an impoundment of greater than 3,000,000 m^3) (ICOLD, 2011; CONAGUA, 2018). This figure is undoubtedly an underestimate, given the exclusion of a large number of smaller retention ponds and reservoirs from national statistics. Comparably, the entire African continent contains a total of 1,207 dams, 135 of which are considered large (Darwall et al., 2011). Dams that are constructed for irrigation purposes (e.g. the Ricardo Flores Magón Dam located on the Río Verde, Oaxaca) are typically small, and some connectivity can remain during the rainy season, allowing small fish to pass over them. However, sediment pattern alteration and lateral berms downstream of the main structure often reduce the quality of downstream habitat.

Construction of large hydropower dams can have considerable impacts on freshwater habitat quality immediately downstream (Graf, 2006; Gómez-Balandra et al., 2012). The channelization of water as it enters the dam structure and the force of discharge as it exits releases a large amount of suspended material into the water column, resulting in sedimentation, reduced visibility, and reduced dissolved oxygen. Large dams can exceed 100 m in height and reservoirs can extend for 60 km or more upstream.

These structures are major barriers to upstream, downstream, and lateral fish migration, resulting in fragmented populations, reduced reproductive success in species that migrate upstream to spawn, and mortalities associated with injuries sustained from blunt trauma when migrating over dam structures (Pelicice et al., 2015).

Dam cascade systems drastically alter riverine habitat. One such example is La Yesca Dam, El Cajón Dam, and Aguamilpa dams on the Río Grande de Santiago, which have collectively converted over half of the 520 km long river into reservoirs. Aquaculture and fishing are popular in these large reservoirs, resulting in the intentional introduction of non-native species (e.g., Cichlidae and Centrarchidae) through government-sponsored aquaculture cooperatives. Additionally, the intermittent release of large volumes of water

Water exiting the Ricardo Flores Magón Dam on the Río Verde results in increased water turbidity, erosion and sedimentation downstream. © Jorge Izurieta & Pilar Saldaña

causes downstream erosion.

Dam construction is not limited in use to hydropower development. As urban populations rise and water demand increases, aquifers that once provided drinking water for large cities are rapidly depleting (Scott, 2011). As a result, the construction of large dams to support reservoirs have been proposed in the Río Verde (a tributary of the Río Grande de Santiago) to enhance water security in the states of Guanajuato and Jalisco. Dam construction continues unabated in a number of major river drainages and for a variety of purposes.

Another important driver of biodiversity loss is water stress resulting from human use, which is concentrated in the Lerma-Chapala basin, where some 45 million people rely on surface and groundwater for waste disposal, food production,

Damming for agricultural irrigation is common in many smaller rivers and streams in Mexico (Presa Cayehuacán Puebla/Morelos). © Topiltzin Contreras-MacBeath

Fish mortalities in the Río Grande de Santiago due to construction associated with the completion of La Yesca Dam. © Carlos Lecanda, Alejandro Ordoñez & María Antonieta Gómez Balandra.

and everyday use. Water stress is also particularly evident in the arid regions of Mexico such as Mesa del Norte, where the little existing water is typically reserved for agricultural and livestock production (Bunge, 2010a, 2010b). More than two decades ago, Contreras-Balderas & Lozano-Vilano (1993) identified 92 springs and 2,500 linear km of river habitat that had completely dried in this region. The loss of surface water and aquatic habitat resulting from human water use in this region, which includes the species-rich Bravo-Conchos basin that hosts 122 species of freshwater fishes is highly alarming (Contreras-MacBeath et al., 2014).

Several non-native species have been introduced into the Río Grande de Santiago and Bolaños (tributary) rivers to support local fisheries and aquaculture, including *Oreochromis aureus* (top left), *Micropterus salmoides* (top right), *Lepomis macrochirus* (bottom left), and *Oreochromis niloticus* (bottom right). © Alejandro Ordoñez & Maria Antonieta Gómez

In the Río Bravo basin, water extraction for agricultural and domestic uses, the Falcón and Amistad dams, and many other reservoirs upstream in both the U.S. and Mexico are major drivers of natural flow regime disruption, which has consequently affected the integrity of freshwater ecosystems (Small et al., 2009). The Río Bravo had a runoff of over 12,000 million m3/year in 1962 that declined precipitously to less than 2% of that by 2002 and was dry for months in the coastal delta floodplain in 2002 and 2004 (Contreras-Balderas et al., 2008). Ichthyological surveys have demonstrated that freshwater habitat in the lower reaches is much reduced, and many of the original freshwater fish fauna's species have been replaced by brackish and marine invaders (Contreras-Balderas et al., 2002). A similar situation can be observed in the Río Conchos, the main tributary of the lower Río Bravo. In recent years, increased water demand and low irrigation efficiencies in that basin combined with more severe drought conditions to promote competition for water resources in both Mexico and the United States (Ingol-Blanco & McKinney, 2010). The resulting impacts on freshwater fish abundance and diversity have been severe (Edwards et al., 2002).

One of the most evident examples of human-induced natural flow modification can be seen in the Colorado River system, which harbors approximately 100 dams and water diversions, including 11 in the main river channel and in its main tributary the Green River, many of which are in place north of the US-Mexico border (Adler, 2007). In recent years, the demand for water has been so severe that the Colorado delta, the only portion of the river in Mexico, has only sporadically received freshwater input. As a result, the estuary that historically supported a diverse freshwater fauna has been converted into a highly saline water body that supports considerably fewer freshwater species (Carriquiry et al., 2011). This loss of freshwater habitat has resulted in the extirpation of several freshwater species (Torres-Orozco & Pérez-Hernández, 2011), including *Gila elegans* and *Rhinichthys osculus*, two historically widespread and abundant species that are now regionally extirpated from the Mexican portion of the basin. The Colorado pikeminnow *Ptychocheilus lucius* was once a widespread apex predator and the largest cyprinid endemic to the Colorado River that could grow to 1.8 m and 36 kg, but human-induced flow modifications have caused it to be extirpated from its historical Mexican range (Miller, 1961).

***Priapella olmecae* (EN) is endemic to a small number of streams north of Catemaco Lake, near the town of Playa Agua Fria in Veracruz, Mexico. A primary threat to this species is pollution associated with construction projects within the watershed.** © Juan Carlos Merino

Perhaps the most extreme example of water use and its impact on endemic species richness is demonstrated by El Potosí and Ojo de Agua la Presa in Bolsón de Sandia (Contreras-Balderas & Lozano-Vilano, 1996), two springs that once existed in the endorheic basins of southwestern Nuevo León. Unsustainable agricultural practices and livestock production quickly destroyed the underlying aquifer and the surface springs dried, ultimately leading to the extinction or extinction in the wild of six endemic species *Cyprinodon alvarezi*, *Megupsilon aporus*, *C. veronicae*, *C. longidorsalis*, *C. inmemoriam* and *C. ceciliae* (Contreras-Balderas & Lozano-Vilano, 1996).

3.5.2 Pollution

Pollution is a global, human-induced problem that impacts most of the world's water courses, often resulting in a species reduction or total loss of native fish communities and other aquatic organisms. Unsustainable industrial, domestic, and agricultural activities can produce levels of pollution that are catastrophic to fish diversity, resulting in dead rivers and lakes (Richter et al., 1997). One of the most severe environmental problems in Mexico is related to freshwater pollution associated with the lack of wastewater treatment (Perevochtchikova, 2010). A National Water Commission (CONAGUA) report in 2018 found that only 63% of municipal and 38% of industrial wastewaters were treated, and of those few outfalls that were treated, 64% discharge directly into adjacent lakes, lagoons, and coastal waters, which often contain suspended solids and pathogens that exceed national standards and further pollute aquatic systems (Bunge, 2010c).

Widespread pollution impacts approximately 80% of Mexico's hydrological basins to varying degrees. However, the most extreme cases are the Pánuco, Lerma-Santiago, San Juan, and Balsas rivers, which receive 50% of all of the country's residual water discharges (Torres-Orozco & Pérez Hernández, 2011). The most polluted aquifers are in the "Comarca Lagunera", the Valley of Mexico, the Bajío region, and the Mezquital Valley, and all are primarily the result of leachate pollution from agriculture. Severe cases of surface water pollution occur in the Mesa Central and more specifically in the Lerma-Chapala complex (IMTA, 2009), as well as in tributaries in the highlands of the Balsas and Pánuco rivers (CONAGUA, 2018). There is extensive documented aquatic ecosystem alteration due to pollution in these regions that spans decades (Bernal-Brooks, 1998; Fisher et al., 2003; von Bertrab, 2003; Cotler et al., 2006; Sedeño-Díaz & López-López, 2007, Flores López et al., 2012; Brito et al., 2015; Ontiveros-Cuadras et al., 2019), as well as documentation of resulting impacts on freshwater fish abundance and diversity (Soto-Galera et al., 1991, 1998, 1999; Lyons et al., 1995, 1998, 2000, 2019; Contreras-MacBeath et al., 1998; Mercado-Silva et al., 2002, 2006, 2009; Méndez–Sánchez et al., 2002; Domínguez-Domínguez et al., 2005, 2006, 2008; Contreras-MacBeath, 2005; De la Vega-Salazar,

Many of Mexico's karst ecosystems are not easily accessible by the public, or are privately managed by restricted-access ecotourism companies. Despite limited access, the connectivity of these systems leave them vulnerable to pollution, groundwater abstraction, and saltwater intrusion © Río Secreto

2006; Magurran, 2009; Ornelas-García et al., 2012; Torres-Olvera et al., 2018). Cumulatively, these sources conclude that pollution in lentic and lotic freshwater systems is one of the main threats to approximately 100 Mexican freshwater fish species, and a primary driver of localised extirpation in many cases.

Some critical examples of this situation include: *Algansea barbata*, a historically abundant species from the headwaters of the Río Lerma, thought to be extinct but rediscovered in 2000 at one site in close proximity to a fish farm (Figueroa-Lucero & Ontiveros-López, 2000); *Chirostoma riojai*, also from the upper Lerma, extirpated from 85% of its natural range primarily due to pollution (Soto-Galera & Alcántara-Soria, 2007; Méndez-Sánchez et al., 2008); and *Allotoca dugesii*, originally considered one of the most widely distributed species in the Lerma basin, but currently found in 50% of its original range (Díaz-Pardo, 2002). In a study by Domínguez-Domínguez et al. (2008), four out of 41 species of studied Goodeids were extirpated from all historical sampling localities. Declines in historical range for the remaining Goodeids ranged from 80-99% (three species), 60-79% (11), 40-59% (10), 20-30% (9), and 0-20% (4). Additionally, *Notropis boucardi* from the upper Balsas drainage in the state of Morelos disappeared from 60% of its native range due to the growth of the city of Cuernavaca and associated pollution of adjacent stream habitat (Contreras-MacBeath & Rivas, 2008), and subsequently has become the flagship of an important restoration project led by the federal government (CONAGUA, 2008).

Perhaps the best-documented example of the impact of pollution on fish communities in Mexico is the demonstration by Soto-Galera et al. (1999) that pollution was the primary factor that drove *Chirostoma charari* to extinction, and was a major factor in the localised extirpations of *N. calientis*, *N. sallaei* and *Hubbsina turneri*.

Drilling activities in coastal waters of the Gulf of Mexico account for 78% of Mexico's oil extraction, with the remaining 22% coming from states rich in oil deposits such as Tabasco and Chiapas. These activities, in addition to sulphur extraction and petrochemical production, have had documented impacts on both coastal-marine and freshwater

In some areas of Mexico, untreated urban wastewaters are discharged directly into freshwater ecosystems © Elizabeth González

ecosystems (De la Maza & Bernárdez, 2003). Botello (1996) conducted a study to evaluate metal concentration in freshwater fishes in Laguna "El Yucateco", Tabasco, finding that the concentration of lead in *Parachromis friedrichsthalii* (LC) was 15.68 µg g–1, over six times higher than the national-permitted concentration for human consumption (2.5 µg g–1). In the same study, concentrations of cadmium, chromium, lead and nickel in *P. friedrichsthalii*, *Vieja bifasciata* and *Mayaheros urophthalmus* also exceeded permitted safe consumption thresholds. The introduction of heavy metals and their incorporation into tissues presents a potential risk to local subsistence, artisanal, and small-scale commercial fisheries that target these species as food items.

3.5.3 Invasive species

Non-native species introductions are among the most important, least controlled, and least reversible of human impacts, with profound impacts on biodiversity, biogeochemistry, and economic value at the ecosystem level (Strayer, 2010). This is particularly true in freshwater habitats already under stress from the combined effects of water scarcity, pollution, and habitat modification, partly because non-native species are more likely to successfully establish in disturbed areas (Dudgeon et al., 2006). Introductions in aquatic systems can be intentional (e.g., stocking for aquaculture or the introduction of predatory species for recreational fishing) or incidental, (e.g., escape from aquaculture facilities or introduction via shipping ballast water) (Zambrano et al., 2006). In Mexico, non-native species have been introduced through a wide variety of pathways (Contreras-MacBeath et al., 1998; Contreras-Balderas et al., 2008). For example, intentional stocking programmes of non-native food fishes to promote subsistence fisheries are actively promoted in man-made reservoirs (Meléndez, 2019).

In 1904 only 4 non-native fish species had been documented in Mexico, 7 were found in 1969, 55 in 1983, 94 in 1997, 115 in 2008 (Contreras-Balderas et al., 2008), and 118 in 2009 (Aguirre et al., 2009). As a result, interest in invasive species and their impacts on native fish communities has rapidly increased and recently spurred the development of the National Invasive Species Strategy (Comité Asesor Nacional sobre Especies Invasoras, 2010) and comprehensive works on freshwater invasion ecology (Mendoza & Koleff, 2014). There are between 104-118 non-native fishes established in Mexico (Contreras-Balderas et al., 2008; Aguirre et al., 2009; Espinosa-Pérez & Ramírez, 2015; Gesundheit & Macías Garcia, 2018), with rapid increases noted in recent years as the result of national stocking programmes, lack of management, and poor enforcement or regulations (Ochoa-Ochoa et al. 2019). Contreras-Balderas (1999) records at least 76 native species of fishes that are directly impacted by invasive species, though this is almost certainly an underestimate given the age of the study and continued non-native species introductions.

Conclusive documentation of the direct negative effects of invasive species on native fishes is not easily obtained, and has often promoted intense debate (Gurevitch & Padilla, 2004; Clavero & Garcia-Berthou, 2005; Valero et al., 2008; Camacho-Cervantes et al., 2014; Gesundheit et al., 2018). However, a number of studies have identified the impacts of tilapia (*Oreochromis* spp.) in many regions of the world (Canonico et al., 2005). In Mexico, five species of *Oreochromis* and one hybrid have been introduced (Aguirre et al., 2009). One of the best documented cases of impact of these fishes in a natural system is that described by Strecker (2006) in Laguna Chichancanab, where an increase in parasite loads on the endemic *Cyprinodon* species flock followed introduction of non-native fishes. She also documents the disappearance of the large schools (50-1000 individuals) of *C. simus* that were seen in 1981, suggesting that the possible cause of population decline was the result of competition with juvenile *Oreochromis* for zooplankton. This study also suggests that the reduction in the size of *C. maya* may be due to the reduction of ostracods, resulting from the death of *Chara* vegetation due to bioturbation and deposition of large amounts of feces produced by *Oreochromis*. It is important to mention that the invasion of the Lake by the transplanted Mexican native *Astyanax bacalarensis* has also impacted the native *Cyprinodon* species flock.

Another example related to the introduction of tilapia is that of *Fundulus lima*, a species endemic to a series of oases in Baja California, where four non-native species are established, *Cyprinus carpio*, *Poecilia reticulata*, *Xiphophorus hellerii*, and *Tilapia cf. zillii* (Ruiz-Campos et al., 2006), with the last noted to have had particularly dramatic impact on the *Fundulus*. Finally, we note the possible extinction in nature of *Allotoca goslinei*, which has not been collected since 2004 (Helmus et al., 2009). This is apparently a consequence of the introduction of *X. helleri* in 2002-2004, which has since replaced it throughout its range.

More recently, the establishment and spread of armoured catfish *Pterygoplichthys* spp. (plecos) have had major impacts on native biodiversity. In the lowlands of Tabasco and Chiapas, plecos have had negative impacts on artisanal and commercial fisheries (Amador del Ángel & Wakida-Kusunoki, 2014), and their introduction has altered nutrient dynamics, primarily by remineralising organic nitrogen (Capps & Flecker, 2013). One of the potential mechanisms of impact is ingestion of native cichlid eggs, which spawn on depressions in the bottom of lakes and streams (Nico, 2010).

***Pterygoplichthys* spp. now comprise a large relative abundance of freshwater fish biomass in Tabasco and Chiapas.** © Topiltzin Contreras-MacBeath

3.5.4 Overfishing and aquatic resource use

Despite the challenge of evaluating the effects of fishing due to complex system responses and the presence of other pressures, there is ample evidence that overfishing is a significant factor in the decline of species abundance and fishery productivity (Allan et al., 2005).

Uncertainty regarding fishery population status in 56 (86%) of 65 large Mexican lakes and reservoirs (Naranjo & Dirzo, 2009) and lacking information regarding fisheries in large river systems have resulted in a limited number of well-documented examples of overfishing impacts on Mexican freshwater fishes. Interpretation of government-reported fisheries statistics is problematic due to the amalgamation of fisheries into species groups, rather than single species. Additionally, most available statistics address introduced species groups such as *Oreochromis* and *Tilapia* that are intentionally stocked to improve subsistence and artisanal fisheries (Contreras-Balderas et al., 2008).

One the best-known and well-studied inland fisheries in Mexico is that of Lake Pátzcuaro, located in the central highlands of the country. Since long before the Spanish conquest of Mexico, this 97.5 km^2 lake has been intensively fished for eight native species, and recently four exotics were incorporated into the fishery (Orbe-Mendoza et al., 2002). Native species in the fishery include four endemic *Chirostoma* in the family Atherinopsidae, with "pescado" (*C. estor*) being the largest and most valuable, and three other species (*C. grandocule*, *C. patzcuaro* and *C. attenuatum*) usually caught and marketed together as "charales". Three species of Goodeidae also contribute to the fishery: the "tiro" *Goodea atripinnis*, the "chegua" *Alloophorus robustus*, and the "choromu" *Allotoca diazi*, as does a species of Cyprinidae, the "acúmara" *Algansea lacustris*. In 1981, total landings of all species were estimated at 737 metric tonnes. Landings and fishing effort grew steadily until 1988, when yield peaked at 2,524 metric tonnes. Since then, landings have dropped precipitously to a low of 392 metric tonnes in 1998. Declines in catch appear to be largely due to overfishing, although habitat loss and reduced water quality from sedimentation and eutrophication have also reduced fish populations to an extent that the three endemic *Chirostoma*, *A. lacustris* and *A. diazi* are considered threatened by The American Fisheries Society's Endangered Species Committee (Jelks et al., 2008), and the majority of which were assessed as threatened species in the present report. The introduction of *Micropterus salmoides* was also a factor, although this predator itself also declined due to habitat deterioration (Ramírez-Herrejón et al., 2014). Only *A. diazi* is considered threatened by the Mexican Environmental Authority (SEMARNAT, 2010), primarily due to political pressure from local fishermen who oppose the listing of these species to prevent the establishment of stricter fishing regulations. The Mexican Government has tried to regulate the fishery through the Mexican Fisheries Authority (Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación) by means of the legal instrument "Carta Nacional Pesquera" (SAGARPA, 2006), but results have been limited due to a lack of enforcement and implementation.

A similar situation has been documented for the native *Chirostoma* of the largest Mexican lake, Chapala (1,100 km^2), where there are six species of "charales" (*C. jordani*, *C. chapalae*, *C. labarcae*, *C. arge*, *C. consocium*, and *C. contrerasi*) and three "pescados blancos" (*C. lucius*, *C. sphyraena*, and *C. promelas*). During the 1930s, the Chapala fishery was estimated at 1,000 metric tonnes annually, with a sustained increase reaching its peak in 1981 at 17,700 metric tonnes. Continued overfishing, combined with habitat loss resulting from water extraction and pollution have since reduced annual harvest to 3,200 metric tonnes (SAGARPA, 2004). The charales fishery in Lake Chapala was so reduced by 2000 that fishery statistics failed to consider *Chirostoma* a main fishery (Rojas, 2005). Of all of Chapala's native species, only *C. labarcae* and *C. promelas* are considered threatened by the Mexican Environmental Authority (SEMARNAT, 2010).

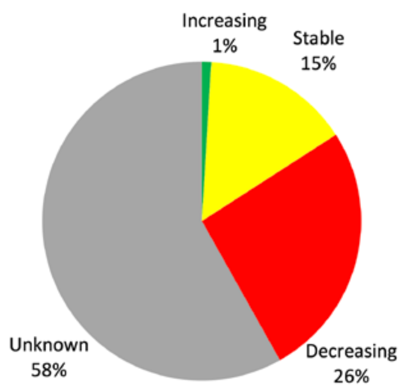
Inhabitants rely heavily on Coatetelco Lake in Morelos to provide drinking water, income through fishing, and agricultural irrigation. © Conservation International

3.6 Population trends

Population trends are key indicators of species conservation status. It provides critical information on the magnitude of threats, and can be used to identify species and regions that are priorities for conservation planning and action.

Of the 516 species for which population trend was evaluated (20 species were omitted because they are already Extinct or Extinct in the Wild and therefore do not have a measurable population trend), 134 (26.0%) are considered to be in decline. Conversely, just 5 (1.0%) species are increasing, and 77 (14.9%) species have populations that are currently stable. The population trend of 300 species (58.1%) is currently unknown (Figure 3.5). This major data deficiency clearly highlights the need for more comprehensive population monitoring. Given the lack of information relating to population trends, the current estimation of decline is very likely an underestimate.

Figure 3.6: Population trend of Mexican freshwater fishes



Chapter 4

Existing conservation measures

Contents

4.1 Habitat protection

In Mexico, habitat protections have been designated primarily through the establishment of protected areas and Ramsar sites. Mexico´s National Protected Area Commission (CONANP) manages 182 marine and terrestrial protected areas. The total surface area of protected terrestrial habitat in Mexico sums to 25.3 million ha (CONANP 2019), an area larger than the entire United Kingdom. This is an important conservation effort that represents 11.1% of the nation's territory.

There are also 142 Ramsar sites in Mexico, which cover a total area of 8,657,057 ha (Ramsar, 2019). Many of these sites have been established within federal protected areas, 14 are also state and municipal protected areas, and 63 sites are protected under other modalities.

These conservation efforts have been effective in protecting many terrestrial species and habitats in Mexico (Dirzo et al., 2009; Figueroa et al., 2011; Halffter, 2011), but the results of the assessments presented here, in addition to the collated results of many published studies (Contreras-MacBeath, 2005; De la Vega-Salazar, 2006; Domínguez-Domínguez et al., 2006; Contreras-Balderas et al., 2008; García-Moreno et al., 2008; Jelks et al., 2008; Mercado-Silva et al., 2009; Pedraza, 2011; Hermoso et al., 2016), suggest that while protected areas have conferred some benefits for freshwater biodiversity, many species of freshwater fishes in Mexico are still at risk of extinction.

Ineffective protected areas for freshwater fishes arise primarily because most are designed and designated with a terrestrial focus (Saunders et al., 2002; Abell et al., 2007; Suski & Cooke, 2007; Lawrence et al., 2011; Williams et al., 2011), and even though many freshwater fishes are distributed in habitats within protected areas, there are rarely any species-specific conservation actions directed towards them (Contreras-MacBeath, 1997; Contreras-MacBeath, 2005; Pino-Del-Carpio et al., 2010). Additionally, freshwater habitats within protected areas often contain a number of established non-native species that are not actively managed, and protected areas often fail in preventing the impacts of upstream pressures within the park, given the connectivity of freshwater systems (Strecker, 2006; Ramírez-Herrejón et al., 2010; Mejía-Mojica et al., 2012; Contreras-MacBeath et al., 2014; García et al., 2014).

Poza Tío Cándido, a freshwater spring at Cuatro Ciénegas in Coahuila, Mexico. © Héctor Espinosa Pérez

There are few cases in Mexico where protected areas and Ramsar sites have specific actions intended at protecting freshwater fishes. One exception is the action plan that address the "Área de Protección de Flora y Fauna Cuatro Ciénegas" in the state of Coahuila (INE, 1999), which is a federal protected area and also a Ramsar site that has a management plan, including specific conservation directives towards the conservation of *Cyprinella xanthicara* (EN), *Etheostoma lugoi* (CR) and *Xiphophorus gordoni* (EN).

Another example of conservation action specifically directed towards freshwater fishes can be observed in the state of Chiapas, where the state protected area "Humedales Maria Eugenia" was designated in part for the conservation of *Tlaloc hildebrandi* (EN). Consequently, the management plan contains species-specific action items directed towards *T. hildebrandi* (SMAVeHN, 2011). Additionally, the state protected area "El Texcal" in the state of Morelos has promoted specific actions involving local communities directed towards the conservation of *Notropis boucardi* (EN) (González-Flores, 2012).

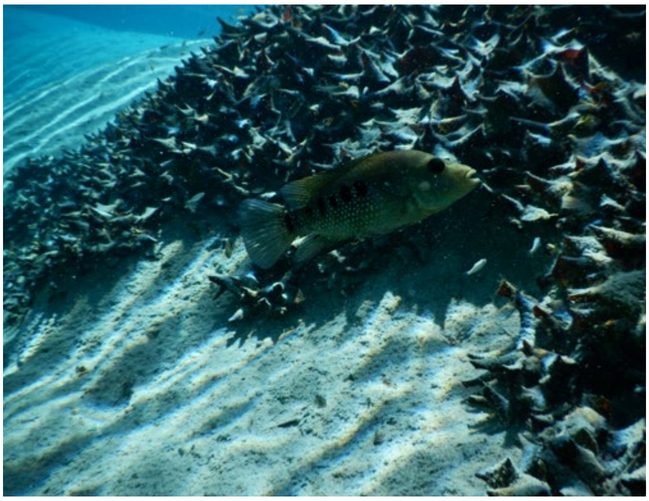
The Lacanjá River, flowing through Montes Azules Biosphere Reserve in Chiapas, Mexico. © Héctor Espinosa Pérez

4.2 Species-level protection

In Mexico, species level protection is typically designated under the General Wildlife Law (Ley General de Vida Silvestre, DOF 2018), the role of which is "to regulate and coordinate actions among Federal, State and Municipal governments in issues related to the conservation and sustainable use of wildlife and of its habitats within the Mexican territory". In Article 1, the General Wildlife Law states that species whose total lifespan is spent in aquatic habitat falls under the jurisdiction of forestry and fisheries laws unless the species is designated as threatened. As such, protections conferred by the General Wildlife Law are restricted to threatened freshwater fish species.

Federally threatened species in Mexico are designated by the "Norma Oficial Mexicana (NOM-059-SEMARNAT), Protección ambiental-especies nativas de México de flora y fauna silvestres". The latest version of the list (SEMARNAT, 2010) includes 2,556 Mexican threatened species, 204 of which are fish, and 188 of which are freshwater fish species.

The National Commission on Protected Areas (CONANP) is a federal commission responsible for implementing the Program for the Conservation of Species at Risk (PROCER). The main goal of this initiative is "to contribute to the conservation of threatened species and their habitats, promoting the collaboration of academic institutions and other partners". In order to achieve its mission statement, Species Conservation Action Plans (PACE) are developed as guidelines for conservation action. Currently there are 40 published PACE reports that deal with species or groups of species, but none of them specifically address freshwater fishes. In 2018, CONANP sponsored 101 conservation projects focusing on at least 48 species or groups of species. Two of these conservation projects focused efforts on the eradication of invasive armored catfishes in two separate protected areas. Funding was also allocated towards evaluating the current situation of Mexican freshwater fishes, but the results of this study have not yet been made public (CONANP, 2019).



***Herichthys minckleyi* (EN) in Poza La Becerra, Cuatro Ciénegas, Coahuila, Mexico. This species is endemic to Cuatro Ciénegas and is also listed as Endangered in the Norma Oficial Mexicana.** © Héctor Espinosa Pérez

More recently, the Mexican government established 10 Water Reserves (Reservas de Agua), adding to three existing reserves, that protect 300 unique drainage basins using environmental flow criteria (SEMARNAT, 2018). These new regulations apply environmental flow criteria to approximately 50% of Mexico's surface water, and directly benefit 82 protected areas and 64 Ramsar sites (WWF, 2018). The distribution of these Water Reserves generally coincide with the four centres of freshwater fish richness described for Mexico (Contreras-MacBeath et al., 2014). If properly managed, these new regulations have the potential to protect or improve the conservation status of over 450 freshwater fish species.

4.3 Fisheries regulations

Mexican fisheries legislation is federally designated by the General Sustainable Fisheries and Aquaculture Law (Ley General de Pesca y Acuacultura Sustentables), which defines regulatory guidelines for fisheries and aquaculture. From this general law, several technical standards or Norms (Normas) have been produced to regulate fisheries activities. For freshwater species, the technical standard NOM-060-SAG/PESC-2016 regulates fisheries activities in Mexican continental freshwaters for 57 native species belonging to 19 families, including specific fisheries regulations for *Algansea lacustris* (CR), *Yuriria alta* (EN), and *Chirostoma humboldtianum* (VU). Specific fisheries regulations are also defined for 43 different water bodies, including lakes, rivers and reservoirs (DOF, 2016). An additional 16 Norms regulate fisheries that include native fish species in water bodies such as lakes Catemaco (DOF, 2007), Chapala (DOF, 2015a), and Pátzcuaro (DOF, 2015b), among others.

4.4 Ongoing conservation action

4.4.1 *In situ* conservation action

In-situ conservation initiatives in Mexico are limited. One excellent example is the conservation initiative directed towards the endemic *Cyprinodon julimes* (CR) from the "Balneario El Pandeño de los Pando" in the Chihuahuan desert by PRONATURA Noreste A.C., the World Wide Fund for Nature (WWC), and local communities (De la Maza & Vela-Valladares, 2009). This initiative seeks to develop a strategy for establishing a Ramsar site where the species occurs, as well as implement a conservation and monitoring strategy to prevent the extirpation of remaining populations (De la Maza-Benignos et al., 2012). Another successful conservation initiative is directed towards *Notropis boucardi* (EN), an endemic species from the State of Morelos in Central México that has been protected by the Fish Laboratory at the Autonomous University of the State of Morelos with assistance from the state government, and the participation of local communities (Rivas, 2008; González-Flores, 2012; Preciado, 2012). This initiative has resulted in successful translocation of the species into a State Protected Area (Parque Estatal Barranca de Chapultepec), and the establishment of a new population has contributed to its conservation (Contreras-MacBeath et al., 2014). One of the most significant *in-situ* conservation projects has been the reintroduction of *Zoogoneticus tequila* (EN) (once considered Extinct in the Wild) into the Teuchitlán river in Jalisco, Mexico. This initiative was implemented by the Universidad Michoacana de San Nicolás de Hidalgo (UMSNH, Mexico) and Chester Zoo (UK), with support from many international institutions. Reintroduction represented a complex process that included site evaluation, invasive species removal, acclimation of the founding population to semi natural conditions, and an outreach programme targeting members of the local community (Domínguez-Domínguez et al., 2018).

Currently, there are several Mexican academic institutions and NGOs working on *in-situ* conservation initiatives for additional freshwater fish species, including *Skiffia francesae* (EW), *Gambusia eurystoma* (CR), *Gila modesta* (EN), *Tlaloc hildebrandi* (EN), *Cyprinodon fontinalis* (EN), and *Poeciliopsis balsas* (DD).

4.4.2 *Ex situ* conservation action

Ex situ conservation of freshwater fish in Mexico has been occurring for at least 50 years (Lascuráin et al., 2009). This work, which includes contributions from public aquariums in Europe and the United States, academic institutions, and family or genus-specific hobbyist associations, has resulted in the successful culture of nine Extinct in the Wild Mexican freshwater fish species that continue to persist in captivity (Grist, 2010; Dibble, 2010; Grum-Schwensen, 2010; Maceda-Veiga et al., 2016; da Silva et al., 2019).

The Mexico FishArk at the Universidad Michoacana de San Nicolás Hidalgo maintains a number of goodeid populations. © Gordon Reid

The most comprehensive freshwater fish conservation center in Mexico is the FishArk initiative developed by the Universidad Michoacana de San Nicolás de Hidalgo (UMSNH, Mexico) and Chester Zoo (UK) (Domínguez-Domínguez, 2010). The FishArk has maintained 39 species of goodeids since 1998, including *Skiffia francesae* (EW), *Allotoca goslinei* (EW) and more recently the cyprinid *Notropis amecae* (EW). The final goal of the Fishark is to provide individuals that are adapted to natural conditions for eventual reintroduction into historical habitat. As such, reproductive stocks are kept outdoors in large soil ponds, where they are exposed to competitors, predators, variation in natural food supply, and changing environmental conditions, to reduce the effects of hatchery conditioning (Domínguez-Domínguez et al., 2018).

The *Xiphophorus* Genetic Stock Center has operated within the United States for almost a century, making it one of the oldest live animal resource centers worldwide. It is currently housed at Texas State University in San Marcos, Texas (USA). The stock center houses 24 of the 26 identified species of platyfish and swordtails in the genus *Xiphophorus*, and 61 genetic lines representing these species (Walter et al., 2006). While the main goal of the center is to provide pedigreed lines of *Xiphophorus* for laboratory research, it also serves as a state of the art *ex situ* conservation facility that preserves *X. couchianus* and *X. meyeri*, two species that are Extinct in the Wild, and also serves as a repository for an additional 22 species (Walter et al., 2005).

Additional *ex situ* conservation tools are being developed for some Mexican freshwater fishes as a long term, low cost safeguard to biodiversity loss, including cryopreservation repositories that house germplasm (such as germ cells, gametes, or embryos). To date, a protocol has been developed for *Xiphophorus couchianus* (EW), and there are preliminary results for *Xenotoca eiseni* (EN), *Ataeniobius toweri* (EN), and *Goodea atripinnis* (LC) (Liu et al., 2019).

Chapter 5

Recommendations and conclusion

Contents

5.1 Filling the gaps: Data deficiency and research

The Red List, in conjunction with the comprehensive data compiled to support it, has become an increasingly powerful tool for conservation planning, management, monitoring and decision making (Rodrigues et al., 2006). However, species that are assessed as Data Deficient (DD), or those lacking adequate information to make a direct or indirect assessment of the risk of extinction of the species, are often overlooked. In fact, these data represent an important indicator that can be used to generate funding and guide additional research effort in places where it is needed most.

Additional ichthyological sampling will be necessary to better assess Data Deficient species. © Topiltzin Contreras MacBeath

In this assessment, 99 Data Deficient species were evaluated, representing 18.5% of all species assessed. The highest number of DD species occurred in families Poeciliidae, Cichlidae, and Atherinopsidae. Gaining additional empirical evidence regarding current and historic distribution, basic life history, ecology, and major threats should be considered a research priority, given many of these species are likely to meet the threshold for a threatened category as additional data become available.

5.2 Fisheries evaluation

The health of freshwater fisheries is often jeopardized by a lack of research and understanding regarding the impact of fisheries on inland ecosystems, and similarly the impact of human activities associated with inland waters on fisheries and aquatic biodiversity (Cowx & Gerdeaux, 2004; Beard et al., 2011; Phang et al., 2019).

Currently, the majority of freshwater fisheries in Mexico incorporate the introduction of non-native food fishes, which consists of stocking fry into natural and artificial water bodies to generate aquaculture-based fisheries yields. These include, but are not restricted to carp (genera *Ctenopharyngodon, Cyprinus*, *Hypophthalmichthys*, and *Mylopharyngodon*), tilapia (genera *Oreochromis* and *Tilapia*), brook and rainbow trout (genera *Oncorhynchus* and *Salvelinus*), bass (genus *Micropterus*), bluegill (*Lepomis macrochirus*), and channel catfish (*Ictalurus punctatus*) (Arredondo-Figueroa & Lozano-Gracia, 2003). Interpretation of fisheries statistics and their incorporation into conservation planning is difficult because catch records are often collated into species groups rather than single species, and typically include non-native species (Contreras-Balderas et al., 2008; Bartley et al., 2015).

This situation may be the consequence of a misconception that native fisheries are unproductive. This misconception has been refuted by the results of several studies in a number of Mexican basins (Lara, 1997; Inda-Díaz et al., 2009; Mercado-Silva et al., 2011; Córdova-Tapia et al., 2014; Cooke et al., 2016). Native Mexican fisheries were historically utilised by prehispanic cultures, who consumed a wide variety of freshwater fishes and other aquatic organisms, including charales, crayfish, and axolotls. These resources are still utilised today in many rural Mexican communities, where subsistence and artisanal fisheries include cichlids, poeciliids, atherinids, characids and several families of catfishes (Contreras-MacBeath, 1996). Fisheries mismanagement, either through overharvest or sanctioned introductions of non-native species, can have profound impacts on the wellbeing of local communities.

Freshwater fauna, such as this axolotl, continue to play an important role in modern Mexican culture. © Amalia Cortes

One reasonable approach to sustainable fisheries management is to implement principles outlined in the fisheries treaty signed by Mexico during the 1992 Rio Earth Summit. These principles include (1) recognition of the importance of traditional fisheries for domestic consumption, as a source of income for rural communities, and as a means by which social stability, resource conservation and environmental protection is promoted; (2) fisheries must be managed with strong ecological basis, in order to make them sustainable, seeking for them to be socially just, and respectful of cultural, biological and ecological diversity; and (3) this activity has to be managed under an ecological perspective, by using integrated management principles, and taking into account human activities that contribute to the degradation of freshwater ecosystems.

One potential solution is an ecosystem approach to fisheries management, such as those proposed by Beard et al. (2011). It will be important for fisheries management to extend across aquatic boundaries, including freshwater, brackish and marine environments for enhanced sustainable management (Cooke et al., 2014).

A number of research goals must be met to support holistic fisheries management in Mexico. These include (1) quantifying the full range of ecosystem services, including fisheries, provided by fresh waters; (2) quantifying the economic and societal benefits that inland fisheries provide to society; (3) using rapid assessments of stocks to evaluate where fisheries are over- versus under-exploited; (4) determining the relationship between aquatic biodiversity and fishery productivity; and (5) viewing inland fisheries as closely coupled social–ecological systems with dynamics that depend upon human behaviour, societal norms and environmental quality (Beard et al., 2011).

5.3 Development of freshwater protected areas and environmental safeguards

The designation of protected areas, mainly in the terrestrial environment, has been a cornerstone of conservation efforts, and recently the use of large, undisturbed portions of habitat for conservation has become prominent in the marine environment (Suski & Cooke, 2007). However, few models of protected areas specifically designed to address freshwater habitat connectivity exist, and traditional notions of protected areas translate imperfectly to the freshwater realm (Abell et al., 2007). The relative absence of research into the design and management of freshwater protected areas remains a major obstacle to the achievement of conservation goals (Saunders et al., 2002), though methods to address freshwater habitat connectivity during the planning and design phases are gaining traction in Mexico and elsewhere (Esselman & Allan, 2011; Hermoso et al., 2012; Bezaury-Creel, 2014; Bezuary-Creel et al., 2017).

Key research priorities for freshwater protected area planning include: (1) increased impetus on planning for non-riverine freshwater systems; (2) evaluating the effectiveness of freshwater biodiversity surrogates; (3) establishing scientifically defensible conservation targets; (4) developing complementarity-based algorithms that simultaneously consider connectivity issues for both lentic and lotic water bodies; (5) developing integrated conservation plans across freshwater, terrestrial and marine realms; (6) incorporating uncertainty and dynamic threats into freshwater conservation planning; (7) collection and collation of scale-appropriate primary data; and (8) building an evidence base to support improved implementation of freshwater conservation plans (Nel et al., 2009).

The Red List assessments generated as part of this project can be used as a baseline for the identification and delineation of Freshwater Key Biodiversity Areas (KBAs) to guide conservation action at the sites important for those species. KBAs can be used for the identification of priority sites for donor investment, protection under international conventions and national policies, and in setting and implementing private sector environmental safeguards (IUCN, 2016).

Given the limited resources available for pursuing biodiversity conservation targets, efforts should focus on those species and areas most in need, and for which conservation actions are most likely to yield positive outcomes.

A site-based approach on its own will not, however, protect all species and needs to be combined with conservation action at the sub-catchment and catchment scales. For example, migratory fish species may benefit from the protection of breeding sites in the dry season, but also require catchment scale actions to address more widespread threats such as land use change and barriers to movement throughout the catchment. This combined site and catchment approach is particularly important for freshwater ecosystems where high levels of connectivity mean that impacts to a site may originate long distances upstream or downstream.

At the basin (catchment) scale, Integrated River Basin Management (IRBM) approaches are recommended to better coordinate conservation, management and development planning of water, land and related resources across sectors, and to maximise the economic and social benefits derived from water resources in an equitable manner while preserving and, where necessary, restoring freshwater ecosystems.

Implementation of environmental flow methodologies is highly recommended to maintain the quality, quantity and timing of water flows required to sustain freshwater ecosystems.

The list of threatened species provided through this study should be used to inform Performance Standards and Environmental Safeguard policies of donor institutions and the private sector in Mexico to help avoid or minimize impacts of their operations on these freshwater species. Efforts should be taken to ensure that this new information for freshwater fishes is fully utilised within these processes.

Increased efforts are required to trace invasive alien species pathways of introduction in Mexico, prevent future introductions and to manage, or where feasible, eradicate established populations. Information on the distribution of invasive alien species, their impacts, pathways of invasion and management recommendations can be found in the Global Invasive Species Database (GISD) http://www.iucngisd.org/gisd.

Subsistence fisheries in southern Mexico include *Atractosteus tropicus*, a widely consumed species. © Adalberto Rios Szalay

5.4 Species-level conservation action planning

Many of the threatened species identified during the assessment process are in urgent need of a species conservation action plan (PACE) that would include them in the Mexican "Program for the Conservation of Species at Risk" managed by CONANP. Despite ongoing conservation actions directed towards a number of Mexican freshwater fish species, there is currently not a single PACE produced for a Mexican freshwater fish. This important area of research should be addressed by use of the Strategic Planning for Species Conservation Handbook produced by IUCN/SSC species conservation planning task force (IUCN, 2017), this would require planners to (1) conduct a thorough status review; (2) develop, through broad consultation with stakeholders, a vision and goals for the conservation of each species considered; (3) set objectives to help achieve the vision and goals; and (4) address those objectives through geographically and thematically specific actions.

Based on the information generated, a number of species assessed are likely to qualify for ex situ conservation. However, given limited resources for *ex situ* conservation action, guidelines such as those reviewed by McGowan et al. (2017) should be used in order to objectively evaluate candidate species and the role of *ex situ* management in the conservation of that species. These guidelines require a five-step process: (1) compile a status review; (2) define the role(s) that ex situ management might play; (3) determine the precise nature of the ex situ population in order to meet identified role(s); (4) define resources and expertise, and appraise the feasibility and risks; and (5) make a decision that is informed based on the above transparent analysis.

Eight species of Mexican freshwater fishes are Extinct in The Wild. However, the *ex situ* efforts that have ultimately prevented these species from being lost are relatively isolated. The detriment of such isolated conservation actions can be demonstrated by *Megupsilon aporus*, which had been maintained in captivity, but due to the lack of a well implemented conservation strategy, became extinct in 2014 (González et al., 2018). A well-defined, long term ex situ conservation strategy must be developed for EW species and for other species that may be suitable for *ex situ* conservation. To that end, recommendations to form an integrated working group, and research regarding genetic population management, reproductive biology, behavioural characteristics, nutrition, husbandry standards, and cryopreservation are recommended.

Stronger collaborative partnerships are recommended between academics and organisations such as the World Association of Zoos and Aquariums (WAZA), which has a long history of ex situ species management, as well as more available resources (Penning et al., 2009). Captive breeding efforts should be designed and implemented in a scientifically rigorous fashion and in consideration of ultimate reintroduction goals (Attard et al., 2016). This will require additional research in freshwater ecosystem restoration, if it is to be successful.

5.5 Reevaluation and generation of Red List indices

Red List Assessments for Mexican freshwater fish species need to be regularly updated to ensure that conservation priorities are sound and based on the most recent scientific knowledge. This includes funding field surveys to resolve the status of Data Deficient species.

In order to monitor the changing status of biodiversity over time, it remains important to periodically reassess the extinction risk of species. These regular updates should be used to generate a regional Red List Index, and should be utilised to inform managers on the conservation effectiveness of any management interventions.

5.6 Conclusions

Conservation involves making decisions on appropriate action from a wide range of options. For conservation to be effective, decision-makers need to know what actions do and do not work. Ideally, decisions should be based on effectiveness as demonstrated by scientific experiment or systematic review of evidence (Pullin et al., 2004). Conservation action is often implemented ad-hoc rather than based on the systematic appraisal of scientific evidence. This is particularly true for freshwater conservation, where there is a lack of evidence-based studies on how best to support effective implementation (Nel et al., 2009). It is clear that evidence-based approaches to conservation are essential for addressing the many threats that face aquatic ecosystems (Cooke, 2010). Integration of participatory approaches that engage a broad range of potential stakeholders, including land managers, conservationists in the public and private sectors, industry, policymakers, and managers, will be necessary to improve existing conservation measures for freshwater fishes in Mexico.

A number of specific conservation actions are recommended. These include:

1. Integration of these Red List assessments as decision support data regarding the development of National Biodiversity Strategy and Action Plans in Mexico, guidance of decisions in international conventions including the Ramsar Convention on Wetlands, the Convention on Biological Diversity (CBD), the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), the Convention on the Conservation of Migratory Species of Wild Animals (CMS) and Fisheries Agreements.

2. Use of the data presented as an informing tool of conservation planning and investment at the site-level.

3. The promotion and development of an integrated Mexican freshwater fish conservation strategy, including directives to generate additional research on Data Deficient species, evaluation and management of at-risk freshwater fisheries, the planning and establishment of additional freshwater protected areas and environmental safeguards that promote the persistence of suitable habitat, establishment of species level conservation plans and identification of suitable candidate species for ex situ conservation, and planned re-evaluation of conservation status to develop a regional Red List Index.

4. Continued development and strengthening of the Mexican Freshwater Fish Conservation Group, through the IUCN SSC Freshwater Fish Specialist Group (FFSG), the IUCN SSC Freshwater Conservation Committee (FCC) and the Mexican Ichthyological Association (SIMAC).

Chapter 6

Species in the spotlight:

Contents

6.1 The endemic *Allotoca* of the Lake Pátzcuaro and Lake Zirahuén basins

Michael Köck[1]

Lake Pátzcuaro and Zirahuén are two endorheic basins that historically comprised part of a continuous hydrological system that included Lake Cuitzeo and drained into the Lerma River basin. Lake Pátzcuaro is approximately 120 km^2, and is characterized by an average depth of 5 m, turbid water and eutrophic conditions (Torres, 1993). Conversely, Lake Zirahuén is considerably smaller with a surface area of approximately 10 km^2, has an average depth of more than 40 m, and exhibits clear, oligotrophic water (Chacon-Torres & Rosas-Monge, 1998). While connected, they were populated with an almost identical Goodeid fish fauna, including *Allotoca dugesii*, *Alloophorus robustus*, *Goodea atripinnis*, *Skiffia lermae* and the sister species *Allotoca diazi* in Lake Pátzcuaro, and *Allotoca meeki* in Lake Zirahuén, distinguished by minor differences in eye size and number of pharyngeal rays. For these latter two sister species, estimates suggest range reductions of 65% for *A. meeki* and 95% for *A. diazi* (Domínguez-Domínguez et al., 2008).

In 1933, two species of bass (*Micropterus salmoides* and *M. punctatus*) were introduced by federal fisheries agencies, resulting in the establishment of these species in Lake Zirahuén (Domínguez-Domínguez et al., 2005). In the 1970s, stocking programmes for common carp (*Cyprinus carpio*) and tilapia (*Oreochromis niloticus*) resulted in the establishment of these species in Lake Pátzcuaro. Differences in the establishment success of these invaders is likely the result of varying habitat characteristics within each lake. Carp and tilapia prefer the warmer, algae-rich waters of Lake Pátzcuaro, while bass prefer the deeper, clear waters of Lake Zirahuén. In Lake Zirahuén, the establishment of bass has resulted in the extirpation of all goodeids except for *Goodea atripinnis* and *Alloophorus robustus* through predation. Similarly, the native goodeid species of Lake Pátzcuaro have been extirpated resulting from direct competition with non-native carp and tilapia, and water quality degradation from agricultural runoff, livestock production, and sewage discharge from nearby towns. Despite the southwestern portion of Lake Pátzcuaro's status as a Ramsar site (Humedales del Lago de Pátzcuaro, No. 1447), only *G. atripinnis* and *A. robustus* have managed to persist, due to their occurrence in affluents, drainage canals, and other habitat types within the Pátzcuaro drainage.

Part of an outlet canal from the spring near Chapultepec. © Erwin Radax

Habitat degradation and competitive interactions with non-native species in Lake Pátzcuaro is so pervasive that much of the native fauna is now restricted to a small spring system

[1] Haus des Meeres Aqua Terra Zoo, Vienna, Austria

near a decommissioned mill about 10 km east of the main lake, and is very likely the last place where the native *A. diazi* persists (Zambrano et al., 2014; Corona-Santiago et al., 2015). The specific habitat requirements of this species include clear water, dense submerged vegetation, and high dissolved oxygen. Conversely, the majority of Lake Pátzcuaro and its adjacent channels are eutrophic and turbid. A large proportion of the lake's surface is covered by the invasive water hyacinth *Eichhornia crassipes*, which reduces oxygen exchange at the air-water interface (Hernández-Chávez et al., 2015). While the spring system is still relatively intact, preventative measures need to be taken to halt the spread of invasive species. Additionally, water withdrawal directly from the spring and a regional drop in the water table due to excessive groundwater abstraction threaten the persistence of this habitat, and with it the endemic *A. diazi*.

The specific habitat requirements of *A. meeki* in the Lake Zirahuén drainage are nearly identical to those of *A. diazi* in the Pátzcuaro: It requires clear, highly oxygenated water, dense submerged vegetation, and an absence of major predators to persist. Given the widespread presence of non-native bass in this drainage, *A. meeki* is now restricted to Estanque de Condembas, a small spring fed pond in the town of Opopeo about 13 km east of Lake Zirahuén (Lyons, 2011). This ponds has a surface area of approximately 7 km^2 and has also been invaded by predatory bass. These predators are an immediate threat to the last remaining population of *A. meeki*, and have restricted this native species to shallow, densely vegetated portions of the pond and its outflow. Without conservation intervention to restore habitat and manage invasive species, the extinction of this species within the near future is highly likely.

The Estanque de Condembas, a spring fed pond in Opopeo. © Michael Köck

Male *Allotoca meeki* (top) and male *A. diazi* (bottom). © Günther Schleussner and Erwin Radax

6.2 Treasures of the Sierra Madre – Mexico's little-known native trout diversity

Dean A. Hendrickson[2]

Few individuals on our planet do not know what trout and salmon are. They are usually recognised as highly palatable, and often colourful species, and most who know them likely visualize cold, beautiful, pristine, free flowing, alpine or forest streams and rivers as their typical habitats. Many will also know of the remarkable migrations taken by some species, moving from their birth locations in rivers to oceans and then returning to their birthplaces to spawn and die. Some may recognise their importance as prized targets of anglers, particularly fly fishers, who spare no expenses to go after these trophies. Many others who might not be so familiar with the characteristics just mentioned may likely recognise species of this family as the tasty, and usually relatively costly fish found frozen or on ice in grocery stores and fish markets, or in cans, or smoked, or served in restaurants. Their flesh, often pink or rosy-coloured, is prized worldwide.

Cascada de Basaseáchic, Río Mayo. © Joseph Tomelleri

There is no doubt that fishes in this family (Salmonidae) are well known in most of the developed and developing countries of the world and that some have become extremely economically and globally important commercial species that support large-scale recreational as well as wild commercial fisheries, and are massively produced by global aquaculture. At the same time many are also imperilled to some degree.

Before this project, the Red List database contained 140 species of Salmonids. Here we'll focus on the genus *Oncorhynchus,* commonly known as the Pacific salmons and trout, which prior to this project was represented in the Red List by six species. Then, setting aside the many "salmon" of this genus, we'll focus only on trout, specifically those of a large and diverse lineage, best known for one species, the famous rainbow trout (*O. mykiss*). Originally known only from California and other Pacific drainages of the U.S., rainbow trout have long been a prized target of anglers, and the species has been bred in captivity for at least 150 years. High demand for it for both sport fisheries, as well as wild and captive protein production, resulted in it now being established on every continent. It has become not only one of the world's most important recreational fishing species, but also one of the planet's most widely cultured vertebrates. It is effectively global agriculture's "fish version" of the chicken, with global aquaculture production of the species in 2014 reaching 812,940 metric tonnes valued at nearly 4 billion US$ (U.N. Food and Agriculture Organization (FAO) n.d.)

That rainbow trout of global fishery and aquaculture fame is known to be one of about 10 closely related subspecies of what is called the "coastal rainbow" branch of the evolutionary tree of the genus. Most of those are from California, but two native Mexican taxa have long been recognised as part of this lineage, *O. m. nelsoni* (Nelson's trout – recently reviewed by (Ruiz Campos, 2017)) of the northernmost mountains of Baja California, and *O. chrysogaster* (the Mexican golden trout – recently covered by multiple contributors (Ruiz-Luna & Garcia De León, 2016). Recent genetic studies (Abadía-Cardoso et al., 2015) confirm those relationships and reveal, from specimens collected by the bi-national group of researchers known as Truchas Mexicanas (Hendrickson et al., 2003), that Mexico's share of the diversity in this lineage is much greater. At least 10 more, still undescribed species of native trout reside in remote, rugged and isolated corners of the Sierra Madre Occidental extending as far south as the high mountains between Mazatlán and Ciudad Durango. Truchas Mexicanas' fieldwork left no doubt that most share a need for conservation actions to help their often small and fragmented populations persist, and some are critically imperilled (Camarena-Rosales et al., 2006; Hendrickson et al., 2007; Hendrickson & Tomelleri 2019). While their formal descriptions have been delayed for various reasons, recent genetic validation of their distinctiveness, and clear need for recognition of the need for conservation actions on their behalf, led those studying them to petition the IUCN to add them to the Red List while their descriptions are being finalized. That petition was accepted and their assessments were completed as part of this project.

All of the Mexican trout are strikingly beautiful, but just as

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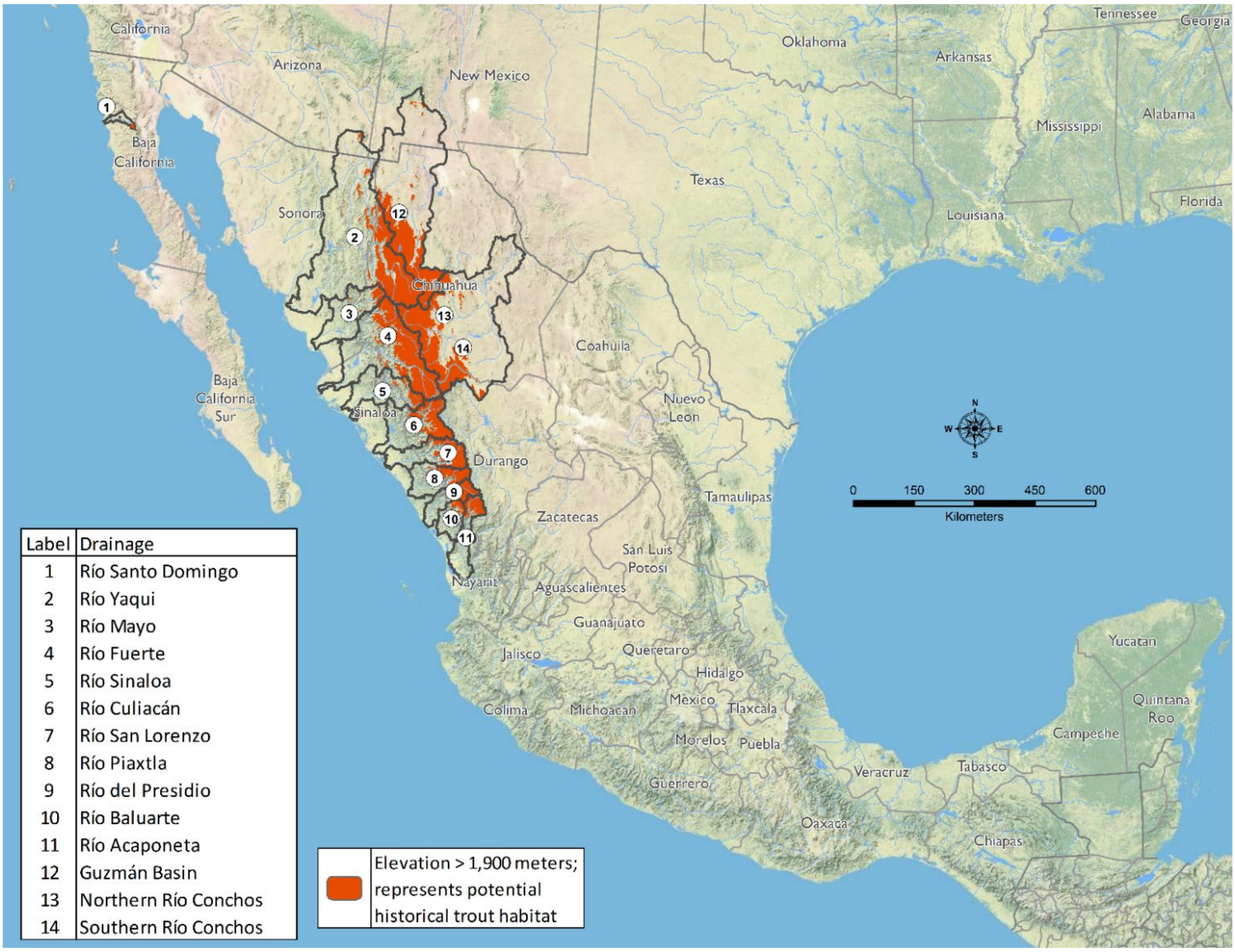


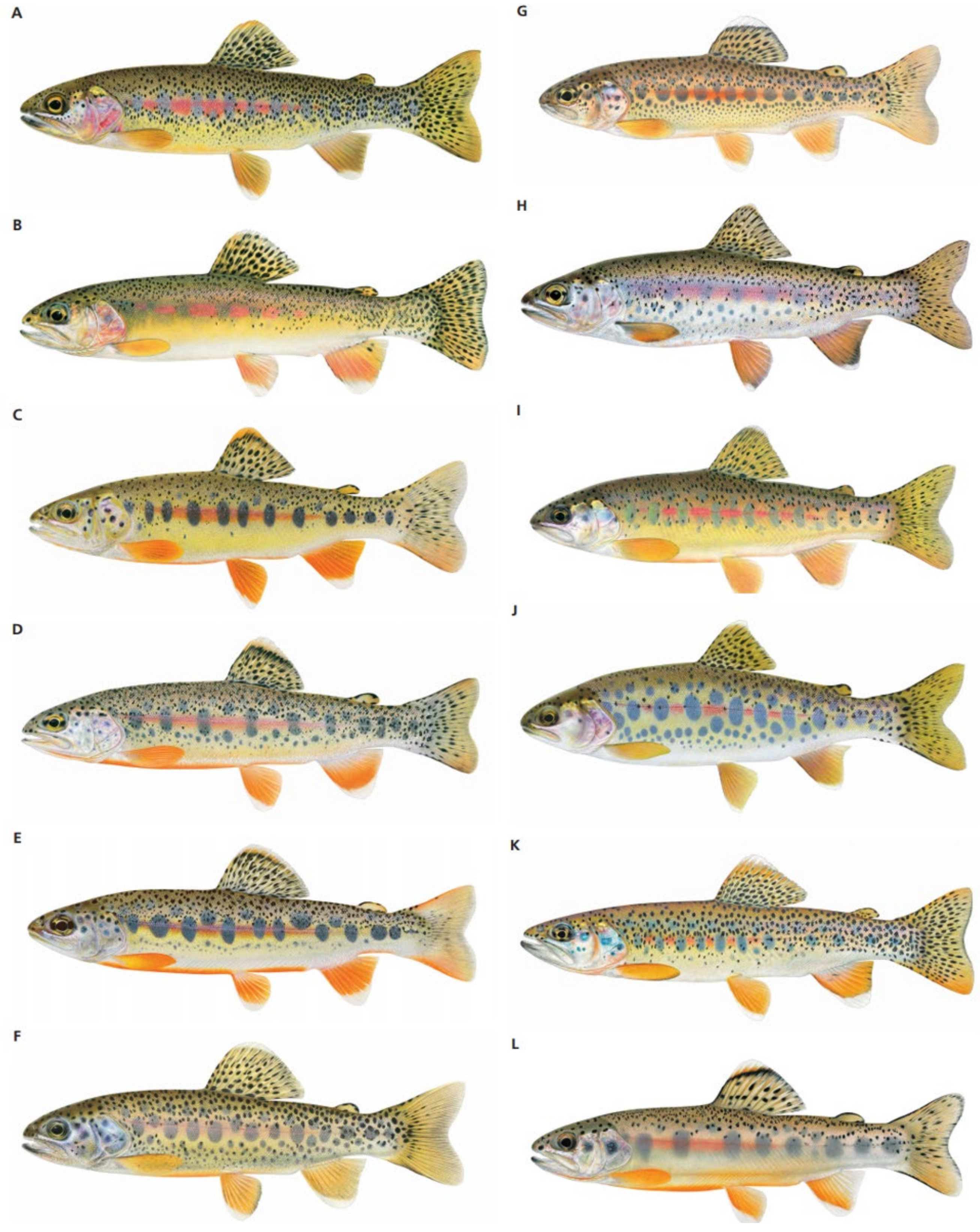
Potential historical distribution of Mexican trout in the Sierra Madre Occidental, as well as major associated river basins.
© Dean Hendrickson & Joseph Tomelleri

Arroyo San Antonio, Río Yaqui (Bavispe subbasin).
© Richard Mayden

earlier researchers found when describing their U.S. relatives, they can be difficult to describe using classical morphological approaches. However, the recent genetics study confirmed that these new Mexican forms are at least as different from one another as are all of their much more thoroughly studied U.S. cousins, and that likely more of the total genetic variation of the entire genus resides in these Mexican species than is found among all of the U.S. representatives of the genus. This rich genetic diversity of the Mexican species is not just of academic interest – it clearly has great potential value for future genetic improvements of the closely related trout stocks now so important in the global aquaculture industry. However, as their recently assigned Red List categories indicate, the potential economic value of these species is significantly threatened.

These new rigorous conservation assessments were done using the most current data available and should help increase both simple awareness of the existence of these valuable species, as well as their conservation needs. However, they also illustrate that much work remains to be done. In particular, almost nothing is known about the ecology and basic biology of these new species. While it's possible to draw inferences from the rich literature on close relatives in the U.S., we advise caution in doing that for these species. Many in Truchas Mexicanas who have collected the specimens on which these assessments were made concur that these trout seem ecologically quite different in many ways from those on the other side of the border. Luckily, the Truchas Mexicanas group of researchers has, like the trout, continued to diversify and grow, and some are now tackling researching the needs pointed out here, as illustrated in the important recent book (Ruiz Campos, 2017).

A Mexican Golden Trout caught in the Río Verde, a Río Fuerte basin tributary. © David Neely



Illustrations of Mexican trout: (A) Río Yaqui trout (Bavispe subbasin), (B) Río Mayo trout (Río Candameña), (C) Mexican Golden Trout (Los Loera subbasin of Río Fuerte, Arroyo las Truchas), (D) Mexican Golden Trout (Río Sinaloa basin, Arroyo Rancho en Medio), (E) Mexican Golden Trout (Río Culiacán basin, Arroyo Santa Rosa), (F) Río San Lorenzo trout (Arroyo la Sidra, above the falls), (G) Río Piaxtla trout (Arroyo el Granizo), (H) Río del Presidio trout (Arroyo Nogales), (I) Río Baluarte trout (Arroyo Santa Barbara), (J) Río Acaponeta Trout (Arroyo las Cebollas), (K) northern Río Conchos trout (Arroyo Ureyna), (L) southern Río Conchos trout (Arroyo del Molino).

6.3 The subterranean fishes of the Yucatan Peninsula Jairo Arroyave[3]

The Mexican blind brotula, *Typhlias pearsei* (VU)

Locally known as dama blanca ciega (Spanish for "blind white lady") or sak kay (Mayan for "white fish"), *Typhlias pearsei* is an endemic freshwater fish species of the Yucatan Peninsula (YP), a geologically unique and fascinating region in southeastern Mexico characterized by a karstic topography and the ensuing almost total lack of surface runoff (i.e., rivers, streams, lakes, etc.). Freshwater bodies in the region are mostly limited to water-filled sinkholes (locally known as *cenotes*) and flooded underground caves that are part of a massive aquifer underlying the limestone surface (Schmitter-Soto et al., 2002). Whereas most of the freshwater fish fauna in the region is restricted to the cenotes, which provide comparatively productive habitats nourished with light and allochthonous organic matter, *T. pearsei* is one of only two fish species currently adapted to living in the dark flooded caves of the YP (the other being the blind swamp eel, *Ophisternon infernale* (Miller et al., 2005). Such adaptation to life in hypogean (subterranean) habitats is reflected in its distinctive phenotype, which displays typical troglomorphic traits (i.e., eye loss and albinism), hence its common name. Besides being depigmented and blind, as a viviparous brotula (Ophidiiformes: Dinematichthydae), *T. pearsei* bears live young and displays the typical body plan of its confamilials: large and scaleless head, laterally compressed and teardrop-shaped body, and long dorsal and anal fins reaching the caudal-fin origin (Møller et al., 2004).

Despite its relatively small size (rarely exceeding 10 cm standard length), *T. pearsei* is one of the largest species of the stygofauna present in the flooded caves of the YP (consisting mostly of crustaceans) and therefore it is likely a top predator of the ecosystem it inhabits (Illife, 1993). Although not much is known about the ecology of *T. pearsei*, the species appears to be confined to habitats out of reach of sunlight, for besides underground flooded caves (where cave divers have spotted individuals at depths of up to 40 meters), it has only been observed at surface level in dark cenotes located inside dry caves (pers. obs.).

From a biogeographic perspective, *T. pearsei* is unique among the freshwater fish species that inhabit the YP because it is the only species in the region derived from a marine ancestor that colonized the flooded caves near the coast from adjacent coral reefs (Wilkens, 1982).

Lateral view of the Mexican blind brotula *Typhlias pearsei* swimming in a flooded cave in the state of Yucatan. © Benjamin Magaña

This colonisation event is believed to have occurred after dry limestone caves filled with water upon deglaciation and the resultant sea level changes in the Caribbean Sea at the end of the Pleistocene, after the Last Glacial Maximum (Wilkens, 1982). Interestingly, whereas a large number of viviparous brotulas inhabit coral reefs around the world, the few that inhabit continental waters are confined to limestone caves, just like *T. pearsei* (Møller et al., 2016). From a taxonomic point of view it is worth noting that while originally described in 1938 by Hubbs under the genus *Typhlias,* subsequent authors synonymized it with *Ogilbia* and *Typhliasina*; the latter name dominating recent literature until 2017, when the name *Typhlias* was resurrected because the names *Ogilbia* and *Typhliasina* were unnecessary in the first place (Scharpf, 2017).

Although the latest IUCN extinction risk assessment (2019) categorizes *T. pearsei* as Vulnerable (VU) on the basis of geographic range and quality of habitat, prior evaluations––including North American (Jelks et al., 2008) and local (federal)––listed it as Endangered (SEMARNAT, 2010). The endemic nature of *T. pearsei*, coupled with the fragility of its ecosystem currently threatened by pollution, groundwater extraction, and saline intrusion (Kane, 2016; Deng et al., 2017; Saint-Loup et al., 2018), certainly make it a vulnerable species. If these threats continue and/or intensify, it is only a matter of time before this species will move into a higher threat category on the IUCN Red List.

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Mexican blind brotula *Typhlias pearsei*. Eyes and pigment are lacking. © Benjamin Magaña

The blind swamp eel, *Ophisternon infernale* (EN)

Although technically not a true eel (strictly speaking, eels are fishes from the order Anguilliformes), the blind swamp eel, *Ophisternon infernale* (Synbranchiformes: Synbranchidae), locally known as "falsa anguila ciega" or "anguila ciega yucateca", is a freshwater fish endemic to the Yucatan Peninsula (YP) in southeastern Mexico. Besides its endemism, *O. infernale* is exceptional in that, apart from the Mexican blind brotula (*Typhlias pearsei*), it is the only fish species confined to the subterranean waters of the flooded caves that underlie the karstic landscape of the YP. Like *T. pearsei*, as adaptations to life in darkness, *O. infernale* exhibits typical troglomorphic traits such as the absence of both pigmentation and eyes. Apart from these conspicuous attributes, *O. infernale* is characterized by its elongated, worm-like body shape, and a bulbous head bearing numerous sensory pores (Schmitter-Soto, 1998). Although it has been reported that *O. infernale* can grow up to a standard length of about 35 cm (Navarro-Mendoza & Schmitter-Soto, 2016), most individuals found in the wild tend to be considerably smaller, no longer than 15-20 cm (pers. obs.).

Due to its cryptic behavior (usually observed burrowed under the sediment or hiding inside tangles of submerged roots and crevices) (pers. obs.) and the relative inaccessibility of its habitat, not much is known about the ecology of *O. infernale*. Like its syntopic distant cousin, the Mexican blind brotula, *O. infernale* is restricted to flooded caves (only accessible by means of cave diving, a highly technical and even dangerous endeavour) and cenotes located well inside dry caves (pers. obs.) and therefore completely dark and not readily reachable. Despite the challenges to its study, it has been reported that *O. infernale* feeds on guano and small crustaceans such as the troglobitic shrimp *Creaseria morleyi*, and that it tolerates low oxygen levels, even being able to breathe atmospheric oxygen (Schmitter-Soto, 1998). Notwithstanding population sizes and other demographic parameters are unknown, *O. infernale* appears to be extremely rare, and when spotted, only one or a few individuals are usually observed at a time (pers. obs.). Whether this abundance pattern is primarily a result of crypsis or due to small population sizes/densities remains to be seen.

From an evolutionary perspective, although its exact phylogenetic placement has yet to be determined (Perdices et al., 2005), it is reasonable to consider that *O. infernale* speciated when a lineage of the more geographically widespread swamp eel, *O. aenigmaticum*, colonized the cenotes and flooded caves of the YP. The exact timing of such divergence and whether colonization occurred one or multiple times (therefore involving multiple *O. aenigmaticum* lineages), however, is unknown.

Blind swamp eel *Ophisternon infernale* in native habitat. © Erick Sosa

By virtue of its rarity, endemism, and restricted geographic distribution, in addition to the current threats faced by its habitat and ecosystem (Kane, 2016; Deng et al., 2017; Saint-Loup et al., 2018), *O. infernale* has recently been categorized as Endangered (EN) by the IUCN. Nonetheless, if current threats continue and/or intensify, a higher expectation of extinction will certainly ensue. Besides being federally listed as endangered in the NOM-059-SEMARNAT-2010 (a compendium of species or populations of wild flora and fauna at risk in Mexican territory) (SEMARNAT, 2010), no specific conservation measures are known to have been implemented for this species.

6.4 The commercial fisheries of Lake Chapala – Charales and pescados blancos Norman Mercado Silva[4]

Chapala, in West Central Mexico, is the largest lake in the country (~ 1100 km^2) and the largest shallow lake in the world (Limón & Lind, 1990). A shallow (mean depth ~ 4.5 m), eutrophic system, Chapala is primarily fed by waters from the Lerma River, and has experienced severe water fluctuations over time. The Lake Chapala ecosystem faces numerous threats from point and non-point pollution, fishery exploitation, and the introduction of non-native species (Trujillo-Cardenas et al., 2010; Moncayo-Estrada et al., 2012). The lake supports important subsistence and commercial fisheries, and harbors 26 species including eight species in the central Mexico endemic genus *Chirostoma* (Atherinopsidae), the central Mexico endemic subfamily Goodeinae, and native and endemic cyprinid fish species. Additional non-native species have established in the lake, including common carp *Cyprinus carpio* (Cyprinidae) and tilapia *Oreochromis niloticus* (Cichlidae) (Moncayo- Estrada & Buelna-Osben, 2001).

Images of pescados blancos *Chirostoma promelas* (top right), *C. sphyraena* (top left) and charales *C. labarcae* (bottom right) and *C. consocium* (bottom left) from Lake Chapala, Mexico. © John Lyons

"Charales" and "pescados blancos", silversides in the genus *Chirostoma* (Atherinopsidae) are an important biological, cultural, and economic component of the lakes in Central Mexico, including Lake Chapala (Barbour, 1973; Berlanga-Robles et al., 2002; Miller et al., 2005; Moncayo-Estrada et al., 2012; Mercado-Silva et al., 2015). There are up to 13 species of silversides that have been a resource since pre-Hispanic times and continue to provide a commercial and subsistence fishery (1.2 million metric tonness produced in 2012) (Berlanga-Robles et al., 2002; Bloom et al., 2013).

Silversides are the most important native fishery in Chapala (Moncayo-Estrada et al., 2012). Five species of charal – *Chirostoma chapalae*, *C. labarcae*, *C. arge*, *C. jordani* and *C. consocium* - and three of pescados blancos - *C. lucius*, *C. promelas* and *C. sphyraena* - coexist in Lake Chapala (Rojas Carrillo, 2005). Charales, usually 5 -10 cm in adult length, are relatively abundant in the lake. Being morphologically similar, all charales are grouped together for fisheries purposes. While they are traditionally captured from the wild, they are also reared in fish pens throughout the lake. Once they reach a commercial size, they are extracted, sun-dried, and sent out for sale in local and regional markets. Pescados blancos, usually ~20cm in adult length, have experienced severe declines in Lake Chapala stemming from overexploitation, hybridisation, habitat alteration and pollution, and exotic species introduction. Traditionally an important fishery, pescados blancos experienced high demand through time which contributed to declines in their size and abundance, especially after 1970 (Moncayo-Estrada et al., 2012). *Chirostoma lucius* is known to hybridise with *C. sphyraena* which has probably contributed to the former being rarely captured today. All species have been affected by reductions in available habitat and water quality. Additionally, large areas of Lake Chapala are infested with non-native species like water hyacinth, which grow in thick mats on top of the water and reduce habitat availability.

Charales drying on the shoreline of Lake Chapala, Mexico. © John Lyons

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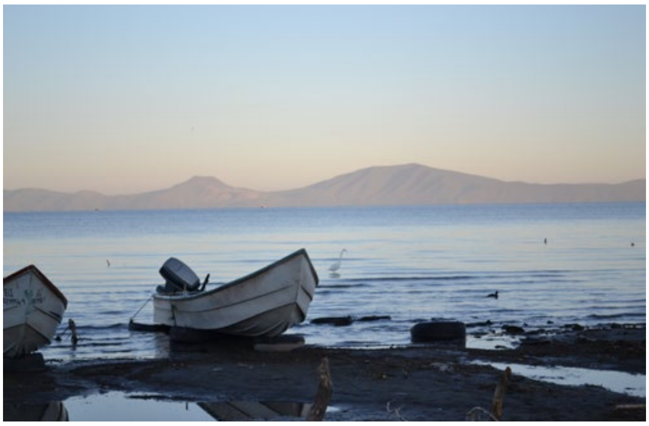

Artisanal fishing boats on the shoreline of Lake Chapala, Mexico. © Norman Mercado Silva

These threats have led to *C. promelas* being listed as Endangered (EN) by the IUCN and the Mexican list of endangered species, and *C. arge* (a species more often dwelling at the mouth of the Lerma as it arrives in Lake Chapala) being listed as Vulnerable (VU) by IUCN. While the other two pescados blancos and several charales can still be found in nature and provide a fishery in Lake Chapala, they also face numerous environmental problems that need to be addressed. Efforts have been implemented in Lake Chapala and its watershed to protect these native silversides and their habitat. These include initiatives for the improvement of water quality and quantity in the watershed, and aquaculture efforts geared towards pescados blancos production in captivity (Rojas-Carrillo, 2005).

6.5 Diversity in the desert – The diminutive pupfishes of the genus *Cyprinodon* Arcadio Valdés Gonzalez[5]

The genus *Cyprinodon* represents a unique lineage of fish species. Their ancestors can be traced as far back as 10-11 million years during the late Miocene. The genus experienced significant speciation at 9,000-41,000 thousand years ago (Echelle et al., 2005) that continued as recently as 105 years ago (Martin et al., 2015). The genus has wide ranging species such as *C. artifrons*, which is found in springs and headwater relicts of an ancient shoreline from the Mayan Yucatan Peninsula, through Mexico and around the Caribbean coastal region. Another wide-ranging species is *C. variegatus*, which occurs from Massachusetts USA southward to Venezuela. The genus is also characteristic of more range restricted species, which occur in isolated inland springs throughout the ancient Rio Grande and Colorado River systems. One such example is *C. diabolis*, a highly restricted endemic that only occurs in Death Valley, Nevada.

A live specimen of *Megupsilon aporus* (EX). The last remaining captive population of this species was lost in 2012. © Arcadio Valdés Gonzalez

Cyprinodon are small fish. Many of the species are limited in distribution to rough and arid conditions in small pond springs, creeks, and pools, generally in places where no other fish survive (Álvarez del Villar, 1970). The genus contains approximately 50 species that occur in the arid regions of southwestern North America and Mexico in relatively small bodies of water, often restricted to single, isolated streams or springs (Miller, 1981). About 20 of these are spread over the Yucatan Peninsula region and extend as far south as Venezuela (Smith et al., 1990; Wildekamp, 1995).

By the middle of the last century, Alvarez del Villar (1970) reported only seven *Cyprinodon* species, but by 2005 Miller

A live specimen of *Cyprinodon longidorsalis* (EX). This species was lost in 1993 due to extensive groundwater extraction. © Arcadio Valdés Gonzalez

et al. (2005) cited 28. By 2010, three of the species were classified as Extinct (EX), 16 Endangered (EN), and six of 25 species were considered threatened by the Mexican NOM (2010). The diversity contained within this diminutive group of fishes is still being discovered today, with five additional species under study and soon to be described.

These species demonstrate resilience to environmental change, a unique evolutionary development, and rapid genetic drift and adaptation, providing ichthyologists with a valuable opportunity to understand their complex biology and ecology, and expand on the simple understanding that "where there are fish, there is water with quality to sustain life". Freshwater is crucial to all life, and the intrinsic value of protecting the biodiversity of the *Cyprinodon* is demonstrated in the important role that their habitats have played in human development. Unfortunately, many of the habitats these species occupy are increasingly threatened by urban growth, unsustainable agricultural development, extensive groundwater extraction, and water basin overexploitation. Pollution from agricultural runoff, solid waste, and sewage discharge from urban centres also present major challenges to the integrity of their environments.

One especially striking example of groundwater overexploitation and its effect on *Cyprinodon* loss is the disappearance of Manantial de El Potosí and Ojo de Agua la Presa, two springs that once existed in the endorheic basin of Bolsón de Sandia. These isolated desert springs were once home to *Megupsilon aporus* (the most ancient close relative of *Cyprinodon*), *C. alvarezi*, *C. inmemoriam*, *C. ceciliae*, and *C. longidorsalis*, (Echelle et al., 2005) all of which are now Extinct or Extinct in the Wild due to the complete desiccation

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Ejido el Potosí, taken from a northern hill looking over the south side of what used to be a spring-fed lake. Rising smoke from the subterranean fire is visible in the center of the picture. © Arcadio Valdés Gonzalez

of their historical habitat following rapid and unsustainable groundwater extraction for agriculture (Contreras-Balderas & Lozano-Vilano, 1996). As this Pleistocene-Holocene ecosystem aged, a significant amount of organic material was deposited and incorporated into ancient lacustrine deposits at the bottom of the spring (Amezcua, 2003; 2009). The extraction of groundwater caused a human-induced decline in the water table underneath, and the lacustrine deposits began to dry. Heat and pressure caused the organic-rich deposits to self-ignite, producing an underground fire that has persisted for more than 20 years. Ultimately, the destruction of these springs has rendered adjacent agricultural land unproductive. Similar situations can be observed at Ejido La Trinidad and Ejido El Sandia about 100 km south in the municipality of Aramberri and in parts of the Mexican state of Puebla (Flores, 2017), where the loss of aquatic habitat due to groundwater over-extraction is expected to continue into the future if no action is taken.

Water abuse has occurred for nearly 50 years at Cuatro Ciénegas, a series of over 350 desert springs, pools, marshes, creeks, rivers, and lakes in the Mexican state of Coahuila. This centre of endemism has experienced significant losses in permanent and ephemeral aquatic habitat. Alfalfa farming to feed livestock extracts water indiscriminately to irrigate adjacent farmlands, resulting in a reduced water table and the endangerment of several endemic species (Torres-Vera et al., 2012). Included among the threatened fauna are *C. atrorus* and *C. bifasciatus*, both of which are affected by habitat loss, habitat alteration, and hybridization. Cuatro Ciénegas is also one of few places on earth that supports modern stromatolites, ancient relicts formed by archaic bacteria that evolved roughly 570 million years ago (Dinger et al., 2006).

Conservation planning and action is needed to curb additional losses to the biodiversity of *Cyprinodon*. The rate at which habitat modification is occurring is likely to produce negative consequences for these species, despite the resilience and adaptability that allows them to occupy harsh conditions where no other fishes persist.


Poza los Gatos, Cuatro Ciénegas, Coahuila, Mexico. Stromatolites can be observed along the banks. © Héctor Espinosa Pérez

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Appendix 1.

IUCN Red List assessment results

Family	Species name	Red List Category	Red List Criteria
ATHERINOPSIDAE	Atherinella callida	EX	
CYPRINIDAE	Evarra bustamantei	EX	
CYPRINIDAE	Evarra eigenmanni	EX	
CYPRINIDAE	Evarra tlahuacensis	EX	
CYPRINIDAE	Notropis aulidion	EX	
CYPRINIDAE	Notropis orca	EX	
CYPRINIDAE	Notropis saladonis	EX	
CYPRINIDAE	Stypodon signifer	EX	
CYPRINODONTIDAE	Cyprinodon inmemoriam	EX	
CYPRINODONTIDAE	Cyprinodon ceciliae	EX	
CYPRINODONTIDAE	Megupsilon aporus	EX	
GOODEIDAE	Characodon garmani	EX	
CYPRINIDAE	Notropis amecae	EW	
CYPRINODONTIDAE	Cyprinodon alvarezi	EW	
CYPRINODONTIDAE	Cyprinodon longidorsalis	EW	
CYPRINODONTIDAE	Cyprinodon veronicae	EW	
GOODEIDAE	Skiffia francesae	EW	
GOODEIDAE	Allotoca goslinei	EW	
POECILIIDAE	Xiphophorus couchianus	EW	
POECILIIDAE	Xiphophorus meyeri	EW	
ATHERINIDAE	Poblana alchichica	CR	B2ab(iii)
ATHERINIDAE	Poblana ferdebueni	CR	B1ab(iii)
ATHERINIDAE	Poblana letholepis	CR	B2ab(iii)
ATHERINIDAE	Poblana squamata	CR	B2ab(iv)
ATHERINOPSIDAE	Chirostoma bartoni	CR	B2ab(ii,iii,iv,v)
ATHERINOPSIDAE	Chirostoma aculeatum	CR	A2ae

Family	Species name	Red List Category	Red List Criteria
ATHERINOPSIDAE	Chirostoma charari	CR	B1ab(iii,v)
ATHERINOPSIDAE	Chirostoma melanoccus	CR	B2ab(iii)
ATHERINOPSIDAE	Chirostoma patzcuaro	CR	B1ab(iii,v)
ATHERINOPSIDAE	Chirostoma riojai	CR	B2ab(ii,iii,v)
CHARACIDAE	Astyanax salvatoris	CR	B1ab(iii)+2ab(iii)
CYPRINIDAE	Cyprinella bocagrande	CR	B1ab(i,ii,iii)+2ab(i,ii,iii)
CYPRINIDAE	Tampichthys dichromus	CR	A2ac
CYPRINIDAE	Algansea barbata	CR	A2c
CYPRINIDAE	Algansea lacustris	CR	A2cd
CYPRINIDAE	Notropis calabazas	CR	B2ab(iii)
CYPRINIDAE	Notropis calientis	CR	A2c
CYPRINIDAE	Notropis marhabatiensis	CR	B2ab(ii,iii,v)
CYPRINODONTIDAE	Cyprinodon latifasciatus	CR	B1ab(iii)+2ab(iii)
CYPRINODONTIDAE	Cyprinodon pachycephalus	CR	B1ab(i,iii)
FUNDULIDAE	Fundulus philpisteri	CR	B1ab(i,ii,iii)+2ab(i,ii,iii)
GOBIESOCIDAE	Gobiesox juniperoserrai	CR	B1ab(i,ii,iii,iv)c(i,ii)+2ab(i,ii,iii,iv)c(i,ii)
GOODEIDAE	Allotoca maculata	CR	B1ab(i,ii,iii,iv)c(ii)+2ab(i,ii,iii,iv)c(ii)
GOODEIDAE	Ameca splendens	CR	B1ab(i,ii,iii,iv)+2ab(i,ii,iii,iv)
GOODEIDAE	Characodon lateralis	CR	B1ab(i,ii,iii,iv)
GOODEIDAE	Allotoca diazi	CR	B1ab(i,ii,iii,iv)+2ab(i,ii,iii,iv)
GOODEIDAE	Allodontichthys polylepis	CR	B1ab(i,ii,iv)+2ab(i,ii,iv)
GOODEIDAE	Allotoca catarinae	CR	B1ab(i,ii,iii,iv)
GOODEIDAE	Allotoca meeki	CR	B1ab(i,ii,iii,iv)+2ab(i,ii,iii,iv)
GOODEIDAE	Neoophorus regalis	CR	B1ab(i,ii,iii,iv)+2ab(i,ii,iii,iv)
GOODEIDAE	Allotoca zacapuensis	CR	B1ab(i,ii,iii,iv)+2ab(i,ii,iii,iv)
GOODEIDAE	Chapalichthys pardalis	CR	B1ab(i,ii,iii,iv)+2ab(i,ii,iii,iv)
GOODEIDAE	Xenotoca doadrioi	CR	B1ab(i,ii,iii,iv)
GOODEIDAE	Xenotoca lyonsi	CR	B1ab(i,ii,iii,iv)+2ab(i,ii,iii,iv)
GOODEIDAE	Hubbsina turneri	CR	B1ab(i,ii,iii,iv)+2ab(i,ii,iii,iv)
HEPTAPTERIDAE	Rhamdia reddelli	CR	B1ab(iii,iv)+2ab(iii,iv)
PERCIDAE	Etheostoma lugoi	CR	B2ab(i,iii)
PERCIDAE	Etheostoma segrex	CR	B1ab(iii,v)

Family	Species name	Red List Category	Red List Criteria
PETROMYZONTIDAE	Tetrapleurodon spadiceus	CR	D
POECILIIDAE	Gambusia eurystoma	CR	B1ab(iii)+2ab(iii)
POECILIIDAE	Gambusia hurtadoi	CR	B1ab(iii)+2ab(iii)
SALMONIDAE	Oncorhynchus sp. nov. 'Baluarte Trout'	CR	B2ab(i,ii,iii,v)
SALMONIDAE	Oncorhynchus sp. nov. 'Acaponeta Trout'	CR	B2ab(i,ii,iii,v)
SALMONIDAE	Oncorhynchus sp. nov. 'Northern Conchos Trout'	CR	B1ab(iii)+2ab(iii)
ATHERINOPSIDAE	Chirostoma promelas	EN	B1ab(i,iii,v)
ATHERINOPSIDAE	Chirostoma attenuatum	EN	B2ab(iii,v)
ATHERINOPSIDAE	Atherinella ammophila	EN	B1ab(i,iii)
ATHERINOPSIDAE	Atherinella lisa	EN	B1ab(i,iii)
ATHERINOPSIDAE	Chirostoma estor	EN	B2ab(ii,iii,iv,v)
ATHERINOPSIDAE	Chirostoma lucius	EN	B1ab(iii)
ATHERINOPSIDAE	Chirostoma mezquital	EN	B1ab(i,iii,v)+2ab(i,iii,v)
ATHERINOPSIDAE	Chirostoma sphyraena	EN	B1ab(iii,iv,v)
CHARACIDAE	Astyanax jordani	EN	B1ab(i,iii)
CICHLIDAE	Herichthys steindachneri	EN	B1ab(iii)+2ab(iii)
CICHLIDAE	Vieja hartwegi	EN	B2ab(iii)
CICHLIDAE	Herichthys bartoni	EN	B1ab(iii)
CICHLIDAE	Herichthys labridens	EN	B1ab(iii)
CICHLIDAE	Herichthys minckleyi	EN	B1ab(iii,v)
CYPRINIDAE	Cyprinella xanthicara	EN	B1ab(i,iii)
CYPRINIDAE	Tampichthys mandibularis	EN	B1ab(iii)
CYPRINIDAE	Gila modesta	EN	B1ab(iii,v)c(iv)+2ab(iii,v)c(iv); C2b
CYPRINIDAE	Hybognathus amarus	EN	B1ab(i,iii)
CYPRINIDAE	Notropis simus	EN	B1ab(i,ii,iii)c(i,ii,iv)+2ab(i,ii,iii)c(i,ii,iv)
CYPRINIDAE	Algansea amecae	EN	B1ab(i,ii,iii,iv)
CYPRINIDAE	Algansea aphanea	EN	B1ab(i,iii)+2ab(i,iii)
CYPRINIDAE	Algansea avia	EN	B1ab(iii)
CYPRINIDAE	Algansea popoche	EN	B1ab(i,iii)c(i)
CYPRINIDAE	Dionda argentosa	EN	B2ab(iii)
CYPRINIDAE	Tampichthys rasconis	EN	B1ab(iii)
CYPRINIDAE	Yuriria alta	EN	A2c

Family	Species name	Red List Category	Red List Criteria
CYPRINIDAE	Yuriria chapalae	EN	B1ab(iii)
CYPRINIDAE	Notropis boucardi	EN	B1ab(i,ii,iii)c(ii)
CYPRINIDAE	Notropis grandis	EN	B1ab(iii,v)+2ab(iii,v)
CYPRINIDAE	Yuriria amatlana	EN	B1ab(i,ii,iii,iv,v)
CYPRINIDAE	Dionda diaboli	EN	B2ab(i,iii,v)
CYPRINODONTIDAE	Cyprinodon atrorus	EN	B1ab(i,ii,iii)
CYPRINODONTIDAE	Cyprinodon bifasciatus	EN	B1ab(i,ii,iii)
CYPRINODONTIDAE	Cyprinodon fontinalis	EN	B1ab(ii,iii)+2ab(ii,iii)
CYPRINODONTIDAE	Cyprinodon eremus	EN	B1ab(iii)+2ab(iii)
CYPRINODONTIDAE	Cyprinodon meeki	EN	B1ab(i,ii,iii)+2ab(i,ii,iii)
FUNDULIDAE	Fundulus lima	EN	A2ce; B2ab(i,ii,iii,iv,v)c(ii)
FUNDULIDAE	Fundulus persimilis	EN	B2ab(i,ii)
FUNDULIDAE	Lucania interioris	EN	B1ab(i,iii)c(i,iii)
GOODEIDAE	Ataeniobius toweri	EN	A2ac; B1ab(iii)+2ab(iii)
GOODEIDAE	Characodon audax	EN	B1ab(i,ii,iii,iv)+2ab(i,ii,iii,iv)
GOODEIDAE	Girardinichthys multiradiatus	EN	B2ab(i,ii,iii,iv)
GOODEIDAE	Girardinichthys viviparus	EN	B1ab(i,ii,iii,iv)+2ab(i,ii,iii,iv)
GOODEIDAE	Xenoophorus captivus	EN	A2ac; B1ab(i,ii,iii,iv)+2ab(i,ii,iii,iv)
GOODEIDAE	Zoogoneticus tequila	EN	D
GOODEIDAE	Allodontichthys hubbsi	EN	B1ab(i,ii,iii)+2ab(i,ii,iii)
GOODEIDAE	Allotoca dugesii	EN	B1ab(i,ii,iii,iv)+2ab(i,ii,iii,iv)
GOODEIDAE	Neotoca bilineata	EN	A2ac; B1ab(i,ii,iii,iv)+2ab(i,ii,iii,iv)
GOODEIDAE	Skiffia lermae	EN	B1ab(i,ii,iii,iv)+2ab(i,ii,iii,iv)
GOODEIDAE	Skiffia multipunctata	EN	A2ac; B1ab(i,ii,iii,iv)+2ab(i,ii,iii,iv)
GOODEIDAE	Xenotoca eiseni	EN	B1ab(i,ii,iii,iv)+2ab(i,ii,iii,iv)
GOODEIDAE	Zoogoneticus quitzeoensis	EN	B1ab(i,ii,iii,iv)+2ab(i,ii,iii,iv)
GOODEIDAE	Xenotoca melanosoma	EN	B2ab(i,ii,iii,iv)
ICTALURIDAE	Ictalurus pricei	EN	B2ab(ii,iii,iv,v)
PERCIDAE	Etheostoma australe	EN	B2ab(i,iii)
PETROMYZONTIDAE	Tetrapleurodon geminis	EN	B1ab(iii)+2ab(iii)
POECILIIDAE	Gambusia longispinis	EN	B1ab(ii,iii)
POECILIIDAE	Poecilia sulphuraria	EN	B1ab(iii)+2ab(iii)

Family	Species name	Red List Category	Red List Criteria
POECILIIDAE	Xiphophorus gordoni	EN	B1ab(iii)
POECILIIDAE	Poeciliopsis catemaco	EN	B1ab(iii)
POECILIIDAE	Priapella olmecae	EN	B1ab(iii)+2ab(iii)
POECILIIDAE	Xiphophorus andersi	EN	B1ab(iii,v)
POECILIIDAE	Poeciliopsis monacha	EN	B2b(iii)c(i,ii,iv)
PROFUNDULIDAE	Tlaloc hildebrandi	EN	B1ab(ii,iii)+2ab(ii,iii)
RIVULIDAE	Millerichthys robustus	EN	B2ab(iii)c(iv)
SALMONIDAE	Oncorhynchus sp. nov. 'Mayo Trout'	EN	B1ab(i,ii,iii,v)+2ab(i,ii,iii,v)
SALMONIDAE	Oncorhynchus sp. nov. 'Sinaloa Golden Trout'	EN	B1ab(i,ii,iii)+2ab(i,ii,iii)
SALMONIDAE	Oncorhynchus sp. nov. 'Culiacán Golden Trout'	EN	B1ab(i,ii,iii,v)+2ab(i,ii,iii,v)
SALMONIDAE	Oncorhynchus sp. nov. 'San Lorenzo Trout'	EN	B1ab(i,ii,iii)+2ab(i,ii,iii)
SALMONIDAE	Oncorhynchus sp. nov. 'Southern Conchos Trout'	EN	D
SYNBRANCHIDAE	Ophisternon infernale	EN	B2ab(ii,iii)
ATHERINOPSIDAE	Chirostoma chapalae	VU	B1ab(iii)
ATHERINOPSIDAE	Menidia colei	VU	B1ab(i,iii)
ATHERINOPSIDAE	Chirostoma humboldtianum	VU	A2bc
CATOSTOMIDAE	Catostomus leopoldi	VU	B1ab(iii)
CATOSTOMIDAE	Catostomus wigginsi	VU	B1ab(iii)
CATOSTOMIDAE	Moxostoma mascotae	VU	B1ab(iii,iv)
CHARACIDAE	Astyanax altior	VU	D2
CHARACIDAE	Astyanax petenensis	VU	B1ab(iii)+2ab(iii)
CHARACIDAE	Astyanax tehuacanensis	VU	D2
CHARACIDAE	Astyanax tamiahua	VU	B1ab(i,iii)
CICHLIDAE	Chiapaheros grammodes	VU	B1ab(iii)
CICHLIDAE	Herichthys tamasopoensis	VU	B1ab(iii)
CYPRINIDAE	Notropis aguirrepequenoi	VU	B1ab(iii)
CYPRINIDAE	Cyprinella alvarezdelvillari	VU	D2
CYPRINIDAE	Gila ditaenia	VU	B1ab(iii)+2ab(iii)
CYPRINIDAE	Gila nigrescens	VU	B1ab(i,ii,iii,v)+2ab(i,ii,iii,v)
CYPRINIDAE	Gila purpurea	VU	B1ab(iii)+2ab(iii)
CYPRINIDAE	Gila robusta	VU	A2ce
CYPRINIDAE	Tiaroga cobitis	VU	B2ab(ii,iii,v)

Family	Species name	Red List Category	Red List Criteria
CYPRINODONTIDAE	Cyprinodon beltrani	VU	D2
CYPRINODONTIDAE	Cyprinodon labiosus	VU	D2
CYPRINODONTIDAE	Cyprinodon maya	VU	D2
CYPRINODONTIDAE	Cyprinodon verecundus	VU	D2
CYPRINODONTIDAE	Cyprinodon bobmilleri	VU	D2
CYPRINODONTIDAE	Cyprinodon esconditus	VU	A2ae; D2
CYPRINODONTIDAE	Cyprinodon suavium	VU	D2
CYPRINODONTIDAE	Cualac tessellatus	VU	B1ab(iii)
CYPRINODONTIDAE	Cyprinodon macularius	VU	B1ab(ii,iii)+2ab(ii,iii)
FUNDULIDAE	Fundulus grandissimus	VU	B2ab(i,ii,iii)
GOBIESOCIDAE	Gobiesox fluviatilis	VU	B2ab(i,ii,iii,iv)
GOBIESOCIDAE	Gobiesox mexicanus	VU	B1ab(iii)+2ab(iii)
GOBIIDAE	Ctenogobius claytonii	VU	B2ab(ii,iii,iv)
GOODEIDAE	Allodontichthys tamazulae	VU	B1ab(i,ii,iii,iv)+2ab(i,ii,iii,iv)
GOODEIDAE	Allodontichthys zonistius	VU	B1ab(i,ii,iii)+2ab(i,ii,iii)
GOODEIDAE	Alloophorus robustus	VU	B1ab(i,ii,iii,iv)+2ab(i,ii,iii,iv)
GOODEIDAE	Chapalichthys encaustus	VU	B1ab(i,ii,iii,iv)+2ab(i,ii,iii,iv)
GOODEIDAE	Xenotaenia resolanae	VU	B1ab(i,ii,iii,iv)+2ab(i,ii,iii,iv)
GOODEIDAE	Zoogoneticus purhepechus	VU	B1ab(i,ii,iii,iv)+2ab(i,ii,iii,iv)
HEPTAPTERIDAE	Rhamdia laluchensis	VU	D2
HEPTAPTERIDAE	Rhamdia zongolicensis	VU	D2
ICTALURIDAE	Ictalurus mexicanus	VU	D2
ICTALURIDAE	Prietella phreatophila	VU	B1ab(iii)
ICTALURIDAE	Prietella lundbergi	VU	D2
LACANTUNIIDAE	Lacantunia enigmatica	VU	D2
MEGALOPIDAE	Megalops atlanticus	VU	A2bd
PERCIDAE	Etheostoma grahami	VU	B2ab(iii)
POECILIIDAE	Gambusia krumholzi	VU	D2
POECILIIDAE	Poecilia velifera	VU	B2ab(ii,iii,iv,v)
POECILIIDAE	Gambusia zarskei	VU	D2
PROFUNDULIDAE	Profundulus balsanus	VU	B1ab(iii)+2ab(iii)
CHARACIDAE	Astyanax ocotal	NT	B1a+2a

Family	Species name	Red List Category	Red List Criteria
CICHLIDAE	Rocio gemmata	NT	
CYPRINIDAE	Cyprinella panarcys	NT	B1ab(iii)
CYPRINIDAE	Tampichthys catostomops	NT	
CYPRINIDAE	Algansea monticola	NT	B1b(i,ii,iii,iv)
CYPRINIDAE	Gila eremica	NT	B1b(iii)
CYPRINIDAE	Notropis cumingii	NT	B1b(iii)
CYPRINIDAE	Notropis tropicus	NT	B1b(iii)
CYPRINODONTIDAE	Cyprinodon macrolepis	NT	B1a+2a
CYPRINODONTIDAE	Cyprinodon simus	NT	
CYPRINODONTIDAE	Cyprinodon salvadori	NT	B1a+2a
DINEMATICHTHYIDAE	Typhlias pearsei	NT	
HEPTAPTERIDAE	Rhamdia macuspanensis	NT	B1a+2a; D2
POECILIIDAE	Gambusia senilis	NT	
POECILIIDAE	Poeciliopsis latidens	NT	B1b(iii)+2b(iii)
SALMONIDAE	Oncorhynchus sp. nov. 'Bavispe Trout'	NT	B1b(iii)+2b(iii)
PROFUNDULIDAE	Profundulus mixtlanensis	NT	B1b(iii)
SALMONIDAE	Oncorhynchus chrysogaster_new	NT	B1b(iii)+2b(iii)
SALMONIDAE	Oncorhynchus sp. nov. 'Piaxtla Trout'	NT	B1a+2a
ACHIRIDAE	Achirus mazatlanus	LC	
ACHIRIDAE	Achirus lineatus	LC	
ACHIRIDAE	Trinectes fonsecensis	LC	
ACHIRIDAE	Trinectes paulistanus	LC	
ACHIRIDAE	Trinectes maculatus	LC	
ANABLEPIDAE	Anableps dowei	LC	
ARIIDAE	Ariopsis assimilis	LC	
ARIIDAE	Potamarius nelsoni	LC	
ARIIDAE	Bagre pinnimaculatus	LC	
ATHERINOPSIDAE	Menidia peninsulae	LC	
ATHERINOPSIDAE	Atherinella guatemalensis	LC	
ATHERINOPSIDAE	Atherinella crystallina	LC	
ATHERINOPSIDAE	Atherinella marvelae	LC	
ATHERINOPSIDAE	Chirostoma consocium	LC	

Family	Species name	Red List Category	Red List Criteria
ATHERINOPSIDAE	Chirostoma jordani	LC	
ATHERINOPSIDAE	Menidia beryllina	LC	
ATHERINOPSIDAE	Membras martinica	LC	
ATHERINOPSIDAE	Atherinella alvarezi	LC	
BATRACHOIDIDAE	Batrachoides waltersi	LC	
BATRACHOIDIDAE	Opsanus beta	LC	
BATRACHOIDIDAE	Batrachoides gilberti	LC	
BATRACHOIDIDAE	Batrachoides goldmani	LC	
BELONIDAE	Strongylura marina	LC	
BELONIDAE	Strongylura exilis	LC	
BELONIDAE	Strongylura timucu	LC	
BELONIDAE	Strongylura hubbsi	LC	
BLENNIIDAE	Lupinoblennius nicholsi	LC	
BRYCONIDAE	Brycon guatemalensis	LC	
CARANGIDAE	Oligoplites saurus	LC	
CARANGIDAE	Caranx hippos	LC	
CARANGIDAE	Caranx latus	LC	
CARANGIDAE	Caranx sexfasciatus	LC	
CARANGIDAE	Oligoplites altus	LC	
CATOSTOMIDAE	Catostomus bernardini	LC	
CATOSTOMIDAE	Moxostoma congestum	LC	
CATOSTOMIDAE	Pantosteus clarkii	LC	
CATOSTOMIDAE	Carpiodes carpio	LC	
CATOSTOMIDAE	Catostomus insignis	LC	
CATOSTOMIDAE	Catostomus cahita	LC	
CATOSTOMIDAE	Cycleptus elongatus	LC	
CATOSTOMIDAE	Ictiobus niger	LC	
CATOSTOMIDAE	Ictiobus bubalus	LC	
CENTRARCHIDAE	Micropterus salmoides	LC	
CENTRARCHIDAE	Lepomis cyanellus	LC	
CENTRARCHIDAE	Lepomis macrochirus	LC	
CENTRARCHIDAE	Lepomis gulosus	LC	

Family	Species name	Red List Category	Red List Criteria
CENTRARCHIDAE	Lepomis megalotis	LC	
CENTROPOMIDAE	Centropomus poeyi	LC	
CENTROPOMIDAE	Centropomus armatus	LC	
CENTROPOMIDAE	Centropomus medius	LC	
CENTROPOMIDAE	Centropomus nigrescens	LC	
CENTROPOMIDAE	Centropomus robalito	LC	
CENTROPOMIDAE	Centropomus viridis	LC	
CENTROPOMIDAE	Centropomus parallelus	LC	
CENTROPOMIDAE	Centropomus ensiferus	LC	
CENTROPOMIDAE	Centropomus mexicanus	LC	
CENTROPOMIDAE	Centropomus pectinatus	LC	
CENTROPOMIDAE	Centropomus undecimalis	LC	
CHARACIDAE	Astyanax angustifrons	LC	
CHARACIDAE	Astyanax argentatus	LC	
CHARACIDAE	Astyanax bacalarensis	LC	
CHARACIDAE	Astyanax brevimanus	LC	
CHARACIDAE	Astyanax finitimus	LC	
CHARACIDAE	Astyanax rioverde	LC	
CHARACIDAE	Astyanax aeneus	LC	
CHARACIDAE	Hyphessobrycon compressus	LC	
CHARACIDAE	Roeboides bouchellei	LC	
CICHLIDAE	Mayaheros urophthalmus	LC	
CICHLIDAE	Astatheros macracanthus	LC	
CICHLIDAE	Wajpamheros nourissati	LC	
CICHLIDAE	Cribroheros robertsoni	LC	
CICHLIDAE	Mayaheros beani	LC	
CICHLIDAE	Cincelichthys pearsei	LC	
CICHLIDAE	Trichromis salvini	LC	
CICHLIDAE	Amphilophus trimaculatus	LC	
CICHLIDAE	Cryptoheros chetumalensis	LC	
CICHLIDAE	Herichthys carpintis	LC	
CICHLIDAE	Herichthys cyanoguttatus	LC	

Family	Species name	Red List Category	Red List Criteria
CICHLIDAE	Rocio ocotal	LC	
CICHLIDAE	Rocio octofasciata	LC	
CICHLIDAE	Thorichthys affinis	LC	
CICHLIDAE	Maskaheros argenteus	LC	
CICHLIDAE	Vieja fenestrata	LC	
CICHLIDAE	Amphilophus istlanus	LC	
CICHLIDAE	Herichthys deppii	LC	
CICHLIDAE	Paraneetroplus bulleri	LC	
CICHLIDAE	Petenia splendida	LC	
CICHLIDAE	Theraps irregularis	LC	
CICHLIDAE	Rheoheros lentiginosus	LC	
CICHLIDAE	Thorichthys meeki	LC	
CICHLIDAE	Thorichthys pasionis	LC	
CICHLIDAE	Chuco intermedium	LC	
CICHLIDAE	Vieja maculicauda	LC	
CICHLIDAE	Herichthys pantostictus	LC	
CLUPEIDAE	Harengula jaguana	LC	
CLUPEIDAE	Dorosoma petenense	LC	
CLUPEIDAE	Dorosoma smithi	LC	
CLUPEIDAE	Alosa sapidissima	LC	
CLUPEIDAE	Brevoortia gunteri	LC	
CLUPEIDAE	Dorosoma cepedianum	LC	
CLUPEIDAE	Dorosoma anale	LC	
CYPRINIDAE	Agosia chrysogaster	LC	
CYPRINIDAE	Algansea tincella	LC	
CYPRINIDAE	Notropis nazas	LC	
CYPRINIDAE	Notropis sallaei	LC	
CYPRINIDAE	Codoma ornata	LC	
CYPRINIDAE	Gila minacae	LC	
CYPRINIDAE	Notropis braytoni	LC	
CYPRINIDAE	Notropis chihuahua	LC	
CYPRINIDAE	Tampichthys ipni	LC	

Family	Species name	Red List Category	Red List Criteria
CYPRINIDAE	Campostoma ornatum	LC	
CYPRINIDAE	Cyprinella formosa	LC	
CYPRINIDAE	Cyprinella lutrensis	LC	
CYPRINIDAE	Notropis amabilis	LC	
CYPRINIDAE	Notropis buchanani	LC	
CYPRINIDAE	Notropis jemezanus	LC	
CYPRINIDAE	Notropis stramineus	LC	
CYPRINIDAE	Pimephales promelas	LC	
CYPRINIDAE	Pimephales vigilax	LC	
CYPRINIDAE	Rhinichthys cataractae	LC	
CYPRINIDAE	Rhinichthys osculus	LC	
CYPRINIDAE	Macrhybopsis aestivalis	LC	
CYPRINIDAE	Campostoma anomalum	LC	
CYPRINIDAE	Cyprinella proserpina	LC	
CYPRINODONTIDAE	Cyprinodon nazas	LC	
CYPRINODONTIDAE	Cyprinodon pisteri	LC	
CYPRINODONTIDAE	Floridichthys polyommus	LC	
CYPRINODONTIDAE	Jordanella pulchra	LC	
CYPRINODONTIDAE	Cyprinodon variegatus	LC	
CYPRINODONTIDAE	Cyprinodon eximius	LC	
CYPRINODONTIDAE	Cyprinodon artifrons	LC	
DACTYLOSCOPIDAE	Dactyloscopus amnis	LC	
ELEOTRIDAE	Dormitator latifrons	LC	
ELEOTRIDAE	Eleotris picta	LC	
ELEOTRIDAE	Gobiomorus maculatus	LC	
ELEOTRIDAE	Dormitator maculatus	LC	
ELEOTRIDAE	Eleotris amblyopsis	LC	
ELEOTRIDAE	Eleotris perniger	LC	
ELEOTRIDAE	Gobiomorus dormitor	LC	
ELEOTRIDAE	Guavina guavina	LC	
EMBIOTOCIDAE	Cymatogaster aggregata	LC	
FUNDULIDAE	Fundulus parvipinnis	LC	

Family	Species name	Red List Category	Red List Criteria
FUNDULIDAE	Fundulus grandis	LC	
FUNDULIDAE	Fundulus similis	LC	
FUNDULIDAE	Fundulus zebrinus	LC	
FUNDULIDAE	Lucania parva	LC	
GASTEROSTEIDAE	Gasterosteus aculeatus	LC	
GOBIIDAE	Microgobius tabogensis	LC	
GOBIIDAE	Sicydium multipunctatum	LC	
GOBIIDAE	Gobiosoma yucatanum	LC	
GOBIIDAE	Evorthodus minutus	LC	
GOBIIDAE	Gobionellus microdon	LC	
GOBIIDAE	Gobioides peruanus	LC	
GOBIIDAE	Microgobius miraflorensis	LC	
GOBIIDAE	Gillichthys mirabilis	LC	
GOBIIDAE	Awaous tajasica	LC	
GOBIIDAE	Awaous banana	LC	
GOBIIDAE	Sicydium gymnogaster	LC	
GOBIIDAE	Gobionellus oceanicus	LC	
GOBIIDAE	Bathygobius soporator	LC	
GOBIIDAE	Ctenogobius boleosoma	LC	
GOBIIDAE	Evorthodus lyricus	LC	
GOBIIDAE	Gobioides broussonnetii	LC	
GOBIIDAE	Gobiosoma bosc	LC	
GOBIIDAE	Ctenogobius shufeldti	LC	
GOBIIDAE	Bathygobius curacao	LC	
GOODEIDAE	Ilyodon furcidens	LC	
GOODEIDAE	Xenotoca variata	LC	
GOODEIDAE	Ilyodon whitei	LC	
GOODEIDAE	Goodea atripinnis	LC	
GYMNOTIDAE	Gymnotus carapo	LC	
GYMNOTIDAE	Gymnotus maculosus	LC	
HEMIRAMPHIDAE	Hyporhamphus roberti	LC	
HEMIRAMPHIDAE	Hyporhamphus gilli	LC	

Family	Species name	Red List Category	Red List Criteria
HEMIRAMPHIDAE	Hyporhamphus unifasciatus	LC	
HEMIRAMPHIDAE	Chriodorus atherinoides	LC	
HEMIRAMPHIDAE	Hyporhamphus meeki	LC	
HEPTAPTERIDAE	Rhamdia quelen	LC	
HEPTAPTERIDAE	Rhamdia parryi	LC	
HEPTAPTERIDAE	Rhamdia laticauda	LC	
HEPTAPTERIDAE	Rhamdia guatemalensis	LC	
LEPISOSTEIDAE	Atractosteus spatula	LC	
LEPISOSTEIDAE	Atractosteus tropicus	LC	
LEPISOSTEIDAE	Lepisosteus oculatus	LC	
LEPISOSTEIDAE	Lepisosteus osseus	LC	
MORONIDAE	Morone saxatilis	LC	
MUGILIDAE	Mugil cephalus	LC	
MUGILIDAE	Mugil trichodon	LC	
MUGILIDAE	Chaenomugil proboscideus	LC	
MUGILIDAE	Joturus pichardi	LC	
MUGILIDAE	Mugil curema	LC	
MUGILIDAE	Dajaus monticola	LC	
PARALICHTHYIDAE	Citharichthys gilberti	LC	
PERCIDAE	Etheostoma pottsii	LC	
PERCIDAE	Percina macrolepida	LC	
POECILIIDAE	Gambusia speciosa	LC	
POECILIIDAE	Pseudoxiphophorus bimaculatus	LC	
POECILIIDAE	Pseudoxiphophorus jonesii	LC	
POECILIIDAE	Poecilia sphenops	LC	
POECILIIDAE	Poeciliopsis viriosa	LC	
POECILIIDAE	Xiphophorus xiphidium	LC	
POECILIIDAE	Gambusia vittata	LC	
POECILIIDAE	Priapella intermedia	LC	
POECILIIDAE	Poeciliopsis fasciata	LC	
POECILIIDAE	Poeciliopsis turrubarensis	LC	
POECILIIDAE	Poeciliopsis prolifica	LC	

Family	Species name	Red List Category	Red List Criteria
POECILIIDAE	Belonesox belizanus	LC	
POECILIIDAE	Brachyrhaphis hartwegi	LC	
POECILIIDAE	Gambusia marshi	LC	
POECILIIDAE	Gambusia sexradiata	LC	
POECILIIDAE	Gambusia yucatana	LC	
POECILIIDAE	Poecilia butleri	LC	
POECILIIDAE	Poecilia mexicana	LC	
POECILIIDAE	Poecilia orri	LC	
POECILIIDAE	Poecilia kykesis	LC	
POECILIIDAE	Poeciliopsis hnilickai	LC	
POECILIIDAE	Poeciliopsis infans	LC	
POECILIIDAE	Poeciliopsis pleurospilus	LC	
POECILIIDAE	Xiphophorus alvarezi	LC	
POECILIIDAE	Xiphophorus birchmanni	LC	
POECILIIDAE	Xiphophorus hellerii	LC	
POECILIIDAE	Xiphophorus variatus	LC	
POECILIIDAE	Gambusia affinis	LC	
POECILIIDAE	Poecilia latipinna	LC	
POECILIIDAE	Poeciliopsis occidentalis	LC	
POECILIIDAE	Poeciliopsis gracilis	LC	
POECILIIDAE	Poecilia formosa	LC	
PROFUNDULIDAE	Tlaloc candalarius	LC	
PROFUNDULIDAE	Tlaloc labialis	LC	
RIVULIDAE	Kryptolebias marmoratus	LC	
SCIAENIDAE	Aplodinotus grunniens	LC	
SYNBRANCHIDAE	Synbranchus marmoratus	LC	
SYNBRANCHIDAE	Ophisternon aenigmaticum	LC	
SYNGNATHIDAE	Microphis brachyurus	LC	
ARIIDAE	Cathorops fuerthii	DD	
ARIIDAE	Potamarius usumacintae	DD	
ATHERINOPSIDAE	Chirostoma arge	DD	
ATHERINOPSIDAE	Atherinella balsana	DD	

Family	Species name	Red List Category	Red List Criteria
ATHERINOPSIDAE	Atherinella elegans	DD	
ATHERINOPSIDAE	Atherinella pellosemeion	DD	
ATHERINOPSIDAE	Atherinella sallei	DD	
ATHERINOPSIDAE	Atherinella schultzi	DD	
ATHERINOPSIDAE	Chirostoma contrerasi	DD	
ATHERINOPSIDAE	Chirostoma grandocule	DD	
ATHERINOPSIDAE	Chirostoma labarcae	DD	
ATHERINOPSIDAE	Chirostoma reseratum	DD	
ATHERINOPSIDAE	Membras vagrans	DD	
CATOSTOMIDAE	Pantosteus nebuliferus	DD	
CATOSTOMIDAE	Pantosteus plebeius	DD	
CATOSTOMIDAE	Ictiobus labiosus	DD	
CATOSTOMIDAE	Ictiobus meridionalis	DD	
CATOSTOMIDAE	Moxostoma albidum	DD	
CATOSTOMIDAE	Moxostoma austrinum	DD	
CHARACIDAE	Astyanax caballeroi	DD	
CHARACIDAE	Astyanax acatlanensis	DD	
CICHLIDAE	Paraneetroplus gibbiceps	DD	
CICHLIDAE	Paraneetroplus nebulifer	DD	
CICHLIDAE	Thorichthys callolepis	DD	
CICHLIDAE	Thorichthys helleri	DD	
CICHLIDAE	Thorichthys socolofi	DD	
CICHLIDAE	Vieja bifasciata	DD	
CICHLIDAE	Vieja guttulata	DD	
CICHLIDAE	Oscura heterospila	DD	
CICHLIDAE	Vieja melanurus	DD	
CICHLIDAE	Kihnichthys ufermanni	DD	
CICHLIDAE	Rheoheros coeruleus	DD	
CICHLIDAE	Thorichthys aureus	DD	
CICHLIDAE	Vieja breidohri	DD	
CICHLIDAE	Maskaheros regani	DD	
CICHLIDAE	Vieja zonata	DD	

Family	Species name	Red List Category	Red List Criteria
CYPRINIDAE	Cyprinella garmani	DD	
CYPRINIDAE	Cyprinella rutila	DD	
CYPRINIDAE	Dionda melanops	DD	
CYPRINIDAE	Gila brevicauda	DD	
CYPRINIDAE	Gila conspersa	DD	
CYPRINIDAE	Gila pulchra	DD	
CYPRINIDAE	Notropis imeldae	DD	
CYPRINIDAE	Notropis moralesi	DD	
CYPRINIDAE	Tampichthys erimyzonops	DD	
CYPRINODONTIDAE	Cyprinodon albivelis	DD	
ELEOTRIDAE	Gobiomorus polylepis	DD	
ELOPIDAE	Elops affinis	DD	
GOBIIDAE	Gobionellus hastatus	DD	
HAEMULIDAE	Pomadasys crocro	DD	
HEMIRAMPHIDAE	Hyporhamphus rosae	DD	
HEMIRAMPHIDAE	Hyporhamphus mexicanus	DD	
ICTALURIDAE	Ictalurus australis	DD	
ICTALURIDAE	Ictalurus lupus	DD	
MUGILIDAE	Mugil liza	DD	
POECILIIDAE	Poecilia latipunctata	DD	
POECILIIDAE	Poeciliopsis sonoriensis	DD	
POECILIIDAE	Priapella bonita	DD	
POECILIIDAE	Xiphophorus clemenciae	DD	
POECILIIDAE	Poeciliopsis turneri	DD	
POECILIIDAE	Heterophallus milleri	DD	
POECILIIDAE	Carlhubbsia kidderi	DD	
POECILIIDAE	Gambusia atrora	DD	
POECILIIDAE	Gambusia aurata	DD	
POECILIIDAE	Heterophallus echeagarayi	DD	
POECILIIDAE	Gambusia panuco	DD	
POECILIIDAE	Gambusia regani	DD	
POECILIIDAE	Heterophallus rachovii	DD	

Family	Species name	Red List Category	Red List Criteria
POECILIIDAE	Phallichthys fairweatheri	DD	
POECILIIDAE	Poeciliopsis baenschi	DD	
POECILIIDAE	Poeciliopsis balsas	DD	
POECILIIDAE	Poeciliopsis lucida	DD	
POECILIIDAE	Poeciliopsis lutzi	DD	
POECILIIDAE	Poeciliopsis presidionis	DD	
POECILIIDAE	Priapella compressa	DD	
POECILIIDAE	Xenodexia ctenolepis	DD	
POECILIIDAE	Xiphophorus continens	DD	
POECILIIDAE	Xiphophorus cortezi	DD	
POECILIIDAE	Xiphophorus evelynae	DD	
POECILIIDAE	Xiphophorus kallmani	DD	
POECILIIDAE	Xiphophorus maculatus	DD	
POECILIIDAE	Xiphophorus malinche	DD	
POECILIIDAE	Xiphophorus milleri	DD	
POECILIIDAE	Xiphophorus montezumae	DD	
POECILIIDAE	Xiphophorus multilineatus	DD	
POECILIIDAE	Xiphophorus nezahualcoyotl	DD	
POECILIIDAE	Xiphophorus nigrensis	DD	
POECILIIDAE	Xiphophorus pygmaeus	DD	
POECILIIDAE	Poecilia chica	DD	
POECILIIDAE	Poecilia maylandi	DD	
POECILIIDAE	Poeciliopsis scarlli	DD	
POECILIIDAE	Priapella chamulae	DD	
POECILIIDAE	Gambusia alvarezi	DD	
PROFUNDULIDAE	Profundulus oaxacae	DD	
PROFUNDULIDAE	Profundulus punctatus	DD	
PROFUNDULIDAE	Profundulus parentiae	DD	
RIVULIDAE	Cynodonichthys tenuis	DD	
SALMONIDAE	Oncorhynchus sp. nov. 'Presidio Trout'	DD	

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