An analysis of the spatial distribution of Freshwater Fishes of Mexico, their conservation status, and the development of a conservation strategy for species with imminent risk of extinction based on contemporary theories and practices.

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ABSTRACT

Due to human activities freshwaters are experiencing declines in biodiversity far greater than those in the most affected terrestrial and marine ecosystems, consequently freshwater fishes are by far the most affected group of vertebrates. This situation stands true for Mexican freshwater fishes and their corresponding ecosystems. In this respect, Mexico has a long history of environmental policy, and seeking to protect its biodiversity, the country has carried out a series of important initiatives in response to the adoption of the Convention on Biological Diversity (CBD), such as the creation of the National Biodiversity Commission in 1992, the elaboration of the National Biodiversity Strategy, regional action plans, as well as conservation strategies for terrestrial and marine species and environments, but unfortunately, little has been done in relation to the conservation of freshwater species, nor the ecosystems they live in. With this in mind, the main aim of this study is to analyze the spatial distribution of the Freshwater Fishes of Mexico, their conservation status, and to develop a conservation strategy for species with imminent risk of extinction.

In order to develop the strategy four basic phases were taken: (1) assessment of the freshwater fishes of Mexico, (2) determination of conservation priorities, (3) identification and diagnosis of problems, and (4) planning solutions. These were achieved through a series of different methodologies for each particular case.

The first part of the assessment phase consisted in developing an updated species list of Mexican freshwater fishes that resulted in a working list of 616 fish species grouped in 61 families for Mexican freshwaters (265 are Mexican endemics). Globally there are approximately 12,000 described freshwater fish species, so results show that Mexico holds 5.1% of the global freshwater fish diversity. This is a large figure considering that the Mexican territory represents only 1.3% of the world global land area.

The second part of the assessment phase consisted in developing a study of richness and endemism which was crucial for identifying hotspots and consequently for directing conservation efforts. This was done by mapping and overlaying individual species distributions by means of geographical information systems based on museum data. The results of this study confirmed several previously proposed centers of

freshwater fish richness (Southeastern Mexico, the Mesa Central, the Bravo-Conchos river system and the Panuco and Tuxpan-Nautla rivers). Seven areas with high CWEI endemism values were identified, but the valley of Cuatrociénegas was recognized as a true center. An alarming result was the identification of a “Ghost” center of endemism (Llanos El Salado) in Southwestern Nuevo León, where the six endemic Cyprinodont species that were present in this center are all extinct or extinct in nature. 49 single site endemics were identified that are distributed all over Mexico, but it is noteworthy to mention Chichancanab lagoon in the border between Yucatan and Quintana Roo, where a flock composed of 6 endemic Cyprinodonts is present. Three hotspots of richness + endemism were identified for Mexico, the most important of which is the Mesa Central where impacts by human activities have had a detrimental effect on fish populations.

In order to determine conservation priorities the risk of extinction for each of the 616 species was assessed according to the IUCN Red List Categories and Criteria: Version 3.1. Results show that 218 species (36%) in 25 families are classified as threatened, 49 are critically endangered (8%), 82 are endangered (14%), 88 are vulnerable (14%). With a total of 160 threatened species, five families compromise 73% of the total, these are Cyprinidae with 55 threatened species, Goodeidae with 38, Poeciliidae with 23, Atherinopsidae with 22 and Cyprinidontidae with 21. Lost fishes, both extinct and extinct in the wild represent 3% of the total with 20 species, 15 of which are Mexican endemics. There are only 18 species (3%) classified as Near Threatened, these belong to 9 families, most diverse of which is Poeciliidae with 7 species. Data Deficient species account for only 2% of the total. Over half of the species (56%) are considered as Least Concern. These figures are very similar to those found for European freshwater fishes, but differ (are worse) from what has been found for Africa, and for global data.

Once these phases were completed, an assessment was carried out on the Mexican legal and institutional framework related to freshwater fish species conservation, as well as the effectiveness of ongoing biodiversity conservation strategies by means of on *ex-post* analysis based on the two Mexican governmental policies related to ecosystem and biodiversity conservation, which are those related to Protected Areas and Conservation of species at risk, implemented by the National Commission on

Protected Areas. Results show that even though there have been many successful strategies in the terrestrial realm, over the past 16 years there is a tendency of more freshwater fish species being imperiled. So it is fair to say that conservation programs have not had a positive impact on freshwater fishes.

Due to the large number of threatened freshwater fish species found, within such a large country, with limited economic resources for species conservation actions, a decision was made to identify as conservation targets, those species with imminent risk of extinction. After applying a prioritization method, 45 species within nine families, distributed in 30 different sites were identified as those with the highest extinction risk.

With the information produced in the previous sections a conceptual model was developed that included scope, vision, and the conservation goal of preventing imminent extinctions. Direct threats were then identified for these sites (recreational activities, water management/use, water pollution and invasive species), and from these contributing factors. Based on the former, 10 general actions are proposed to minimize the impact of these contributing factors, and a case study with *Notropis boucardi* from the higher Balsas river basin is presented as an example of how these actions can be applied to achieve conservation results.

In general terms it can be said that by collating and analyzing data in a systematic manner, by using geographical information systems, and by discussing the results in the context of contemporary theories or views related to conservation practice, the present study has not only contributed to the knowledge of Mexican freshwater fish species, their conservation status and threats, but has set the basis for the implementation of specific conservation actions for species with imminent risk of extinction.

It is clear that much work is still needed in order to change the precarious situation of Mexican freshwater fishes and their habitats, but while the Federal Government needs to work harder in aspects such as water treatment and sanitation, there is an opportunity in State and Local governments, that could take the lead in protecting their critically endangered freshwater fish species. Fortunately the database produced for this study, as well as the ten conservation actions identified can serve as the starting point for specific local conservation initiatives.

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A	(Threatened)
ANAAE	(National Association of State Environmental Authorities)
BOD_5	(Biochemical Oxygen Demand)
CBD	(Convention on Biological Diversity)
CE	(Critically Endangered)
CITES	(Convention on International Trade in Endangered Species of Wild Fauna and Flora)
CMP	(Conservation Measures Partnerships)
CNA	(National Water Commission),
COD	(Chemical Oxygen Demand)
CONABIO	(Mexican Biodiversity Commission)
CONAFOR	(National Forest Commission)
CONAGUA	(National Water Commission)
CONANP	(National Commission of Protected Areas)
CWEI	(Corrected Weighted Endemism Index)
DD	(Data Deficient)
E	(Endangered)
E	(Extinct)
e	(Mexican endemic)
ECOL	(Environment Secretariat – SEMARNAP)
EOD	(Electric Organ Discharges)
EW	(Extinct in the Wild)
FFSG	(Freshwater Fish Specialist Group)
GBIF	(Global Biodiversity Information Facility)
GDP	(Gross Domestic Product)
IMTA	(National Water Technology Institute)
INECC	(National Ecology and Climate Change Institute)
IUCN	(International Union for the Conservation of Nature)
LAN	(The National Water Law)
LC	(Least Concern)
LGEEPA	(Ecological Equilibrium and Environmental Protection Law)
LGVS	(General Wildlife Law)
N	(Native)
NE	(Not Evaluated)
NOMs	(Technical Standards)
NT	(Near Threatened)
NUCL	(Energy Secretariat)
OECD	(Organization for Economic Co-operation and Development)
PACE	(Action Plan for Species Conservation)
PESC	(Fisheries Sub-Secretariat of SEMARNAT)
PND	(National Development Plan)
Pr	(Special Protection)
PROCER	(National Program for the Conservation of Species at Risk)
PROFEPA	(Federal Environmental Protection Agency)
Ramsar	(Convention on Wetlands)
RE	(Regionally Extinct)
RECNAT	(Natural Resources SEMARNAP)
REPDA	(Public Registry of Water Duties)
SAGARPA	(Agriculture, Food and Fisheries Secretariat)
SCT	(Communications and Transportation Secretariat)
SEMARNAP	(Ministry of the Environment, Natural Resources and Fisheries)

SEMARNAT	(Ministry of the Environment, and Natural Resources)
SSA	(Health Secretariat)
SSC	(Species Survival Commission)
STPS	(Labor Secretariat)
TUR	(Tourism Secretariat)
UMAs	(Units for conservation, management and sustainable use of wildlife)
UNFCCC	(United Nations Framework Convention on Climate Change)
Vu	(Vulnerable)
WWF	(World Wildlife Fund)

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Chapter 1: Introduction

1.1 General introduction

Since the Industrial Revolution, as the development of civilization and the so called domination of man over nature advanced exponentially, human beings have progressively abused other species with which they share the planet to the extent that, in the majority of cases, the natural environment of which we are a part has been put into a deep environmental crisis (Myers *et al*. 2000, Contreras-MacBeath 2005, MEA 2005, Pereira *et al*. 2010, Braunisch *et al*. 2012). This era in which human actions have become the main driver of global environmental change has now been referred to as the Anthropocene (Crutzen & Stoermer 2000). The impact has been such that the planetary boundaries that are defined as the safe operating space for humanity with respect to the earth system and are associated with the planet's biophysical subsystems or processes have been surpassed (Rockström *et al*. 2009). Being the dominant species on Earth, humans have a moral obligation to ensure the long-term persistence of ecosystems and their component species (Sodhi & Ehrlich 2010). Conservation biology emerged as a discipline with the prime aim and justification to benefit biological diversity, whether through identifying patterns and mechanisms, quantifying changes, recognizing problems, or testing solutions (Sutherland *et al*. 2009). Consequently conservation biology is a mission-driven discipline (Meine *et al*. 2006) that seeks to counteract the current biodiversity crisis and thus prevent extinctions (Redford *et al*. 2011).

A global review and analysis of the impact of conservation work on the status of the world's vertebrates, including fishes, amply demonstrates that taking action can often be worthwhile (Hoffmann *et al*. 2010, Lotze *et al*. 2011). But in order to achieve conservation results, work has to be done beyond assessment and basic research, thus practical conservation management actions are needed both in the wild and outside of the natural habitat, primarily at a local level (Garrow & Marr 2012). Another important aspect to consider is to go beyond the wrong idea that by conserving charismatic species, those located at the upper parts of the trophic chain or the ones with economic importance, it will be also possible to protect all biodiversity (Rubio-Salcedo *et al*.

2013). Consequently work has to be orientated towards the protection of non-charismatic species, a category in which most freshwater fish species can be placed.

1.2 Background

1.2.1 Freshwater fishes and why we should protect them

In contrast with other vertebrate gropus such as mammals, birds and even amphibians, which receive much conservation attention by academis, media and NGOs, this is not the case of freshwater fishes, where it is still very difficult to get public, political and consequently economic support for their conservation. This situation has been recognized by organizations such as IUCNs Freshwater Conservation Sub-Committee (FSCS) and its Freshwater Fish Specialist Group (FFSG). The FCSC has gone as far as to determine its Mission to be "*Making a case for freshwater biodiversity*". With this in mind, members of both organizations have worked on compiling information related to the values of freshwater fishes, which have resulted in the attached review (Reid *et al.* 2013). Data from that paper are used in several parts of this introduction.

Fishes constitute slightly more than one half of the total number of approximately 54,700 recognized living vertebrate species. In 2006 Nelson mentioned descriptions for 27,950 valid species of fishes, compared to 26,750 amphibians, reptiles, birds and mammal species combined. But there is still much taxonomic work to be done, evidenced by the fact that in the period 2005-2011 there were 2,748 new fish species described (Figure 1.1), about half of which live in freshwaters (Miksik & Schralm 2011).

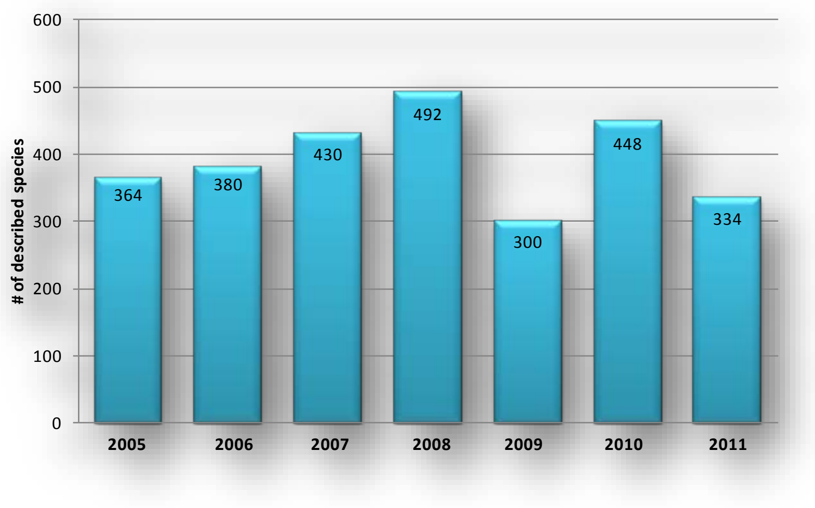


Figure 1.1 *Number of new fish species described by year (data from Miksik & Schralm 2012).*

Considering that freshwater may form less than 0.01% of available global water, it is surprising that there are approximately 12,000 freshwater fish species (43%) versus 15,900 species (56%) living in a marine environment. There is also a small number of species (<1%) which are diadromous such as the Salmon and eels. While marine fish communities contain more species in total, freshwaters are far richer per unit habitat volume. In freshwater systems, over 12,000 species occur at one per 15 km^3 of water (cf. one per 100,000 km^3 of sea water), reflecting the productivity, physiographic diversity and geographical isolation of freshwater habitats (Ormerod 2003).

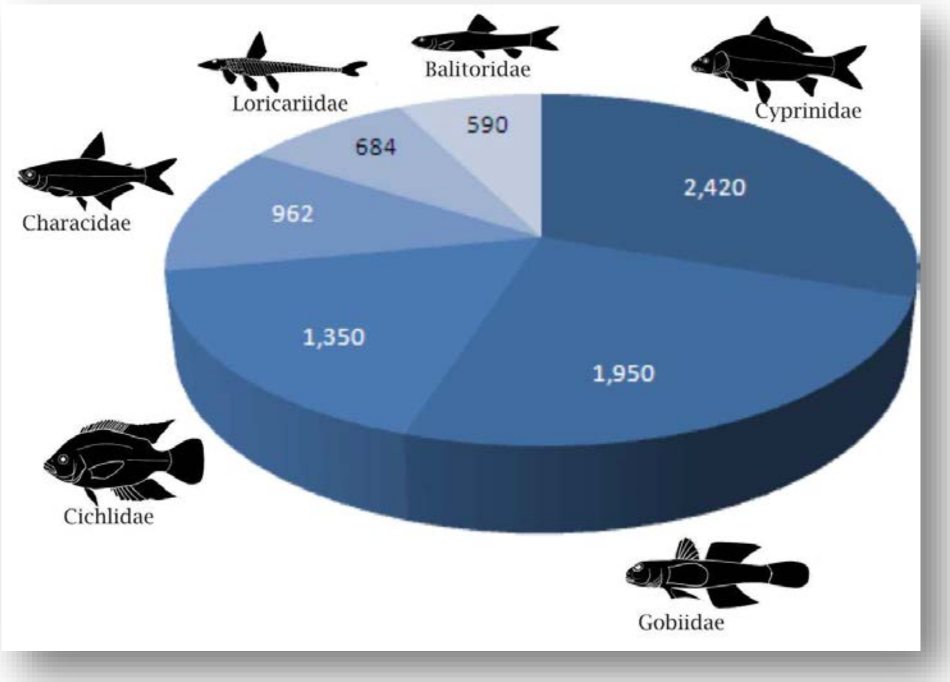


Figure 1.2 *Most abundant fish families, Cyprinidae (carps and minnows), Gobiidae (gobies), Cichlidae (Cichlids), Characidae (Characins, tetras), Loricariidae (Suckermouth armored catfishes), and Balitoridae (river loaches).*

There are 515 fish families, the six largest of which contain about 30% of all species some 7,956, and about 6,100 of these live in freshwaters (Figure 1.2). By adding the number of species of each of the four most diverse fish families (Cyprinidae, Gobiidae, Cichlidae and Characidae) 6,682 species are obtained, which are mostly freshwater species, this number is slightly larger than 6,347 known amphibians and much larger than the 5,488 known mammals listed by Hilton-Taylor *et al*. (2009).

Freshwater fishes include wonders such as the Giant Mekong catfish (Critically Endangered) (2.7 m and 300 kg); the world's smallest vertebrate (*Paedocypris progenetica*) (7.9 mm) in the Indonesian peat swamps; the amazing Archer fish of the mangroves; and the beautiful Arowanas of tropical rainforest habitats (Figure 1.3).

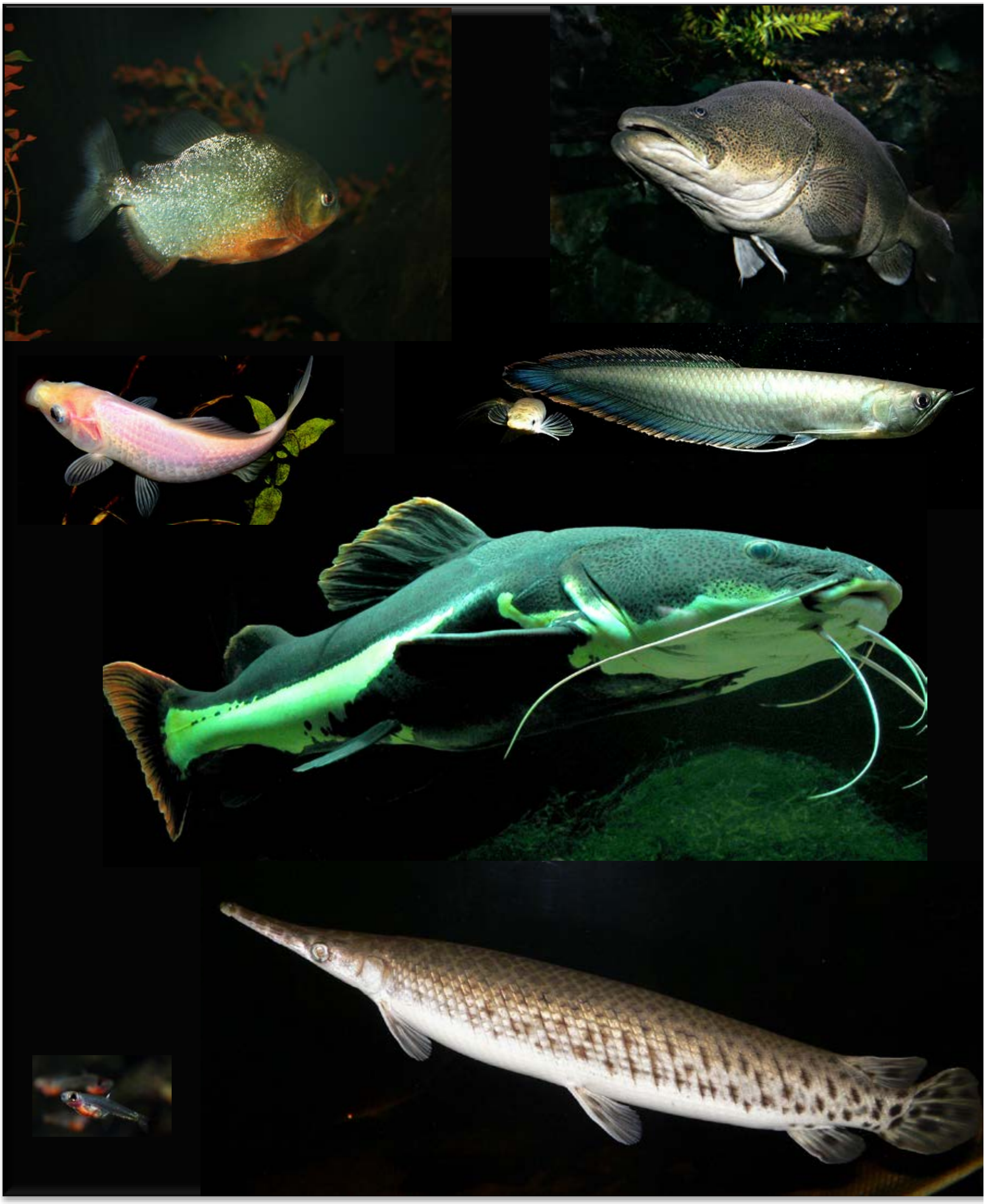


Figure 1.3 *Some examples of freshwater fish species.*

The key drivers for conserving freshwater fishes are often poorly communicated or understood, but they relate to ecosystem services, economic resources, nutrition and health, recreation, science and innovation, historical and cultural dimensions, these are described below:

Fish populations generate several ecosystem services that are essential for the functioning and resilience of freshwater systems, such as regulating food web dynamics and nutrient balances, *regulating carbon flux and serving as active links between ecosystems.* Fish generate a large number of services related to their movement patterns, including daily, seasonal, and yearly migration patterns in lakes, rivers, estuaries, and oceans. Fish that are consumed also transport nutrients across spatial boundaries and thereby link different ecosystems. It has been found that carcasses of Coho salmon (*O. kisutch*) constituted a food source for 22 species of mammals and birds living near the river (Holmlund & Hammer 1999).

Today, fishing remains the largest extractive use of wildlife in the world, with an annual capture of 158 million tonnes (91.4 wild capture and 66.6 aquaculture) (Figure 1.4). Wild capture freshwater fisheries are in the extent of 11.6 million tonnes annually (FAO 2014). Fishing provides a lasting vestige of utilizing the resources of a global commons, which are often part of maintaining traditional and cultural customs (Clausen & York 2008). It is estimated that freshwater fishes make up more than 6% of the world's annual animal protein supplies for humans (FAO 2007). Some 108.4 million people are employed directly in small-scale fisheries, including a surprisingly large number (60.4 million) dependent on inland waters (Ormerod 2003, UNEP 2010). Recreational fishing accounts for at least 4% of the worlds fish catch. It has an overall value of US$116 billion a year (Helfman 2007).

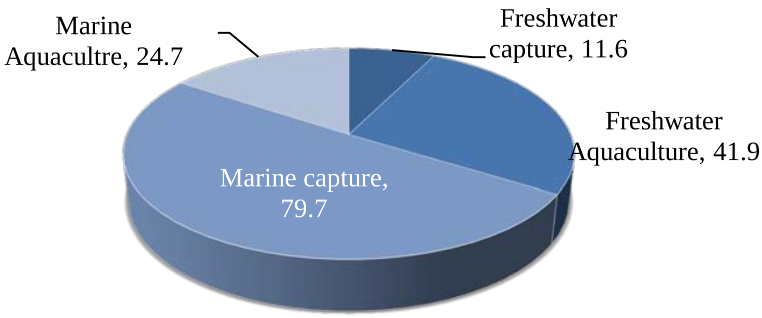


Figure 1.4 *Global wild capture fisheries and aquaculture production in millions of tonnes (FAO 2014).*

About 94% of all freshwater fisheries occur in developing countries (FAO 2007), so at the most basic level; fish provide direct benefits (such as food) to people in developing countries (Figure 1.5). They provide a livelihood and income for millions of the world's poorest people, and also contribute to the overall economic wellbeing of many developing countries by means of export commodity trade, tourism and recreation (Worldfish Center 2002, Beard *et al*. 2011). In the Mekong River basin alone, some 55.3 million people depend on freshwater fish for nutrition and livelihoods, with an estimated average fish consumption of 56.6 Kg/person/year (Baran *et al.* 2007).

Figure 1.5 *Subsistence fisheries are the main source of animal protein for many local communities.*

The catch from inland fisheries is believed to be greatly underreported by a factor of two or three (Revenga *et al.* 2000, UNEP 2010), so the annual catch could well be close to 30 Million Tonnes. The interesting issue related to this estimation, is that the 20 Million extra tonnes are related to unrecorded subsistence fisheries, so they represent a rich source of animal protein for the poor. It has been estimated that fish account for 20% of animal-derived protein in low-income food deficit countries, compared with 13% in the industrialized countries. While low income food deficit countries have more than doubled per capita fish consumption from 6 kg/year to 14 kg/year, per capita consumption has leveled off in industrialized countries since the late 1980s (Delgado *et al.* 2003). Today about 1 billion people—largely in developing countries—rely on fish as their primary animal protein source, and this is especially true for poor rural communities (Allan *et al.* 2005).

The use of fishes as research animals is a large and rapidly growing industry. This is because of their undemanding space and maintenance requirements, rapid reproduction, numerous offspring, ease in genetic manipulation and the less-restrictive legal requirements concerning invasive or intrusive experimental procedures in an industrial context (Reid *et al*. 2013). Fish are used by health agencies in management to mitigate vector-borne diseases like schistosomiasis and malaria. Due to bioaccumulation, predatory species have also been used as sentinels for the presence of toxic chemicals in waterways (Holmlund & Hammer 1999). South American tropical fish *Apteronotus albifrons* (Gymnotiformes) have been proposed as biological early warning system to detect the presence of potassium cyanide in water by means of its electric organ discharges (EOD). Thanks to its neurogenic electric organ, this fish continually emits wave form electric signals, which are very stable under constant ambient conditions, but tend to vary in the presence of pollutants. The ultimate aim is to incorporate the technique into a system for detecting changes in the quality of surface waters (Thomas *et al*. 1996).

Freshwater fish are excellent research models in areas such as phylogenetics, evolutionary biogeography and ecology, examples the African cichlid fish radiations which are amongst the most diverse extant animal radiations, provide a unique system to test predictions of speciation and adaptive radiation theory (Seehausen 2006). The present fish fauna is living witness to climatic changes in the past, a fact that gives information about past climate. For example, the distribution of Arctic charr (*Salvelinus alpinus*) in Scandinavian lakes reveals a climatic pattern of a maximum water temperature of 16°C from the most recent glaciation period 10 000 years ago to today (Holmlund & Hammer 1999).

Fish-keeping for pleasure began with the Sumerians more than 4,000 years ago, but keeping fish indoors is a more recent development that occurred in the Ming dynasty (1368-1644), when the Chinese kept goldfish in bowls (Roots 2007). This activity is a very important international industry valued at US$15-$30 billion a year. With over 4,000 freshwater fish species (Sales 2003), these dominate the trade, accounting for 80%-90% of estimated 350 million fishes traded annually (Helfman 2007). The worldwide trade in ornamental fishes has an export value of about US$186 million, a substantial proportion of which is from developing countries (Watson 2000). Contemplation of fishes in aquariums is also an important activity that some 450 million visitors visiting > 315 large-scale, free-standing public aquariums each year. Beijing Aquarium alone accounts for 17.3 million visitors (Penning *et al.* 2009).

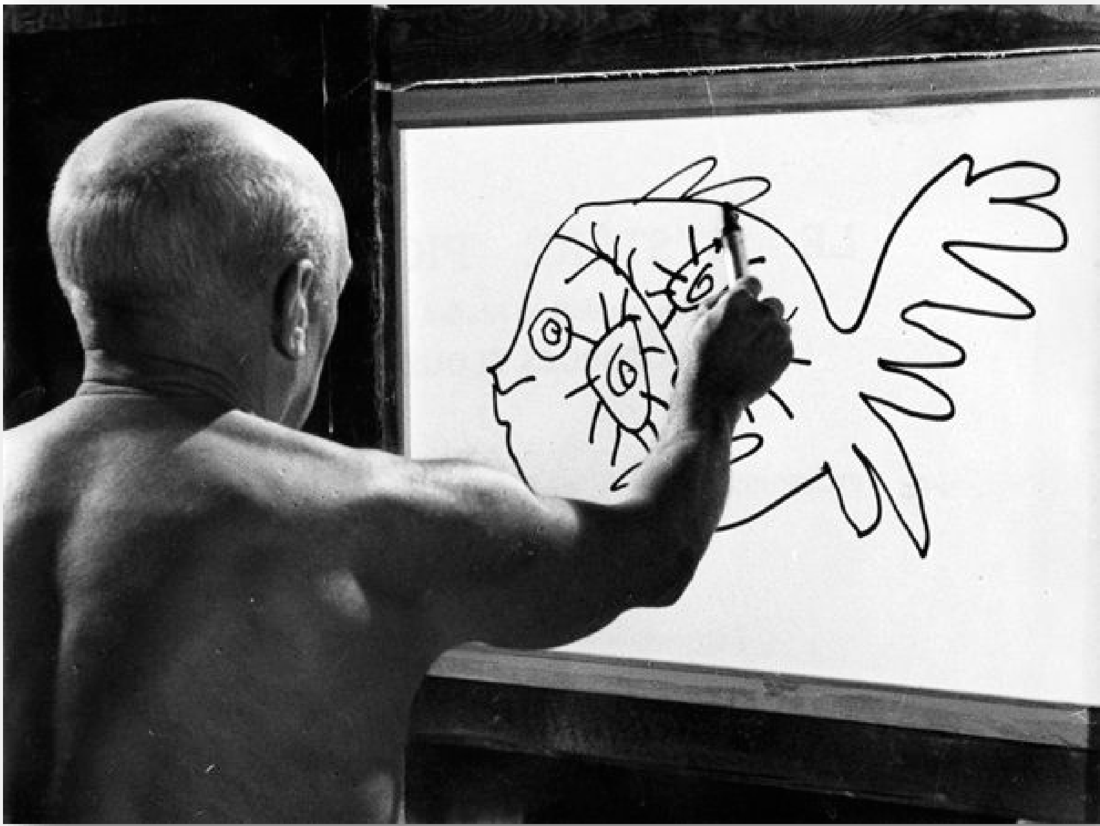


Figure 1.6 *Pablo Picasso painting a fish portrait.*

Freshwater fish have been significant in inspiring art, literature and society in many countries for centuries. The earliest written records of Koi carp, were first described in writing from a Chinese book written during the Western Chin Dynasty, around 265-420 A.D (Roots 2007). Freshwater fish also have a part to play in the cultures of the different ethnic groups in Singapore. Some Malays believe that the Climbing Perch (*Anabas testudineus*) has the supernatural power of warding off or warning against the presence of evil spirits in the house (Lim & Ng 1990). Salmon figure prominently in Celtic tales, and are primarily associated with wisdom and prophecy. They often inhabited the sacred wells, feeding on the fruits (often, hazelnuts) of the tree of life

(Strahan 1902). Fish have been the subject of works of art for at least 14,000 years and appeared in 'primitive art from many cultures. In the twentieth century, fish were painted by many modern artists, including Matisse, Picasso, Klee, Masson, Beckman, Soutine, Magritte, and Thiebaud (Moyle & Moyle 1991).

1.2.2 Freshwater fish conservation

Human activities have severely affected the condition of freshwater ecosystems in almost every part of the world; this has been done through the construction of dams, water extraction, pollution of lakes and rivers, introduction of alien species, overfishing and aquaculture. As a consequence of this, the capacity of freshwater systems to sustain their natural biodiversity has been greatly reduced to such an extent that many fish populations are rapidly declining and there have been many recent extinctions (Revenga *et al*. 2000, MEA 2005, Dudgeon *et al*. 2006, Abell *et al*. 2008, Salafsky *et al*. 2008, Mittermeier *et al.* 2010). It has been documented that the rate of freshwater biodiversity loss is much higher than that of terrestrial and marine ecosystems (Ricciardi & Rasmussen 1999, Dudgeon *et al*. 2006).

Preliminary results from IUCN Red List evaluations (IUCN 2009) show high percentages of threatened species for groups such as freshwater fishes (22%), amphibians (30%) and Odonata (13%), some of which are facing severe threat of extinction (freshwater fishes 5% and amphibians 7.7%) in comparison with terrestrial groups (birds 1.8% and mammals 3.4%).

Despite this combination of extraordinary richness (some 100,000 species), high endemism, and exceptional threat, few broad scale conservation planning efforts have targeted freshwater systems and their dependent species (Abell *et al*. 2008). This might be due in part to the fact that with the exception of amphibians and freshwater crabs, there are no complete assessments for any other freshwater groups (Darwall *et al*. 2009).

In 2004 IUCN saw the need to have a global group of experts to focus on freshwater fish conservation and thus created the Freshwater Fish Specialist Group (FFSG). This network of volunteers works with IUCN in evaluating the global conservation status of freshwater fishes, and freshwater ecosystems in general, also in maintaining fish biodiversity and securing sustainable fisheries and their benefits to local communities.

Among the main activities developed by the FFSG are: (1) production and dissemination of scientific information, (2) raising awareness on their values; and (3) influencing decision makers at all levels. Currently the FFSG is developing a global freshwater fish conservation strategy in light of the current extinction crisis and the accelerated decline of fisheries worldwide.

One of the most ambitious projects in course is the evaluation of the conservation status of the freshwater fishes of the world by means of IUCN Red List criteria. To this date complete evaluations have been done for Europe (Kottelat & Freyhof 2007) and Africa (Snoeks *et al*. 2011), and evaluations are underway for parts of Asia, North America, Mesoamerica, and a portion of the Amazon river basin. It is expected to complete in three years the global freshwater fish assessment and by demonstrating the global crisis that this group is facing, attention and more funds will be put into their conservation, as has happened with amphibians.

Once the African assessment was completed, the number of freshwater fishes assessed greatly increased and the proportions among categories varied much. Currently 5,593 freshwater fish species have been evaluated (Figure 1.7), 1,604 of which are threatened (29%), 2,644 are considered as least concern (47%), there are 1,039 data deficient species (19%), and there are 56 species considered as extinct of extinct in the wild (0.68%) (IUCN 2011.1).

Regarding conservation strategies, one of the main topics is related to protected areas because the designation of protected areas, mainly in the terrestrial environment, has been the cornerstone of conservation efforts, and recently the use of large, undisturbed portions of habitat for conservation has become prominent in the marine environment (Suski and Cooke 2007), but freshwater protected areas have fallen far behind as conservation strategies, maybe because few models of good protected area design exist, and because traditional notions of protected areas translate imperfectly to the freshwater realm (Abell *et al*. 2007).

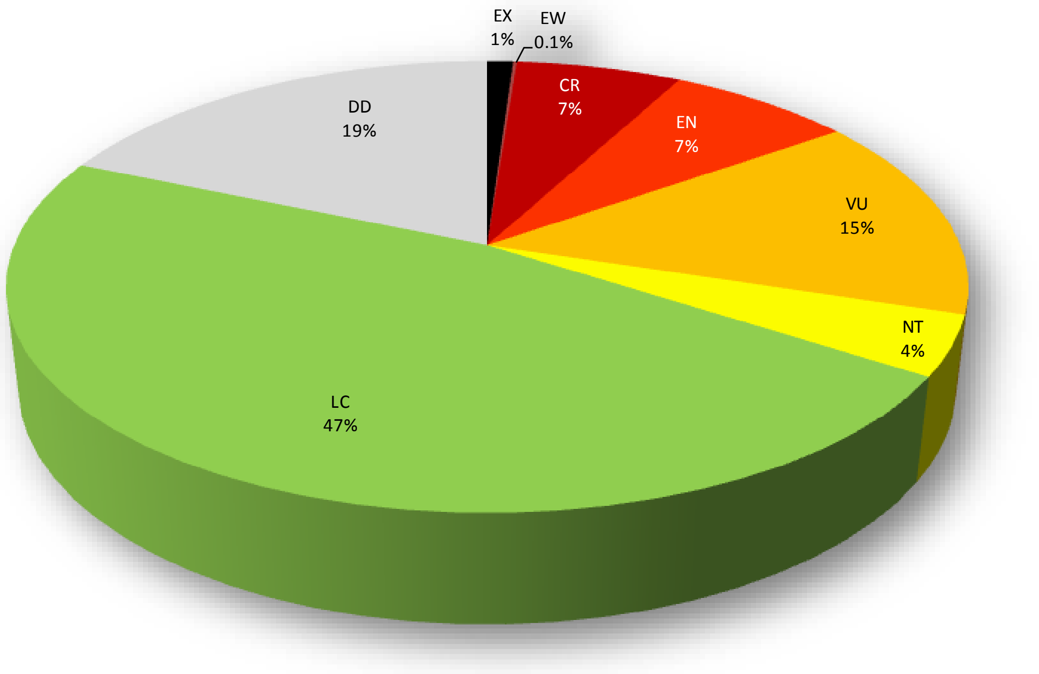


Figure 1.7 *Proportion of IUCN Red List Categories for the 5,593 freshwater fish species evaluated. Based on UICN 2011.1 data.*

With this in mind and following the goal of influencing decision makers at all levels, the FFSG participated in drafting IUCNs proposal of including a freshwater perspective on protected areas for the tenth conference of the parties to the Convention on Biological Diversity (CBD) celebrated from the 18th to the 29th of October 2010 in Nagoya, Japan. Goal 11 of the Biological Diversity Strategic Plan 2011-2020 establishes that *"by 2020, at least 17 per cent of terrestrial and inland water, and 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscape and seascapes"*. In order for this to become a reality, more research into freshwater protected areas must be promoted, and a revision of the current Protected Area System must be carried out, and as stated by Abell *et al*. (2006) new conservation categories for the freshwater environment will need to be designed. In the same manner, threatened freshwater species must be incorporated into innovative conservation strategies such as Areas of Zero Extinction (García-Moreno *et al*. 2008).

1.3 Aims and objectives

In correspondence with the global freshwater fish conservation initiative described in the previous section, in the present study aims to develop a Mexican freshwater fish conservation strategy for fishes in imminent risk of extinction that will provide an important framework for future conservation policy in Mexico using recommended procedures developed by IUCN. It will also provide an independent test of models developed for the planning and implementation process. This will be accomplished through the following aims and objectives.

1.3.1 General aim

The general aim of this study is to analyze the spatial distribution of the Freshwater Fishes of Mexico, their conservation status, and to develop a conservation strategy for species with imminent risk of extinction.

1.3.2 Specific aims and objectives

Aim 1: Produce and updated list of the freshwater fishes of Mexico.

Objectives:

a) To produce an updated species lists of freshwater fishes inhabiting the Mexican territory.
b) To identify endemic species.
c) To analyze the data in order to identify speciose groups and rare species.
d) To compare our results with other regions.

Aim 2: To analyze the current distribution of freshwater fish species across Mexico in terms of richness and endemism, and to identify hotspots as a tool for management.

Objectives:

a) To analyze the distribution range of Mexican freshwater fishes.
b) To identify freshwater fish species richness centers within Mexico.
c) To identify areas of endemism for the freshwater fishes of Mexico.
d) To identify freshwater fish hotspots within Mexico that could define conservation action.

Aim 3: To assess the extinction risk of each of the Mexican freshwater fish species using IUCN Red List criteria.

Objectives:

e) Rank individual species according to IUCN categories
f) Identify patterns of those species deemed to be at risk
g) Compare the results with those published for freshwater fishes from other regions of the world, and with those previously described for Mexico

Aim 4: To assess the effectiveness of current Mexican conservation strategies with regards to freshwater fish species conservation.

Objectives:

a) To describe the legal and institutional framework of Mexico related to freshwater fish conservation.
b) To evaluate the impact of official conservation programs on freshwater fish species by means of *ex-post* and institutional gap analysis.

Aim 5: To develop a conservation strategy for species with imminent risk of extinction.

Objectives:

a) Identify priority sites with species in imminent risk of extinction
b) Identify a series of concrete actions aimed at reducing threats.

1.4 Thesis structure

The success of any conservation effort is directly correlated to a good planning process, which can be related to many areas of conservation but that mainly underpins site management plans, species action plans and integrated conservation development plans (Sutherland 2000). The best model of conservation planning is the one described by Knight *et al*. (2006) that divides it into three categories: (1) systematic conservation assessment, (2) implementation strategy and (3) conservation management, (Figure 1.8). This thesis has been structured around this model.

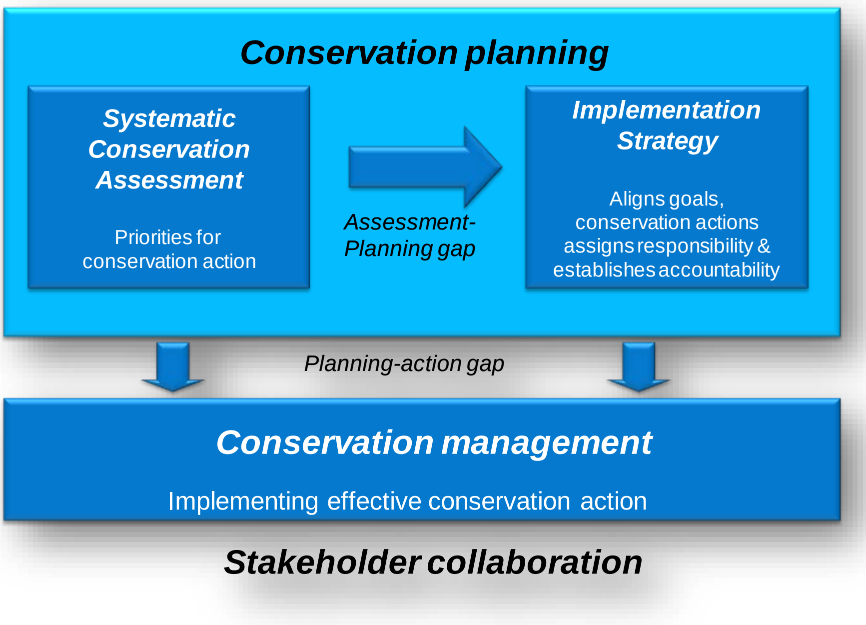


Figure 1.8 *Operational model for implementing conservation action (Based on Knight et al. 2006).*

In the last 30 years there has been a considerable evolution in focus, strategies and development of tools for conservation planning (Sarkar *et al*. 2006, Kukkala & Moilanen 2012). This evolution went from a phase in which much of the early work focused on questions of the genetics and demographics of small populations, population and habitat viability, landscape fragmentation, reserve design based, and management of natural areas and endangered species (Meine 2010), to emphasis placed on the design of conservation area networks based on the theory of island biogeography (Diamond 1976), which were replaced by efforts that use detailed biogeographic distributional information for the systematic identification of protected areas (Margules & Pressey 2000, Cowling & Pressey 2003, Rodrigues *et al*. 2004, Rondinini *et al*. 2006). Conservation planning is now evolving from being primarily concerned with the identification of protected area networks associated with the key biodiversity area concept (Eken *et al.* 2004, Darwall & Vie 2005, Bennun *et al*. 2007, Knight *et al.* 2007, Edgar *et al.* 2008) that is based on metrics of vulnerability and irreplaceability (Langhammer *et al.* 2007, Brooks 2010), to a process of prioritizing, implementing, and managing actions for the conservation of biological diversity and other natural resources, inside and outside protected areas (Wilson *et al.* 2009, Mora & Sale 2011) and it is said that in order for it to gain effectiveness, it needs to include stages dedicated to understanding the social-ecological system in which conservation actions are to be implemented, including cultural, economic, and institutional contexts, and the norms, values, and other human factors that underpin opportunities for and constraints on effective conservation (Guerrero *et al.* 2013).

Many large-scale conservation planning initiatives have been developed, such as WWF ecoregions (Mittermeier *et al*. 1999, Olson *et al*. 2001, Abell *et al*. 2008, Abell *et al*. 2010), biodiversity hotspots (Myers 1990, Myers *et al*. 2000), more recently Areas of Zero Extinction (American Bird Conservancy 2005, Butchart *et al*. 2012), these have been among the effective responses to the need in guiding global conservation investment, but all of the progress of global biodiversity conservation priority-setting, planning at much finer scales is necessary to allow implementation on the ground or in the water (Eken *et al*. 2004, Brooks 2010).

In this respect, in Mexico several conservation planning initiatives have been carried out at national (Arizmendi 2003, Íñigo & Enkerlin 2003, CONABIO *et al*. 2007, CONABIO *et al*. 2007a), regional (Bezaury *et al*. 2000, Dinerstein *et al*. 2000, Ortega-Huerta & Peterson 2004, Carvajal *et al*. 2005, COBI & TNC 2005, Enríquez-Andrade *et al*. 2005, Aguirre *et al*. 2007, Pronatura México & TNC 2007) and local levels (Conservation International 2000, CEAMA-CONABIO 2003, Peresbarbosa 2005, CONABIO *et al*. 2007b), that are related to specific ecosystems, habitats or species groups.

Even though planning processes as the ones described above have implicit priority setting, once areas, ecosystems, habitats or species have been selected, scheduling conservation action is needed due to the fact that normally available resources for conservation are insufficient to adequately protect all of the natural features (Pressey & Taffs 2001). Thus how to distribute limited resources between conservation objects is probably the most pressing issue facing the global conservation community (Mittermeier *et al*. 1998, Wilson *et al*. 2006).

Consequently extensive literature has been produced regarding priority setting, some of which has been focused on decision making (Kirkpatrick 1983, Hoekstra *et al*. 2005, Bottrill *et al*. 2008, McDonald-Madden *et al*. 2008, Leader-Williams *et al*. 2010, Wilson *et al*. 2010, Fischer *et al*. 2011) and on economic and cost benefit analysis (Moran *et al*. 1996, Cullen *et al*. 2001, Hughey *et al*. 2003, Joseph *et al*. 2009, Laycock *et al*. 2009). There have been many publications related to the definition of priorities in different regions of the world (Cogalniceanu & Cogalniceanu 2010), for species or species groups (Rodriguez *et al*. 2004, Cullen *et al*. 2005, Nicholson & Possingham 2006, Wallace *et al*. 2010) and for *ex situ* conservation (Balmford *et al*. 1996, Vázquez-Yanes & Rojas 1996). In the case of Mexico, priority setting has been developed for marine and terrestrial regions (Arriaga *et al*. 1998, Arriaga *et al*. 2000) and currently there is an ongoing process for priority setting in freshwaters at the national level.

With all this in mind, this thesis has been structured around eight chapters (summarized in figure 1.9), where in the introductory chapter (1) a description of general conservation issues and those related to freshwater fishes is given, and the general aspects of conservation planning and priority setting used in subsequent chapters are analyzed. In chapter 2 a description of Mexican freshwater resources, and their status is given.

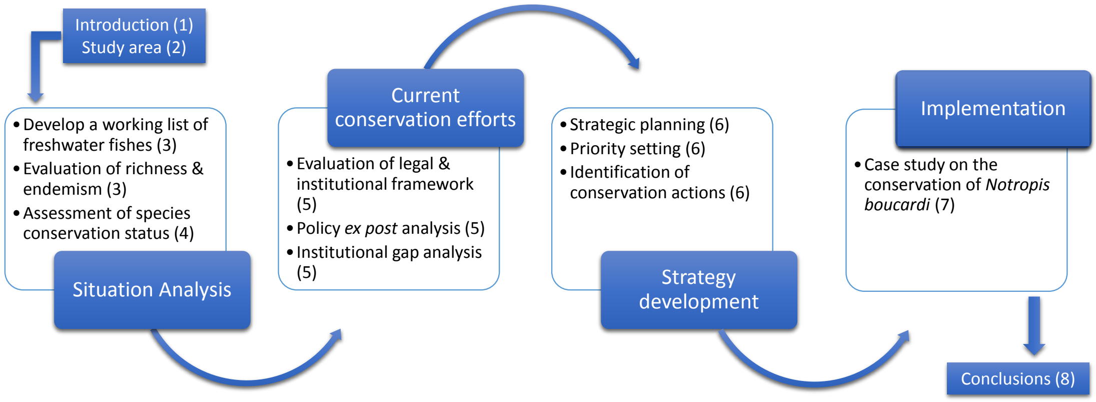


Figure 1.8 *Diagram showing thesis structure (the numbers in parenthesis represent chapters).*

The first part of the conservation planning process relates to an analysis of the situation of the conservation objects, reason for which in chapter 3 a working list of Mexican freshwater fish species was developed, after which in the same chapter an evaluation of richness and endemism was carried out and freshwater fish hotspots were identified. In chapter 4 the conservation status of the 616 Mexican native freshwater fish species was defined using IUCN Red List criteria. After finding the precarious situation in which Mexican freshwater fishes are, in chapter 5 the Mexican legal and institutional framework, and conservation programs are evaluated by means of *ex-post* analysis, and a discussion of these issues is given using the institutional gap analysis framework. This not only gives light on why the situation is as it is, but establishes the basis for a conservation strategy to be developed. Chapter 6 deals with strategy development by defining the mission, vision and scope where species in imminent risk of extinction are selected, a conceptual model is developed and ten general conservation actions related to the main threats and their contributing factors are proposed. Even thogh conservation implementation goes beyond the scope of this study, in chapter 7 a case study related to the conservation of *Notropis boucardi* is presented as an example of how the actions can be applied. Finally in chapter 8 the main findings of the previous chapters are summarized and the next steps towards the application of the strategy are defined.

Chapter 2: Study area

2.1 Characterization of Mexican Freshwater resources

Mexico is the southernmost country in North America, and it extends 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 of which represent continental area and 5127 km^2 are islands. It has 11,122 km of coastline; 7828 km correspond to the Pacific Ocean and 3294 km to the Gulf of Mexico and Caribbean (CNA 2008). Two large mountain ranges extend along its continental territory in a north-south axis, the Sierra Madre Oriental and the Sierra Madre Occidental, joining through the Trans-Mexican Volcanic Belt, and continuing towards Central America with the Sierra Madre del Sur. These ranges produce 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). About 65% of the country corresponds to mountain ranges, and according to the geographical distribution of temperature and rainfall, 32% is desertic and arid, 36% semiarid and 32% sub-humid and humid.

All these features produce a great variety of habitats as a result of so-called geographic effects, including altitudinal compensation, which accounts for the high mountains close to the equator having ecosystems characteristic of higher latitudes. Furthermore, this diverse region has served as a corridor for organismic dispersal between the Nearctic and Neotropic and represents a transition zone between these provinces (Pielou 1979). As a consequence, Mexico is regarded as a mega-diverse country, owing to the great number of species found within its borders; it hosts at least 10% of the terrestrial diversity on the planet, with a global second place in the abundance of reptiles, and among the five most diverse countries in mammals, amphibians, and flowering plants (Espinosa & Ocegueda 2008).

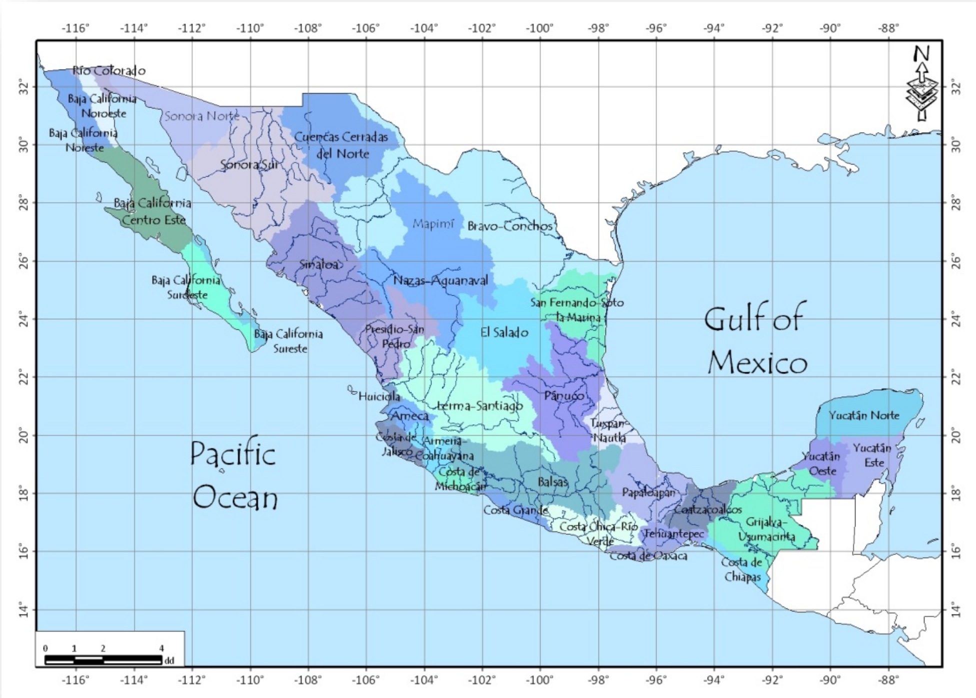


Figure 2.1 *Map of Mexico showing main rivers and river basins.*

Aquatic ecosystems are also highly diverse; there are close to 320 hydrological basins that have an average water discharge of 410 km^3. With regard to the volume of water discharged, 37 main basins can be distinguished, 12 of which drain to the Gulf of Mexico and the Caribbean, 19 to the Pacific Ocean and Gulf of California, and six are endorheic. There are 50 main rivers and river basins (Figure 2.1); the largest ones draining into the Pacific are Yaqui, Fuerte, Mezquital, Lerma-Santiago, and Balsas, whereas in the Gulf of Mexico the main rivers are Bravo, Pánuco, Papaloapan, Grijalva, and Usumacinta (Lara-Lara *et al*. 2008).

With respect to lentic environments, it is estimated that there are 70 main lakes (Table 2.1), with sizes that vary between 1000 and 10,000 hectares. They cover an area of 370,000 ha. Lake Chapala in Jalisco is the largest of Mexican lakes, followed by Cuitzeo and Pátzcuaro in Michoacán, Catazajá in Chiapas, del Corte in Campeche, Bavicora and Bustillos in Chihuahua, and Catemaco in Veracruz. There are also some 14,000 reservoirs, but most of these have a surface area smaller than 10 hectares, while those with larger areas represent two thirds of total water surface. Among the largest dams are La Amistad, Falcón, Vicente Guerrero, Álvaro Obregón, El Infiernillo, Cerro de Oro, Temascal, Caracol, Requena and Venustiano Carranza (Aguilar 2003).

Table 2.1 *Area and storage volume in Mexico's main lakes by state (CONAGUA 2010).*

Lake	Catchment area (Km^2)	Storage capacity (Millions of m^3)	Basin	State
Chapala	1116	8126	Lerma-Santiago	Jalisco-Michoacán
Cuitzeo	306	920	Lerma-Santiago	Michoacán
Patzcuaro	97	550	Lerma-Santiago	Michoacán
Yuriria	80	188	Lerma-Santiago	Guanajuato
Catemaco	75	454	Papaloapan	Veracruz
Tequesquitengo	8	160	Balsas	Morelos
Nabor Carrillo	10	12	Valle de México	México

Altitudinal differences, as well as the climatic conditions in Mexico mentioned above allow the presence of a great variety of aquatic environments such as temperate mountain lakes and streams with clear and cold water, subtropical environments that suffer dramatic changes in water flow and turbidity during the rainy season, and wide tropical rivers and costal lagoons, in other words, a mosaic of freshwater environments that has had an important impact on the diversity and structure of fish communities in Mexico, as well as on the presence of endemic species associated with different water basins (Figure 2.2).

Figure 2.2 *Examples of different freshwater habitats found in Mexico.*

2.1.1 Ichthyofaunal provinces of Mexico

Based on modern distributions of freshwater fishes, endemicity, geologic, climatic and fossil evidence, Miller (2005) recognizes eight ichthyofaunal provinces for Mexico, largely corresponding to major river basins and thus with hydrographic patterns more so than with climatic or biotic subdivisions based on terrestrial organisms. Given the detailed description that Miller (2005) makes of these provinces, and that in Chapter 4 when analyzing richness and endemism their representative species and main characteristics are considered, here these are only listed (1) Penninsular Baja California, (2) North Western Pacific Slope Drainages, (3) Tamesi-Panuco Complex, (4) Mesa Central, (5) Balsas River, (6) South Western Pacific Slope Drainages, (7) Chiapas-Nicaragua, and (8) Usumacinta. Other regions are considered as transition zones (Figure 2.3).

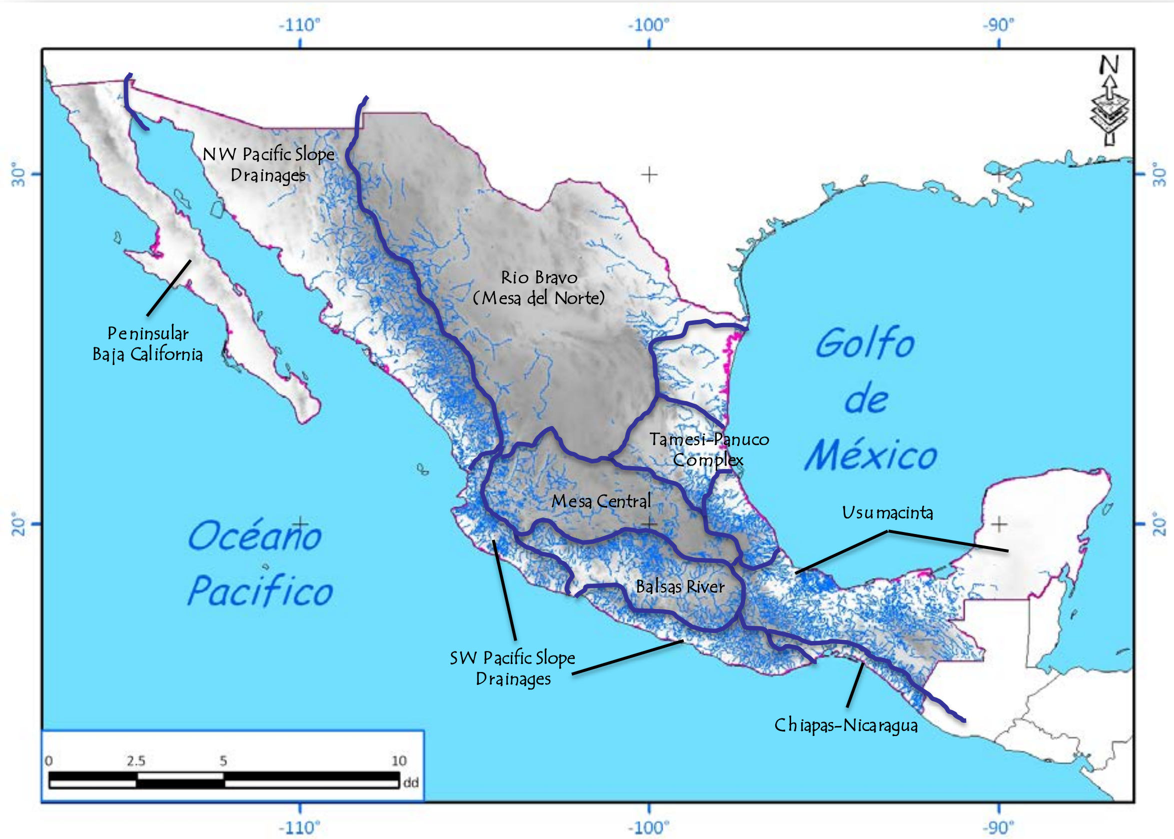


Figure 2.3 *Ichthyofaunal provinces of Mexico. Unlabeled regions represent zones of transition among provinces (Map redrawn from Miller 2005).*

2.1.2 Status and threats to freshwater resources

Unfortunately, Mexico suffers from most of the environmental problems associated with unsustainable human development, such as resource overexploitation, pollution, and loss of biodiversity (OCDE 1998, INEGI 2000). It is not an exaggeration to state that aquatic ecosystems are possibly the most affected by human activity; thus rivers, lakes, lagoons, and seas receive a great quantity of contaminants from large cities, from industrial parks, and from livestock and agricultural activity. This situation has had its impact on freshwater species (Dirzo *et al.* 2009) and on freshwater fishes (see chapter 4).

These threats rarely act in isolation; rather, they have synergistic effects that complicate management priorities and responses (Thieme *et al.* 2010). Moreover, recent global analyses of progress towards the CBD 2010 targets showed that indicators of the state of biodiversity are trending downward, while indicators of threat intensity of pollution, over-exploitation and invasive species are increasing (Butchart *et al.* 2010)

2.1.2.1 Water pollution

In 2007, the National Water Quality Monitoring Network operated by the Mexican water authority (CONAGUA) had 1,014 sites, distributed throughout the country. The evaluation of surface water quality is carried out by using three indicators, five-day Biochemical Oxygen Demand (BOD_5), which determinates the quantity of biodegradable organic matter; Chemical Oxygen Demand (COD), that measures the total quantity of organic matter; and Total Suspended Solids (TSS), that are originated mainly through soil erosion. The BOD_5 and COD are used to determine the quantity of organic matter present in water bodies, mainly from municipal and non-municipal wastewater discharges, while high levels of TSS result in the water body losing its capacity to support the diversity of aquatic life and the resulting affectation of aquatic ecosystems.

Data from monitoring sites in 2007 for the BOD_5 indicator (CONAGUA 2010) show that 14% of the sites had poor water quality (9.4% polluted and 4.6% heavily polluted), 17.6% were acceptable and 69% had good and excellent quality (Table 2.2).

Table 2.2 *Percentage distribution of water quality monitoring sites, by category of BOD_5, 2003-2007 (data from CONAGUA 2010).*

Year	Excellent	Good quality	Acceptable	Polluted	Heavily Polluted
2003	51.8	12.9	15.7	14.3	5.3
2004	41.3	21.8	21.3	10.3	5.3
2005	42.2	21.6	19.2	12.4	4.6
2006	40.4	25.3	17.6	11.3	5.4
2007	38.2	30.2	17.6	9.4	4.6

By looking at the changes in the percentages by category between 2003-2007 (Table 2.2) it would seem that there is a significant positive water quality tendency demonstrated by the 17.3% increase (more than double) in the good quality category, but most of it can be explained by the 13.6% reduction on the excellent water quality category in the same period. Although there was a 4.9% reduction in the polluted water indicator that must be acknowledged.

By drawing a map with the results of CCONAGUA's monitoring sites for 2007 (Figure 2.4) the distribution of polluted, as well as clean sites can be seen.

Figure 2.4 *Distribution of water quality monitoring sites for the DBO_5 indicator in México (Map drawn from the Atlas Digital de México 2010 own analysis).*

Highly polluted sites (red) are concentrated in "Cuenca del Valle de Mexico" in the metropolitan area of Mexico City and polluted sites (orange) are distributed mainly in the Lerma-Chapala-Santiago river system, but are also scattered in other areas of the country.

In the case of the COD indicator from monitoring sites in 2007 (CONAGUA 2010) data show a worst situation where 32.5% of the sites had poor water quality (22.4% polluted and 10.1% heavily polluted), 21.9% were acceptable and 45.6% had good and excellent quality (Table 2.3).

Table 2.3 *Percentage distribution of water quality monitoring sites, by category of COD, 2003-2007 (data from CONAGUA 2010).*

Year	Excellent	Good quality	Acceptable	Polluted	Heavily Polluted
2003	28.8	21.4	18.4	20.4	11.0
2004	23.9	18.5	19.6	26.2	11.8
2005	25.6	16.9	18.1	28.3	11.1
2006	19.5	18.9	23.8	26.8	11.0
2007	21.9	23.7	21.9	22.4	10.1

In this case, by looking at the changes in the percentages by category between the years 2003-2007 (Table 2.3), there is an evident reduction (6.9%) of the excellent water quality category, and all other categories have only minor changes.

Figure 2.5 *Distribution of water quality monitoring sites for the COD indicator in México. (Map drawn from the Atlas Digital de México 2010).*

In the case of COD, highly polluted sites (red) as well as polluted sites (orange) are concentrated in “Cuenca del Valle de Mexico” in the metropolitan area of Mexico City and in the Lerma- Chapala-Santiago river system (Figure 2.5), but polluted sites are also well distributed in other areas of the country.

Data from monitoring sites in 2007 for the TSS indicator (CONAGUA 2010) show that 8% of the sites had poor water quality (5.8% polluted and 2.2% heavily polluted), 14.6% were acceptable and 77.4% had good and excellent quality (Table 2.4).

Table 2.4 *Percentage distribution of water quality monitoring sites, by category of TSS, 2003-2007 (data from CONAGUA 2010).*

Year	Excellent	Good quality	Acceptable	Polluted	Heavily Polluted
2003	44.4	28.7	16.5	7.7	2.7
2004	45.3	29.6	13.1	7.6	4.4
2005	49.4	32.0	11.9	5.3	1.4
2006	45.3	33.0	14.0	5.4	2.3
2007	35.9	41.5	14.6	5.8	2.2

Changes in the TSS indicator percentages by category between the years 2003-2007 (Table 2.4) show a 12.8% increase in good quality category that can be attributed mainly to a 8.5% reduction in the excellent quality indicator. All other indicators have only minor changes.

Figure 2.6 *Distribution of water quality monitoring sites for the TSS indicator in México. (Map drawn from the Atlas Digital de México 2010).*

As shown in Figure 2.6 the TSS indicator by monitoring sites shows a slight concentration of highly polluted sites (red) as well as polluted sites (orange) in central Mexico, although there are some others distributed in other areas of the country, but with no clear pattern.

Based on the results of the water quality evaluations of the three indicators (BOD_5, COD and TSS) applied to the monitoring sites, CONAGUA (2010) determined that 19 catchments were classified as heavily polluted in one, two or all three of these indicators.

2.1.2.2 Water abundance and extraction

As in many other countries, water is not evenly distributed in Mexico, due differences in rainfall, for example, in Tabasco the rainiest Mexican state, yearly precipitation is almost 13 times more than that of Baja California Sur, the driest state (Figure 2.7). This situation has important repercussions on freshwater fish diversity and conservation.

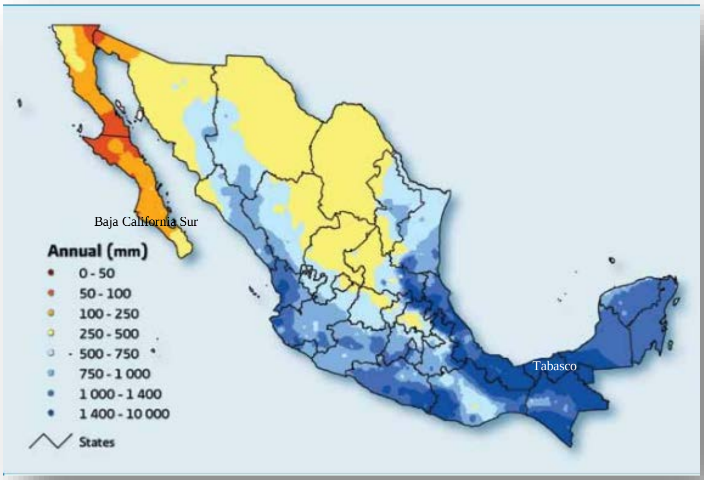


Figure 2.7 *Annual rainfall in México. (CONAGUA 2010).*

A serious problem in Mexico, associated mainly to dry and heavily populated areas is that since the 1970s, the number of overdrafted aquifers has grown steadily, going from 32 aquifers in 1975, 80 in 1985, 97 in 2001, and 101 overdrafted aquifers in 2008 (CONAGUA 2010). This has caused the disappearance of some important freshwater fish habitats, such as the springs in Sandia and Potosi valleys in Nuevo Leon (Contreras-Balderas & Lozano-Vilano 1996). This is also causing saltwater intrusion in 16 aquifers nationwide but mainly in the Baja California Peninsula and in the Mexican Plateau (Figure 2.8). The phenomenon of soil salinization and the presence of brackish groundwater indicate high levels of soil salinity and groundwater produced by high indices of evaporation in areas of low groundwater levels, the dissolution of evaporite minerals and the presence of high-salinity connate water. Brackish water intrusions occur specifically in those aquifers located in geological provinces characterized by ancient, superficial, of marine origin and evaporite sedimentary formations, in which the interaction of groundwater with the geological material through which it passes produces the higher salt content (CONAGUA 2010).

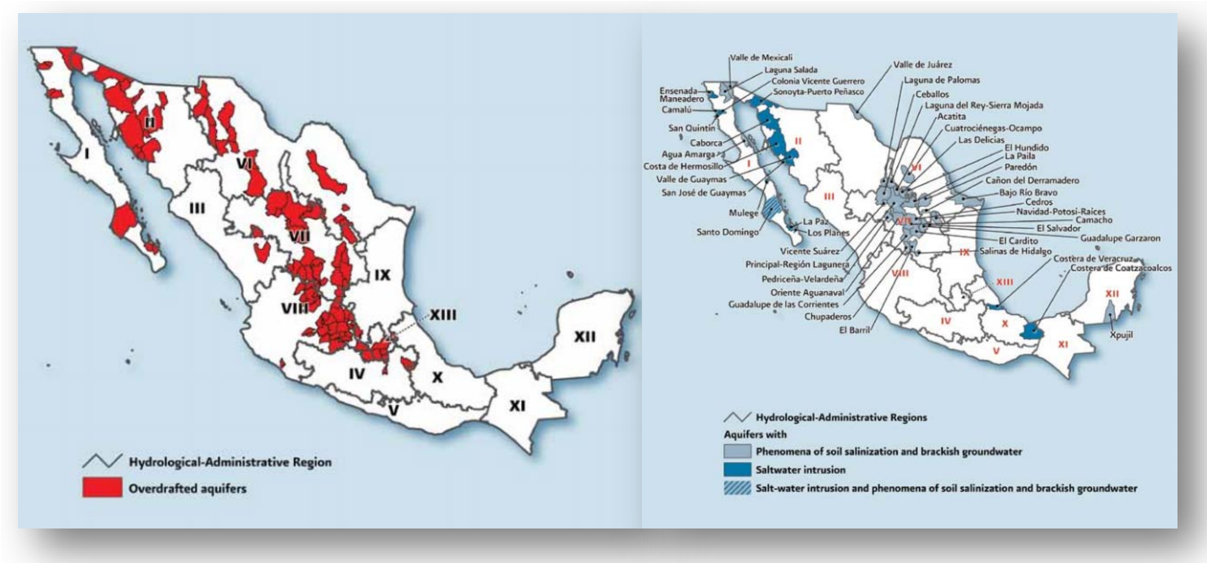


Figure 2.8 *Overdrafted aquifers (left) and aquifers with phenomena of soil salinization and brackish groundwater contamination, and saltwater intrusions (right) in Mexico by CONAGUA's administrative regions (CONAGUA 2010).*

Chapter 3: Diversity, richness and endemism of the freshwater fishes of Mexico

3.1 Introduction

Due in part to its size (1.96 * 10^6 km^2), climatic range, variable habitats and geological history (see section 2.1-Chapter 2), Mexico contains a disproportionately large number of species within its flora and fauna. It hosts at least 10% of the terrestrial diversity on the planet and holds a global first place in the abundance of reptiles, second place for the abundance of mammalian species, and fourth place the abundance of amphibians and plants (Espinosa *et al.* 2008). Currently the number of freshwater species found within Mexico is 616 of which 266 are considered to be Mexican endemics (section 3.5-Chapter 3). There are also 115 exotic species (Contreras-Balderas *et al*. 2008).

This condition, as well as its situation as a transition zone between the nearctic and neotropical biogeographical regions makes Mexico an interesting area for research (Morrone 2005). There have been many studies focusing on describing distributional patterns of terrestrial species on a country wide scale (Ramamoorthy *et al.* 1993, Flores-Villela & Gerez 1994, Koleff *et al.* 2008) however, even though there are many studies dealing with freshwater species at regional levels (Domínguez-Domínguez *et al.* 2006, Huidobro *et al.* 2006), there have been only a few for the whole country (Aguilar-Aguilar *et al.* 2008).

Sound environmental planning and management has to be based upon reliable scientific information (Glickman 1997), and in the case of Strategic Planning for Species Conservation, one of the first steps is to define the taxonomic scope of the species to work with (IUCN/SSC 2008) in this respect, the basic input for this study has been a working list of Mexican freshwater fishes, from which to carry out further analysis.

Fortunately Mexico is among the best studied countries of the world with respect to freshwater fish species, with formal investigations expanding for at least 250 years (Miller 2005). First descriptions of Mexican freshwater species go as far back as Linnaeus (1758) *Systema Naturae*, where 5 Mexican freshwater fishes are mentioned. Other early works are those of Cuvier & Valenciennes (1835) that mention 14 species and Günther (1859-70) that mentions 30. The first contribution of a Mexican ichthyologist dates back to 1837 when Miguel Bustamante y Septien described

Girardinichthys viviparous (Gaspar-Dillanes 2005). Some other early relevant publications are *Fishes of North and Middle America* by David Starr Jordan & Barton Warren, Evermann (1896, 1898, 1900), *the fresh-water fishes of Mexico north of the isthmus of Tehuantepec* by Seth Eugene Meek (1904), and *Biologia Central-Americana* by Charles Tate 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. After this period there have been important and progressive contributions to the knowledge of Mexican freshwater fishes, most of which begin with the work of Professor José Alvarez del Villar, who started his carrier in 1945, who in his productive carrer described 35 species and also started a school of Mexican ichthyologists (Guerra 1998). The second and most cited list is that of Espinosa *et al.* (1993) who mention 506 species, but even though there has been much taxonomic work and many species described since then, no new list has been produced, even though some papers mention species numbers, such as Miller (2005) with 495 species, Froese & Pauly (2006) with 493, and Contreras-Balderas *et al*. (2008a) with 545.

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

Both richness and endemism are important for biodiversity and constitute an essential component of the 'hotspot' concept (Myers 1988, 1990, Myers *et al*. 2000). Myers (2003) has stressed that *"there is an urgent need to document freshwater ecosystems which could prove to be one of the most species-rich hotspots, certainly in terms of fish and one of the most severely threatened of all hotspots"*. In a recent publication Mittermeier *et al.* (2010) worked with the premise that freshwater ecosystems are the ultimate biodiversity hotspot. With this in mind this study presents a country-wide analysis of the distributional pattern of most of the known species of freshwater fishes emphasizing in patterns of richness and endemism and focusing on identifying hotspots for further conservation planning.

The concept of endemism is essential in historical biogeography (Henderson 1991, Crisp *et al*. 2001, Linder 2001), and species rarity, and endemism are among the most frequently cited criteria for establishing conservation priorities (Reid 1998, Schmeller *et al*. 2008, Burlakova *et al*. 2010). A taxon is defined as endemic if its distribution is restricted to a given territory, regardless of territory size (Anderson 1994, Zunino & Zullini 2003). Several formal methods for determining areas of endemism have been proposed (Morrone 1994, Espinosa *et al*. 2001, Szumik *et al*. 2002). Some of these methods are based on the division of an extensive area into quadrats that allow artificially delimited areas to be analysed with a relatively similar size on a minor scale in comparison with other geographical units (Morrone & Escalante 2002, Da Silva *et al*. 2004, Rovito *et al*. 2004, Biondi & D'Alessandro 2006).

From a methodological perspective some authors have avoided arbitrary limits on endemism by counting all species (no matter how widespread) in each cell, but weighting each by the inverse of its range (Dony & Denholm 1985, Usher 1986, Williams & Humphries 1994). Thus, a single-cell endemic has the maximum weight of 1, a species occurring in two cells has a weight of 0.5, and a species occurring in 100 cells has a weight of 0.01. To obtain an endemism score for a cell, these weights are summed for all species occurring in the cell. This is termed as the measure of *weighted endemism*. However, this measure correlates even more with species richness, therefore, it is important to have a measure of endemism that is least related to species richness. This has been done by dividing the weighted endemism index by the total count of species in the cell, thus deriving a new index termed *corrected weighted endemism* (Crisp *et al*. 2001). This index corrects for the species richness effect by measuring the proportion of endemics in a grid cell.

3.2 Aim and objectives

The aim of this study was to produce and updated list of the freshwater fishes of Mexico, as well as to analyze their current distribution across the country in terms of richness and endemism, and to identify hotspots as a tool for management.

Objectives:

e) To produce an updated species lists of freshwater fishes inhabiting the Mexican territory
f) To identify endemic species
g) To analyze the data in order to identify speciose groups and rare species
h) To analyze the distribution range of Mexican freshwater fishes

i) To identify freshwater fish species richness centers within Mexico

j) To identify areas of endemism for the freshwater fishes of Mexico

k) To identify freshwater fish hotspots within Mexico that could define conservation action

3.3 Study Area

(Described in section 2.1-Chapter 2)

3.4 Methods

The list includes all fish species found in freshwaters within the Mexican territory. The definition of freshwater fishes proposed by the Freshwater Fish Specialists Group of IUCN was adopted, which considers them as fish species that live all, or a critical part of its life, in either freshwater inland or brackish estuaries (McGregor *et al*. 2010).

To generate this list, the first step was a revision of Mexican freshwater fish species recognized by the Mexican Biodiversity database held by CONABIO (Mexican Commission on Biodiversity), which resulted in a list of 505 species, after eliminating invasive species. This was then contrasted with freshwater fish species listed by Espinosa-Pérez *et al.* (2003) and Miller *et al.* (2009). Following this, recently described species or changes in nomenclature from several authors that were not considered in previous lists were included (Barbour 2002, Lozano-Vilano 2002, Castro-Aguirre *et al*. 2002, Rodiles-Hernández *et al*. 2005, García-Ramírez *et al*. 2007, Domínguez-Domínguez et al. 2007, 2009, Schmitter-Soto 2007, Schönhuth *et al*. 2008, Pérez-Rodríguez *et al.* 2009, Lang *et al*. 2009, McBride *et al*. 2010).

Once this was done, each species was contrasted against *Fishbase* (Froese & Pauly 2010), in order to check its validity and spelling. Families were arranged following Eschmeyer & Fong (2010), which was also used as taxonomic authority.

For the development of the geographical analysis the methodology employed by Aguilar-Aguilar *et al.* (2008) was followed, which consisted in obtaining geo-referenced distribution records for the freshwater fish species of Mexico. In order to do so, the database of the Mexican Biodiversity Commission (CONABIO) was consulted, as well as that of the Global Biodiversity Information Facility (GBIF). This resulted in obtaining 36,174 records for 534 of approximately 650 freshwater fish species registered for Mexico (this includes exotic species), which represents 82% of the total.

The next step was to construct distribution maps for each taxon in *vector* format using ArcGis 9.3. These were superimposed in a 1:4,000,000 scale map of Mexico obtained from the geo-information module of CONABIO. In order to detect possible distributional inconsistencies and eliminate false positives (Fielding & Bell 1997), each map was reviewed and compared to known species accounts such as those of Miller *et al.* (2009) and Fishbase (Froese and Pauly 2010). This led to the elimination of 358 point records, a relatively small number that corresponds to less than 1% of the total.

Using the same map of Mexico, a 1°X1° grid (each 1° cell is equivalent to 12,345 km^2) was constructed. It took 249 grid-cells to cover the whole study area. These grid-cells were marked by assigning a number from West to East that ranged from 1 to 31 and a letter from North to South, ranging from “A” to “M”. This marker allowed to compare them by means of the geographical layers. The grid was then transformed to *raster* format. Once the grid was obtained, each grid-cell was assigned a consecutive number from 1 to 249.

For evaluation, data of each species was transformed to *raster* format, obtaining a matrix in binary format, with grid-cells with a value of “1” where the species was present and “0” where it was not. The grid with the distributional covertures of each species was then combined using the “combine” command of Arc Info 7.0, which from a series of *rasters*, creates a new one that shows in its database all the possible combinations among all the *rasters* used in the operation.

The end result is a coverture in matricial format with an associated table that contains 534 columns, each representing a species, and 249 lines that represent grid-cells. In this way, the presence-absence information for every species in each grid-cell was obtained. The total of each line then represents species richness in each grid-cell, while the total for each column indicates the distributional range for each species. With this information a map of Mexico was constructed for graphic purposes showing species richness in three categories: 1-30 species (Low), 31-60 species (medium) and 61-90 species (high), a procedure similar to that of Aguilar-Aguilar *et al*. (2008).

The endemism analysis is based on the Corrected Weighted Endemism Index CWEI (Aguilar-Aguilar *et al*. 2008, Crisp *et al*. 2001, Linder 2001) and only 216 of the 266 known Mexican endemics were included. To calculate the Weighted Endemism Index (WEI), each species is weighted for the inverse of its range such that each endemic species distributed in only one grid-cell has a maximum 'weight' of 1; if a species is present in three grid-cells, it has a weight of 0.33 and one in 30 grid-cells has a weight of 0.03. To calculate the value of each grid-cell, the weight values for all the species in that grid-cell are added so that cells with a high number of restricted range species have a higher score than grid-cells with fewer restricted range species (Linder 2001). To correct for the correlation with species richness, and to generate the CWEI, the 'weighted' endemism is divided by the total number of species in a grid-cell (Crisp *et al*. 2001). A map that differentiates between areas of low, moderate and high endemism was produced with the results of this analysis.

Due to the fact that the former is a coarse analysis that considers relatively large areas, and that it is known that some Mexican freshwater fish species have highly restricted distribution ranges that would not be identified by this means, single site endemics (extant species) were analyzed separately, so as to have a finer view of endemism.

In order to identify possible conservation "hotspots" of richness + endemism, the two previous maps were then combined by creating two raster maps both with the same grid size a grid position and the same geo-reference, the first of species richness, the second of species endemism. A cross operation was performed by overlaying the two raster maps by comparing cells at the same positions in both maps and keeping track of all the combinations that occur between the values or classes in both maps. A cross-table and the output cross-map were obtained. The results were stored in an output cross-table and an output cross-map. In the table associated with the output raster, a new item was created containing a unique value for all the possible combinations of the two input classes, as well as the class number and description of the first input map (richness) and those of the second input map (endemism) which makes it possible to identify every single combination. The number of pixels occurring for each combination was counted, as well as the areas of the combinations were calculated. A biodiversity quality indicator was then defined assigning to every combination a value, following the decision rule:

$$IF\ V_r + V_e < 4\ then\ BQI = poor\ else\ if\ 4 \leq V_r + V_e \leq 5\ then\ BQI = medium\ else\ BQI = high$$

This produced a map that correlates richness + endemism.

3.5 Results and discussion

3.5.1 Species list

This process resulted in a working list of 616 fish species grouped in 61 families for Mexican freshwaters (see Appendix A). Considering that globally there are approximately 12,000 described freshwater fish species (Nelson 2006), according to this study, Mexico holds about 5.1% of the global freshwater fish diversity. This is a large figure, taking into account that the Mexican territory represents only 1.3% of the world's land area.

Lévêque *et al*. (2008) registered 74 families and 1411 species of freshwater fishes for North America, which means that, according to this analysis, Mexico has within its territory about 82% of the families and 43% of the species known for this subcontinent.

The number of species presented here represents an important increase over the 506 recorded by Espinosa-Pérez *et al.* (1993), the 545 reported by Contreras-Balderas *et al*. (2008a) or the 555 discussed by Miller *et* al. (2009). Even though there has been much work related to the taxonomy and biogeography of Mexican freshwater fishes, an increase of 62 species in a period of two years seems a very high number; however, a great deal of this has to do to the work of Castro-Aguirre *et al*. (2002), who produced a list of 557 estuarine, lacustrine and vicariant species for Mexico, distinguishing those found in different salinities, from that paper at least 40 records for freshwaters were included.

The number of species (616) is in itself relatively high if we compare it to the 546 species registered for Europe (Kottelat & Freyhof 2007), or the 355 species for Southern Africa (Tweddle *et al*. 2009), but can be regarded as low compared to the 2587 species known in Brazilian freshwaters (Nogueira *et al*. 2010).

The 10 most diverse families (Figure 3.1) comprise 418 species (67.9% of the total). In order of abundance, these are: Poeciliidae (87), Cyprinidae (82), Cichlidae (55), Goodeidae (43), Atherinopsidae (39), Cyprinodontidae (34), Ariidae (21), Catostomidae (19), Gerreidae (19), and Gobiidae (18). As a reflection of a global trend, it is interesting to find in this top ten list the three most diverse fish families, Cyprinidae, Gobiidae, and Cichlidae that according to Nelson (2006), have 2420, 1950 and 1350 species worldwide, respectively. All species of the most diverse family Poeciliidae are members of the subfamily Poeciliinae, which includes only livebearers (Berra 2007). It is represented by 12 genera, the most diverse of which is *Xiphophorus*, with 22 species. But the most diverse genera is *Cyprinodon* with 30 species.

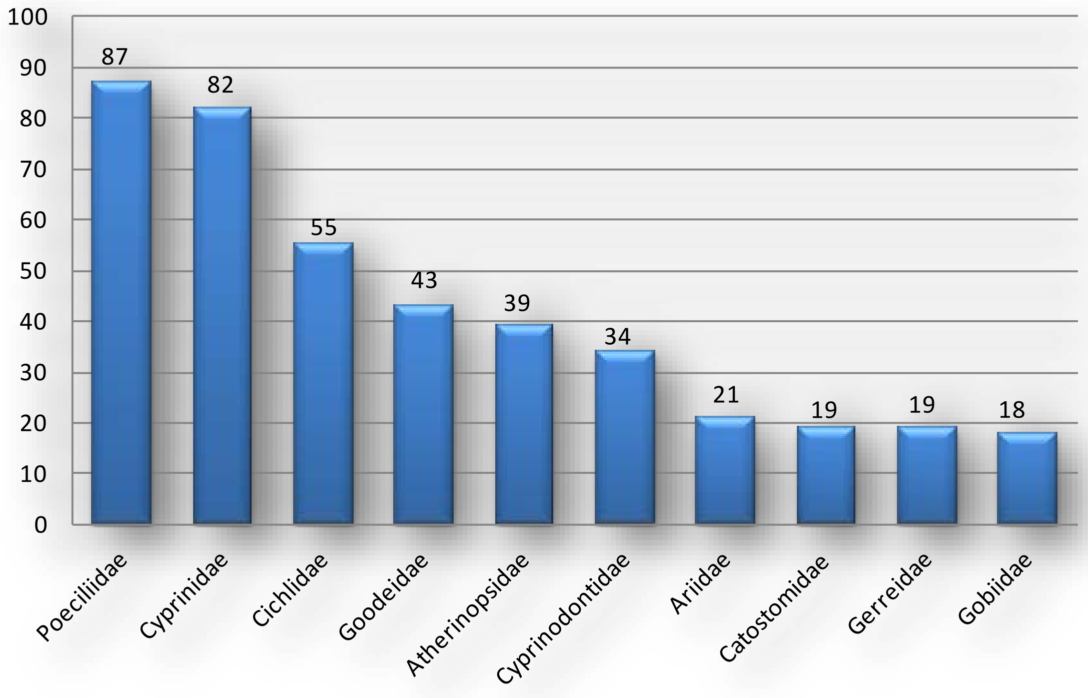


Figure 3.1 *The 10 most diverse freshwater fish families in Mexico.*

At the other end, there are 16 families represented by only one species. Among these, the family Lacantuniidae has to be treated separately, due to the fact that it is monotypic, with *Lacantunia enigmatica* (Rodiles-Hernández. *et al*. 2005) as its only known species.

Apart from species richness, the composition of these dominant families adds to the complexity of this region (Ornelas-García *et al*. 2008) and to its diversity in terms of evolutionary history (Gaston & Spicer 2006), due to the fact the that there are representatives of Nearctic origin such as the Cyprinidae, Catostomidae and Ictaluridae, and others of Neotropical origin, such as the Cichlidae, and of course there are the Goodeidae, which have their origin in the region. This also reinforces the idea that the region has served as a corridor for organismic dispersal between the Nearctic and Neotropic and represents a transition zone between these provinces (Pielou 1979, Miller *et al.* 2009).

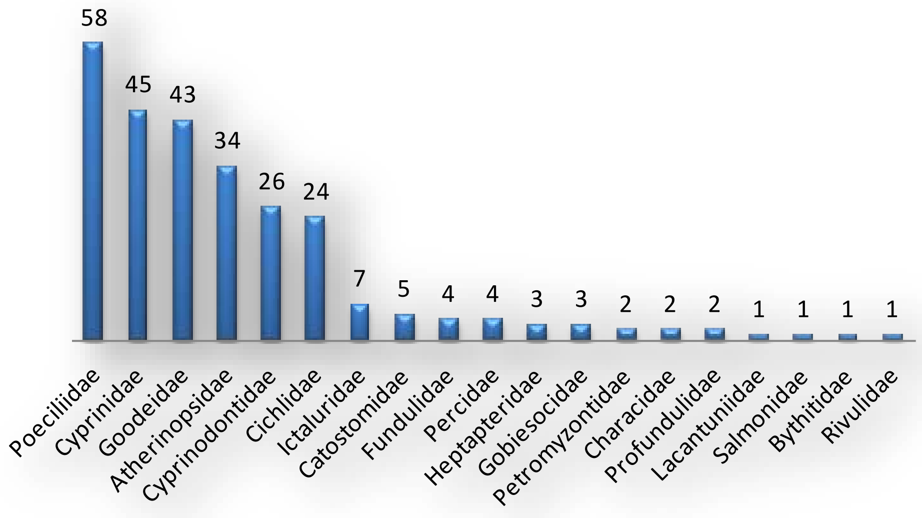


Figure 3.2 *Number of endemic freshwater fish species per family in Mexico*.

Out of the 616 species listed here, 266 are Mexican endemics (43.1%), grouped in 19 families (Figure 3.2). The six most diverse families represent 86.3 % of the total, with 229 endemic species. In this case, Poeciliidae is again the most diverse family, with 58 endemics, followed by Cyprinidae, Goodeidae, Atherinopsidae, Cyprinidontidae and Cichlidae, with 45, 44, 34, 26 and 24 species, respectively.

The Goodeidae family is worth highlighting, due to the fact that out of close to 50 known species, 43 are Mexican endemics and all representatives of the Goodeinae subfamily, which is endemic to Central Mexico (Domínguez-Domínguez *et al.* 2006).

This chapter presents an up todate list of fishes inhabiting Mexican freshwaters, but even though Mexico's ichthyofauna is quite well know, there are still from 30-50 species to be described (Contreras *et al.* 2008, Miller *et al.* 2009) and giving the fact that several groups such as Cichlids and Poeciliids need revisions, as well as new information provided by the use of modern molecular techniques in biodiversity assessments (Hulsey *et al*. 2004, Concheiro *et al*. 2007) an estimation can be made that at least 10% of Mexican freshwater species are yet to be described, so the real number could be close to 700 species.

3.5.2 Distribution range

The 534 freshwater fishes of Mexico used were found to be distributed in 235 of the 249 grid-cells, this represents 94.3% of the country. The 14 grid-cells without the presence of species (see white grid-cells in Figure 3.4) are distributed in the northern portion of Mexico, associated with arid environments, most of them in “El Salado” and “Mapimi” hydrological regions.

The freshwater fish species found to be most widely distributed in Mexico is *Astyanax aeneus* occupying 66 cells or an area equivalent to 26.5% of the country, some 491,093 km^2. The ten species with the widest distribution in Mexico range from 66-45 cells, and these are, *Astyanax aeneus* (66), *Astyanax mexicanus* (65), *Micropterus salmoides* (62), *Poecilia mexicana* (60), *Poecilia sphenops* (55), *Gambusia affinis* (54), *Lepomis macrochirus* (51), *Oreochromis mossambicus* (47), *Heterandria bimaculata* (46) and *Sphoeroides annulatus* (45). By comparing these results with respect to natural distribution maps presented in Miller *et al.* (2009) and Froese & Pauly 2010, some interesting patterns emerge. On the one hand there is a group of species *Astyanax aeneus*, *Astyanax mexicanus*, *Poecilia mexicana* and *Sphoeroides annulatus* with distributions corresponding to their natural boundaries. *Poecilia sphenops* could be included in this group if you consider sites with populations of undetermined taxonomic status mentioned by Miller *et al.* (2009). On the other hand there are species that make this top ten list because of human activities, mostly associated with aquaculture, such as an exotic cichlid *Oreochromis mossambicus* (commonly referred to as Tilapia) which is now the seventh most widely distributed freshwater fish in Mexico. There are four native Mexican species that had relatively small original distributions in Mexico, but that have been translocated to other parts of the country: *Micropterus salmoides* and *Lepomis macrochirus* that have been stocked sport fishing (Contreras-MacBeath *et al.* 1998), *Gambusia affinis* presumably for mosquito larvae control (Miller *et al.* 2009) and *Heterandria bimaculata* that is believed to be dispersed through aquaculture management (Contreras-MacBeath *et al.* 1998). But in any case, by focusing on non-native species at the ecosystem level, rather than the national level (Gozlan *et al.* 2010) it is alarming that 50% of the ten most widely distributed freshwater fishes of Mexico are exotics.

At the other end of the spectrum there are 124 species (23.3% of the total) with ranges restricted to one cell. Most of these are representatives of five families which compromise 67% of the total: Poeciliidae (19 spp), Atherinopsidae (16 spp), Cyprinodontidae (12 spp), Cyprinidae (11 spp) and Goodeidae (9 spp).

By plotting these results it is clear that species-range size distributions for Mexican freshwater fishes fit the strong right-skewed model described by Gaston (1998). That is, most species have relatively small range sizes, and a few have relatively large ones (Figure 3.3), a pattern that has been found for many other taxonomic assemblages (Bell 2001, Jetz & Rahbek 2002).

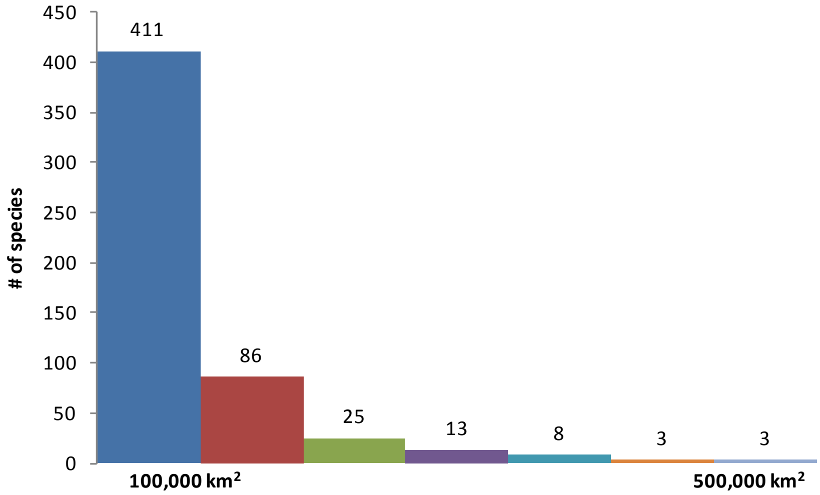


Figure 3.3 *Range size for Mexican freshwater fishes.*

Ceballos (2001) describes rare vertebrate species in Mexico using the 50,000 km^2 criterion of IUCN, finding that 50% of mammal species and 8% of birds are rare. The same author states that in other groups such as reptiles, amphibians and freshwater fishes it must be over 50%. The results presented here confirm this by showing that 57% of Mexican freshwater fishes should be considered rare by the 50,000 km^2 criterion.

Moreover, by considering that each 1° grid cell is equivalent to 12,345 km^2, the 100 species found in this category (19%) roughly fit the criterion of restricted range species of Nogueira *et al.* (2010) who found that of the 2587 freshwater fish species known in Brazilian freshwaters, 819 (32%) had distribution ranges not exceeding 10,000 km^2. As in the case of Brazil, these could be used in the identification of site-scale conservation priorities.

3.5.3 Richness

Richness in the 249 grid squares with records was in the range 1–90 species per grid-cell (mean=19 species). The grid-cell with the most species (90) is localized in Southeastern Mexico in the Papaloapan river basin; it includes Lake Catemaco, los Tuxtlas National Park and the coastal lagoon of Sontecomapan in Veracruz State. Of the 90 species recorded, 6 are exotics, mainly Tilapias introduced for extensive aquaculture. The 86 remaining species are distributed among 27 families, most speciose of which are Poeciliidae with 18 and Cichlidae with 10. Both of these represent 32% of the total. If we group families following Myers' classification of freshwater fishes based on their tolerance to salt water (primary, secondary and peripheral) (Berra 2007), it is found that peripheral families dominate in this grid cell, with 22 families and 50 species, while there are only 2 primary families with 5 species and 3 secondary families with 29 species. This reflects the influence of the paleogeographical history of the region, as well as marine radiations on the freshwater fish fauna (Myers 1966, Miller *et al.* 2009). This is also consistent with what has been described for the whole of North America (Lévêque *et al.* 2008).

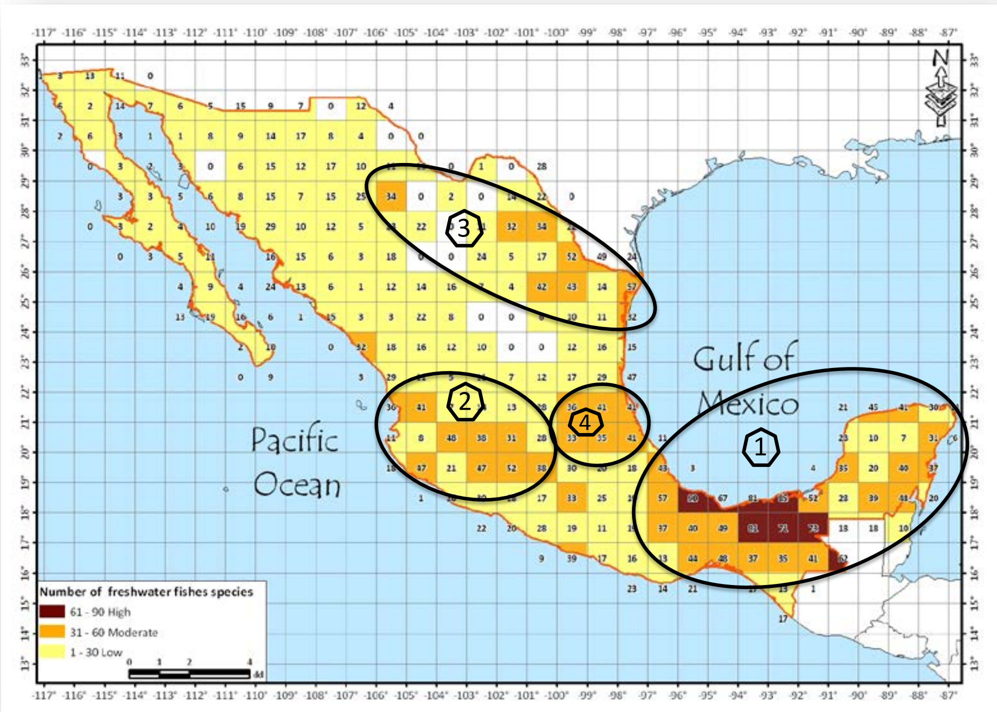


Figure 3.4 *Richness of the freshwater fishes of Mexico. Numbers represent species in each grid-cell. Circles represent centers of richness.*

By viewing figure 3.4, it is evident that highest species richness is found in four distinct centers formed by grid cells with moderate to high diversity that in general terms correspond to the ichthyofaunal provinces of Miller *et al.* (2009):

(1) The first center is localized in Southeastern Mexico, with the largest number of species per grid-cell (62-90) concentrated in the Grijalva-Usumacinta, Coatzacoalcos and Papaloapan rivers (darkest color in the map).This region clearly corresponds to the area of highest availability of water in Mexico (Bunge 2010). By including the Yucatan Peninsula in this centre, it compromises 39 grid-cells and corresponds to the Usumacinta ichthyofaunal province. These findings are in accordance with has been described by Aguilar-Aguilar *et al*. (2008), in a similar analysis for helminth parasites of freshwater fishes. This general pattern is very similar to what has been found for terrestrial vertebrates, where highest richness is always in southeastern Mexico (Koleff *et al.* 2008). This centre has 44 families and 265 species, 16 of which are exotics. The two most diverse families are Cichlidae and Poeciliidae with 42 and 40 species respectively. These are followed by Gobiidae 12, Eleotridae 11, and Ariidae, Cyprinodontidae and Gerreidae with 10 species each. Perhaps due to the large river systems, availability of water and large floodplains (Aguilar 2003, Lara-Lara *et al*. 2008, Bunge 2010), there are species with large distributions, such as *Sciades guatemalensis* (34 grid cells), *Astyanax aeneus* (33), *Cichlasoma urophthalmus* (31), *Poecilia mexicana* (31), *Gambusia yucatana* (29), *Belonesox belizanus* (28), *Rocio ocotal* (28), *Parachromis friedrichsthalii* (27), *Heterandria bimaculata* (24) and *Cichlasoma salvini* (23). But at the other end of the spectrum, there are 71 species with distributions within one grid-cell or 12,345 km^2.

(2) The second centre is found in central Mexico mainly in the Lerma-Santiago river system, which corresponds to the central part of the Mesa Central ichthyofaunal province. It has 8 grid-cells that range from 33 to 52 species, with the highest values concentrated in the region of Michoacan lakes (Patzcuaro and Cuitzeo) as well as Lake Chapala, something that has been described by several authors (Domínguez-Domínguez *et al.* 2006a, Huidobro *et al.* 2006, Mercado-Silva *et al.* 2006). This province also corresponds with the findings of Aguilar-Aguilar *et al*. (2008) for fish helminths. It has 23 families and 122 species, including 19 exotics. The most diverse family is Goodeidae with 25 species, but in the whole of the Mesa Central there are about 41 species (Domínguez-Domínguez *et al.* 2006). Other diverse families are Atherinopsidae, Poeciliidae and Cyprinidae, with 22, 13 and 12 species respectively. The two species with the widest distribution (8 grid-cells) are *Goodea atripinnis* and the exotic *Oreochromis mossambicus*. These are followed by a group of species with relatively wide distributions (7 grid-cells) *Algansea tincella*, *Notropis sallaei*, *Chirostoma arge*, *Ilyodon whitei*, *Poeciliopsis infans*, and the exotics *Oreochromis aureus* and *Xiphophorus hellerii.* This last species is native to Mexico but exotic to the Mesa Central (Miller *et al.* 2009), following the definition proposed by Copp *et al.* (2005). In this centre 55 species with distributions within one grid-cell were found.

(3) The third center is localized in northern Mexico, along the border with the United States, and corresponds to the Bravo-Conchos river system. It compromises 8 grid-cells that range from 32 to 57 species, the most diverse one includes the Rio Bravo delta and part of Laguna Madre, and thus its high diversity is a reflection of the influence of many peripheral fish species. It has 30 families and 122 species, with only 3 exotics. The three most diverse families are Cyprinidae, Poeciliidae and Cyprinodontidae with 24, 14 and 9 species respectively. As in the previous region, species distributions range from 1-8 grid cells. There are five species with the widest distribution *Astyanax mexicanus*, *Gambusia affinis*, *Ictalurus punctatus*, *Lepomis macrochirus* and *Micropterus salmoides*, all native to the region. On the other hand, there are 57 species with distributions within one grid-cell.

(4) The fourth center is found in Eastern Mexico along the central portion of the Gulf, and compromises the Panuco and Tuxpan-Nautla rivers, this last centre corresponds to the Tamesi-Panuco complex ichthyofaunal province. It compromises 7 grid-cells that range from 33 to 41 species. It has 32 families and 125 species, 15 of which are exotics. The most diverse families are Poeciliidae and Cichlidae with 24 and 11 species respectively. Three species are distributed along the whole centre (7 grid-cells), *Astyanax mexicanus*, *Poecilia Mexicana* and *Herichthys cyanoguttatus*. In the case of this last species Miller *et al.* (2009) suggests that for this region it could be a different taxon. There are also 53 species with distributions within one grid-cell.

There are three other grid-cells with relatively high richness, two are along the Pacific coast, one in Guerrero and the other in Sinaloa, but this is due to the influence of peripheral fishes. The last grid-cell has 33 species and is in central Mexico between the States of Morelos and México, thus having the influence of the higher Lerma and Balsas basins. But its high number of species is due mainly to the presence of 14 exotic species, which represent 42% of the total, so by only considering native species it would fall in the low richness category with 19 species. It has been found that in the State of Morelos exotics account for 64% of species richness (Contreras-MacBeath *et al.* 1998).

3.5.4 Endemism

Results show that Mexican endemics are widely distributed in the country due to the fact that the 216 freshwater fish species that were included in this analysis are distributed in 174 of the 249 grid-cells, which represents 70% of the country (colored grid-cells Figure 3.5). There are also areas of moderate endemism all along the country, but with no distinctive pattern.

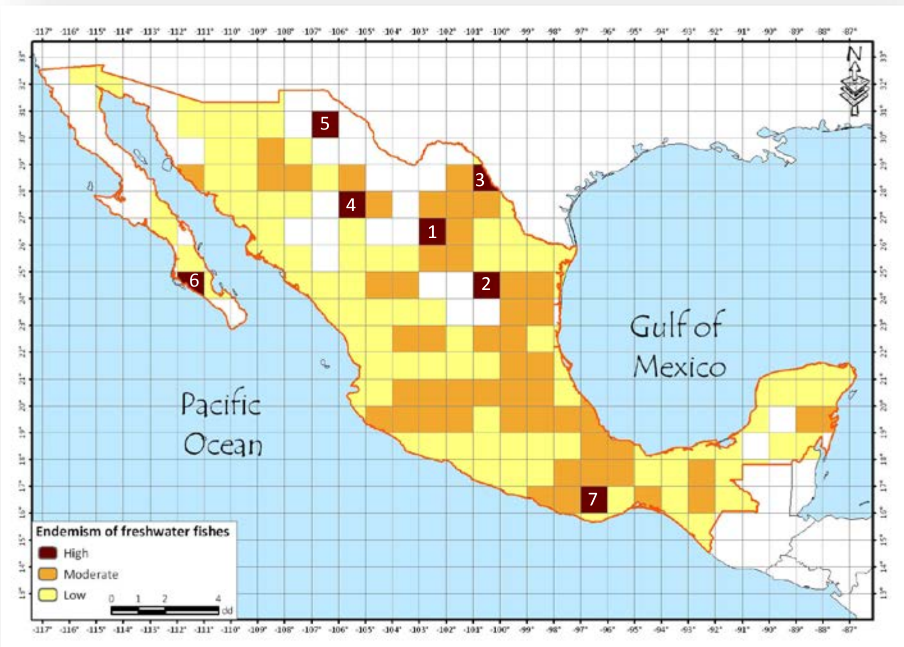


Figure 3.5 *Centers of endemism for Mexican freshwater fishes.*

As a result of CWEI, seven individual grid-cells resulted with high values, these are highlighted in the map (dark color Figure 3.5), most of which are in northern Mexico, associated with arid ecosystems and relatively low species richness, as well as species with restricted distributions. These individual grid-cells can be grouped in two categories: grid-cells 1 and 2 considered as true centers of endemism; the first center of endemism (1) basically compromises the valley of Cuatrociénegas, in central Coahuila, which is a 1000 km^2 desert valley that has the greatest number of endemic species of any place in North America (Stein *et al*. 2000). Much of its biotic diversity is associated with a diverse complex of thousands of geothermal springs, marshes, lakes and streams (Souza *et al.* 2006). It has the highest richness of all the areas of endemism identified in this paper with 10 endemic fish species, but its high CWEI value is determined by *Cyprinella xanticara*, *Cyprinodon atrorus*, *Cyprinodon bifasciatus*, *Etheostoma lugoi*, *Gambusia longispinis*, *Herichthys minckleyi*, *Lucania interioris* and *Xiphophorus gordoni*. This is one of the eight globally outstanding freshwater ecoregions identified for Mexico by Revenga *et al.* (2000). The second center of endemism (2) compromises two springs included in two endorheic basins in Southwestern Nuevo León; El Potosí (Ejido Catarino Rodríguez, Municipio de Galeana), which was the type locality of *Cyprinodon alvarezi* and *Megupsilon aprorus* (both now extinct in nature) and the Ojo de Agua la Presa in Bolsón de Sandia which was inhabited by *Cyprinodon veronicae, Cyprinodon longidorsalis* (both now extinct in nature), *Cyprinodon inmemoriam* and *Cyprinodon ceciliae* (both extinct). Due to the fact that all of the six species present in this center are all extinct or extinct in nature, it should be regarded as a “ghost” center of endemism. It is alarming that as recently as the 11 years ago this area which roughly corresponds to “Llanos El Salado” ecoregion was regarded as vulnerable by Abell *et al.* (2000) and has now disappeared, so it should be further studied in order to describe the stressors that drived these species to extinction, so as to identify and prevent it to happen in other areas with similar conditions.

In contrast with the former, the rest are highlighted by the CWEI due to the fact that they are in areas with low richness of endemic species, and those present have restricted distributions. Center (3) is localized in the northern part of Coahuila, on the border with the United States. It is determined by two species: *Gambusia krumholzi* from Río de Nava, and *Prietella phreatophila* from a series of caves in the same region.

Even though both the sites where these are found are part of the río Bravo basin, they are restricted to México. Center (4) is defined by *Gambusia alvarezi* that is endemic to the Ojo de San Gregorio spring near Ciudad Parral Chihuahua. Center (5) is determined by *Cyprinodon fontinalis* and *Cyprinella bocagrande*, both from Bolsón de los Muertos in Chihuahua. Center (6) is localized in the Baja California Peninsula and is determined by *Gobiesox juniperoserrari*, that is known only from a series of pools in arroyo "Las Pocitas" in Baja California Sur. Center (7) is localized to the south of the country in Río Tehuantepec, Atoyac basin in the State of Oaxaca, and is determined by two species, *Notropis imelda* and *Poeciliopsis lutzi*.

3.5.5 Single site endemics

Due to the fact that this study is part of a project intended to establish conservation priorities for Mexican freshwater fishes, in order to have a more detailed analysis of endemic species distributions, it was important to identify species with discrete distributions known only from one site. As a result of the analysis 48 species in 10 families that can be regarded as single site endemics were found. The most diverse family is Goodeidae with 13, followed by Cyprinodontidae, Cyprinidae, Cichlidae, Atherinopsidae, Poeciliidae and Heptapteridae, with 11, 6, 5, 5, 3 and 2 species respectively, then there are three families with 1 species each (Fundulidae, Profundulidae and Characidae) (Figure 3.6).

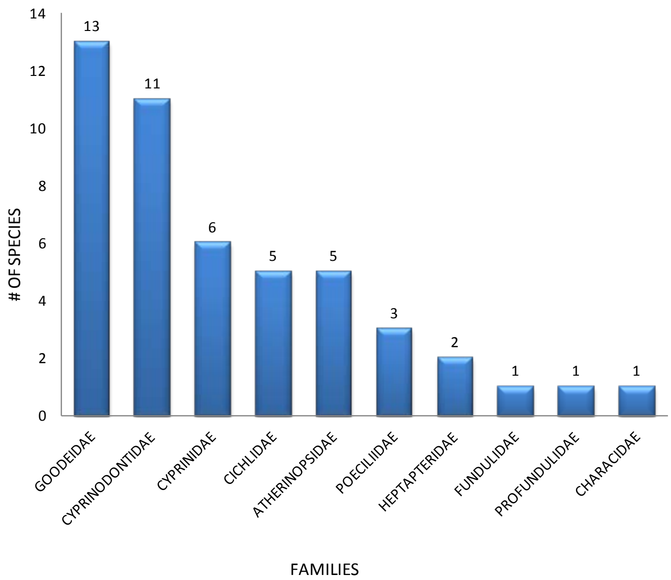


Figure 3.6 *Number of species per family of single site endemics.*

Data represented in Figure 3.7, show that single site endemics are distributed all over the country. Species were found to have highly restricted distribution ranges such as *Zoogoneticus tequila* that is now only found in a 4 meter in diameter spring in Tehuchitlán Jalisco (De la Vega-Salazar *et al.* 2003) and *Cyprinodon julimes* from the Chihuahuan desert that lives in a 742 m^2 thermal spring (De la Maza *et al.* 2010), while others are endemic to larger water bodies such as *Bramocharax caballeroi* restricted to Catemaco Lake in Veracruz which has a surface area of 72.54 km^2 (Torres-Orozco *et al.* 1998). In this last case there are other local endemics such as *Poeciliopsis catemaco* and *Xiphophorus milleri* that live in Lake Catemaco but were not considered because they can also be found in streams and tributaries of the lake (Miller *et al.* 2009).

Figure 3.8 *Map showing records for single site endemic freshwater species in Mexico.*

Even though this is a species orientated approach, a site, Laguna Chichancanab in the border between Yucatan and Quintana Roo, missed by the endemism analysis is highlighted due to the presence of a flock composed of six endemic species of Cyprinodonts (*Cyprinodon beltrani, C. simus, C. maya, C. labiousus, C. esconditus* & *C. verecundus*) (García-Moreno *et al.* 2008). There is also a small region in central-western Mexico, where there are several endemic species of the upper Río Ameca, (*Yuriria amatlana*, *Allotoca goslinei*, *Algansea amecae*, *Ameca splendens* and *Zoogoneticus tequila*) that could be treated as in a center of endemism. The last species mentioned above can only now be found in a single site that is a small spring in Tehuchitlan Jalisco (De la Vega-Salazar *et al.* 2003, Magurran 2009).

3.5.6 Richness + endemism hotspots

In order to identify biodiversity hotspots (Myers, 1988, Crisp *et al.* 2001, Aguilar-Aguilar *et al*. 2008, Myers *et al.* 2000), richness & endemism were correlated and a map was produced (Figure 3.8), where there are basically three hotspots with high values: (1) the Mesa Central, (2) the Central-Southeastern region, and the lower Rio Bravo river. These have been identified as priority areas for conservation in terms of their biodiversity and threats by Aguilar *et al.* (2010).

Among these the Mesa Central stands out, but including headwaters of the Río Ameca, the Lerma-Chapala- Santiago system and extending into the Río Pánuco basin. This whole region includes four of the eight globally outstanding freshwater ecoregions described by Revenga *et al.* (2000) that are distributed along central Mexico. This region has been described as transitional between the Nearctic and Neotropical provinces (Morrone 2005, Huidobro *et al.* 2006, Corona *et al.* 2007) which in the case of fishes contributes to its high richness and endemism (Miller 2005). Within this region two hotspots were identified that have the highest value for the combination of richness and endemism; the first one compromises part of what is known as the “Bajo Lerma” (Díaz-Pardo *et al.* 1993) which includes headwaters of the Río Ameca and lake Chapala, it has 48 species, 38 of which are Mexican endemics (79%), and the second hotspot is formed by two adjacent grid-cells that cover basically the “Medio Lerma”, including lakes Patzcuaro, Cuitzeo and Yuridia, it has 63 species, 49 of which are Mexican endemics (77%). Unfortunately this region has also been identified as one of Mexico’s most impacted river systems by human activities (Garrido *et al.* 2010), something that has also been identified for the region's lakes (Bernal-Brooks 1998, Fisher *et al.* 2003, von Bertrab, 2003), this has had negative impacts on the native fish fauna (De la Vega-Salazar 2006, Domínguez-Domínguez *et al.* 2006, Domínguez-Domínguez *et al.* 2008, Mercado-Silva *et al*. 2009, Magurran 2009), this situation is so bad, that it has led to the extinction of six species: *Chirostoma bartoni, Chirostoma charari, Evarra bustamantei, Evarra eigenmanni, Evarra tlahuacensis* and *Skiffia francesae*, this last species is considered as extinct in the wild (Contreras-MacBeath 2005).

The Central-Southeastern hotspot includes rivers with the most water in Mexico the Coatzacoalcos, Papaloapan and Grijalva-Usumacinta (CONAGUA 2008, Bunge 2010). This hotspot is relevant more because of its richness 208 species, than its endemisms, only 30 species (14.4%). A number that is only relatively low owing to the fact that in their description of the Mesoamerican hotspot, in which this region is included, Myers *et al.* (2000) mention the presence of 4.2% endemic terrestrial vertebrates. Maybe due to the amount of water in this hotspot, as well as the relatively low human population, it is one of Mexico's regions with lowest pollution as indicated by measures of Biochemical Oxygen Demand (BOD_5) and Chemical Oxygen Demand (COD) (CONAGUA 2010), but Rio Grijalva is highlighted as one with large habitat modifications due to the construction of four large dams (Garrido *et al.* 2000). There are two known extinct species in this hotspot *Atherinella callida*, *Priapella bonita* (Harrison & Stiassny 1999).

The last of the hotspots identified is a small area in northern Mexico that corresponds to the lower Rio Bravo. As in the former case, this hotspot is highlighted mainly by its richness of 90 species, rather than its 7 endemics (7.7%). As with many Mexican freshwater ecosystems associated with arid regions, it has been severely impacted by human activities (Contreras-Balderas and Lozano-Vilano 1993). Surveys have demonstrated that the original freshwater fish fauna has been retreating from the lower reaches and is being replaced by brackish and marine invaders (Contreras-Balderas *et al.* 2002). This river that in 1962 had a runoff of over 12,000 million cubic meters/year, in 2002 had less than 2% of that figure, and was dry for months in the delta region, both in 2002 and 2004 (Contreras-Balderas *et al.* 2008).

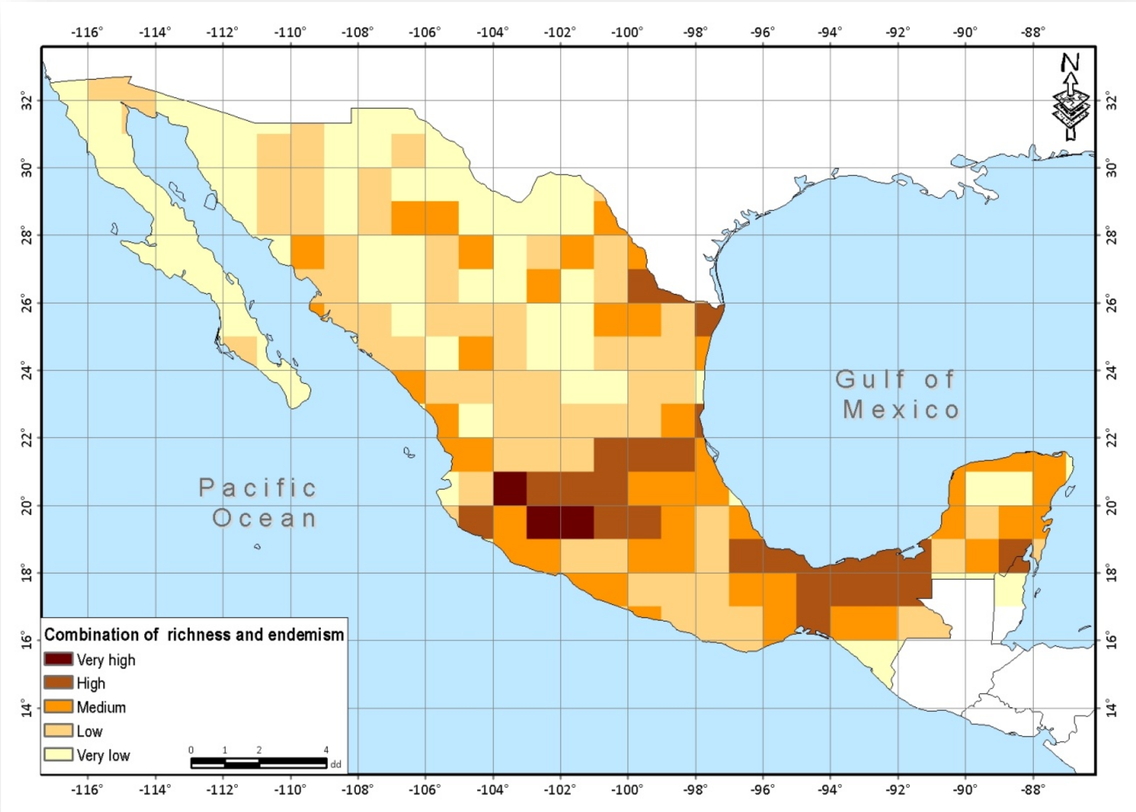


Figure 3.8 *Hotspots of richness + endemism for the freshwater fishes of Mexico.*

3.6 Conclusions

The study of richness and endemism is crucial for identifying hotspots and for directing conservation efforts. Mapping these centers by means of geographical information systems based on museum data have made it possible to confirm several previously identified centres of freshwater fish richness (Southeastern Mexico, the Mesa Central, the Bravo-Conchos river system and the Panuco and Tuxpan-Nautla rivers). Seven areas with high CWEI endemism values were also identified, but the valley of Cuatrociénegas is recognized as a true centre. An alarming result is the identification of a "Ghost" centre of endemism (Llanos El Salado) in Southwestern Nuevo León, where the six endemic Cyprinodont species that where present in this center are all extinct or extinct in nature. 49 single site endemics where found to be very much distributed all over Mexico, but it is noteworthy to mention Chichancanab lagoon in the border between Yucatan and Quintana Roo, where a flock composed of 6 endemic Cyprinodonts is present. Three hotspots of richness and endemism in

Mexico were also identified, the most important of which is the Mesa Central where many impacts of human activities have had a detrimental effect on fish populations.

This study is probably unique in being a country-wide analysis of the distributional pattern of most of the known species of freshwater fishes, but it is suggested that in order to allow for finer detail, further studies should focus at a relatively smaller scale. But this analysis sets the baseline information needed for a systematic conservation assessment of the freshwater fishes of Mexico. The next step should be to complete the threat assessment of each species and once this is completed, it will be possible to cross-reference these findings with the distributional patterns of threatened species and define conservation goals.

Chapter 4: Current conservation status of the freshwater fish of Mexico with an assessment of the main threats.

4.1 Introduction

Human activities have severely affected the condition of freshwater ecosystems worldwide, through increasing threats from dams, water withdrawals, pollution, invasive species, overharvesting and aquaculture. Consequently, their capacity to support biodiversity is highly degraded at a global level, with many freshwater species facing rapid population declines or extinction (Revenga *et al*. 2000, MEA 2005, Dudgeon *et al*. 2006, Abell *et al*. 2008, Salafsky *et al*. 2008). Freshwaters are experiencing declines in biodiversity far greater than those in the most affected terrestrial and marine ecosystems (Ricciardi and Rasmussen 1999, Dudgeon *et al*. 2006). They also have an intimate links to their catchments so land-use alterations affect them directly (Malmqvist & Rundle 2002).

Freshwater ecosystems support an extraordinarily high proportion of the world's biodiversity. In terms of area, freshwater ecosystems occupy only 0.8% of Earth's surface, but they are estimated to harbor at least 100,000 species, or nearly 6% of all described species (Abell *et al*. 2008). Some 12,000 fish species live in fresh water, which represents approximately 43% of global fish diversity and one quarter of global vertebrate diversity (Nelson 2006). When amphibians, aquatic reptiles (crocodiles, turtles) and mammals (otters, river dolphins, platypus) are added to this freshwater fish total, it becomes clear that as much as one third of all vertebrate species occur in fresh water (Dudgeon *et al*. 2006).

Consequently, even though assessments have not been completed for many freshwater groups (IUCN 2009), preliminary findings show high percentage of threatened freshwater species (Table 4.1) from groups such as freshwater fishes (44%), amphibians (30%) and odonata (13%), and that some are facing severe threat of extinction (freshwater fishes 9% and amphibians 7.7%) with respect to terrestrial groups (Birds 1.8% and Mammals 3.4%).

Table 4.1 *Percentage of threatened species for selected groups (Data based on IUCN 2011.1).*

Group/# species assessed	Freshwater Fish /5,593	Amphibians/ 6,2312	Birds/ 10,027	Mammals/ 5,494
Threatened (%)	29	30	12	20
Critically Endangered (%)	7	7	1	3
Data Deficient (%)	19	25	0.6	15

Despite this combination of extraordinary richness, high endemism, and exceptional threat, few broad scale conservation planning efforts have targeted freshwater systems and their dependent species (Abell *et al*. 2008). This might be due in part to the fact that with the exception of amphibians and freshwater crabs, there are no complete assessments for any other freshwater groups (Darwall *et al*. 2009).

Global assessment of other taxonomic groups such as mammals (Schipper *et al*. 2008), birds (Baillie *et al*. 2004) and amphibians (Stuart *et al*. 2004) have raised profile, funds and stimulated conservation action. With this in mind, the IUCN's Freshwater Biodiversity Unit, in collaboration with the Freshwater Fish Specialist Group are undergoing the task of assessing the Freshwater Fishes of the world. To this date Europe (Kottelat & Freyhof 2007), Africa (Darw all *et al*. 2011) and parts of Southeastern Asia have been fully assessed (Blue areas in figure 4.1), North America (including this study of Mexico) parts of South America and several regions in Asia are ongoing (yellow), and there are other areas that have been partially assessed (green), are planned to start (pink), or have not been yet considered (gray).

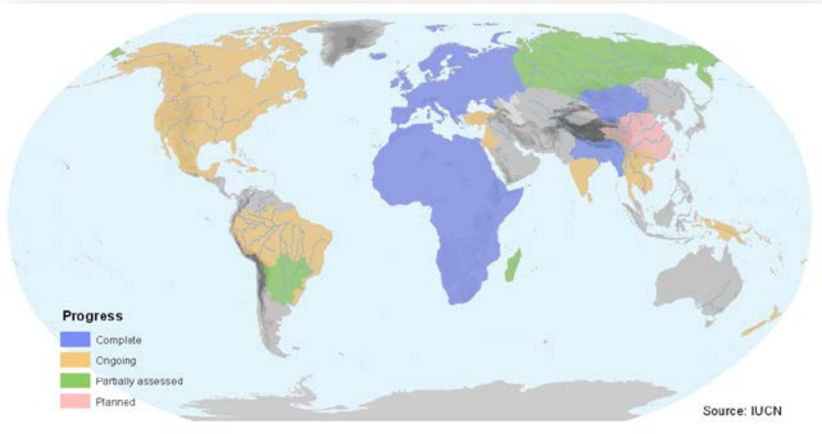


Figure 4.1 *Progress of the global freshwater fish assessment.*

As with many other countries (Rodríguez *et al*. 2000), Mexico has its own system for classifying threatened species, the NOM-059-SEMARNAT-2010 (SEMARNAT 2010), which includes its own methodology (Sánchez *et al*. 2007). As a result of this, the country has published an official listing since 1994 (see section 1.2.4 for a description). This situation has led the IUCN classification system to be marginally used in Mexico both by academics and governmental agencies. Currently only 195 of the 616 freshwater fish species of Mexico (31%) have been assessed using IUCN criteria (UICN 2011.1). Among these 25 species are considered as Critically Endangered, 24 as Endangered, 38 as Vulnerable, and 12 are regarded as Near Threatened. There are 14 species recognized as Extinct and 5 as Extinct in the Wild. 60 species are considered as Least Concerned and 17 as Data Deficient.

But even though Mexico has its own classification system, recently the Convention on Biological Diversity decided that the Red List Index, which is based on Red List data, would serve as a more informative and reliable indicator of the trends in the status of threatened species (Butchart *et al*. 2007), as a signatory to agreed national responses to the Rio Convention (CBD) of 1992, Mexico now needs to evaluate its biodiversity using the IUCN Red List criteria, in order to apply the Red List Index.

4.1.1 Potential threats

In section 2.1.2 a brief description of the potential threats towards Mexican freshwater fish species is given based on a characterization of water pollution in the different regions of the country, based on official data (CONAGUA 2010). But taking in account the body of knowledge there is in Mexico with respect to impacts on freshwaters by means of geographic studies based on socio-economic and environmental data (Cotler 2010), here a brief description with respect to hydrological pressure, diffuse pollution, sanitation, eco-hydrological pressure and climate change.

This description of potential threats has been fundamental in the evaluation of the current conservation status of the freshwater fish species of Mexico presented in section 4.3, and on the subsequent description of direct threats found for individual species, which are described in section 4.6.3.

4.1.1.1 Hydrological pressure on Mexican freshwater basins

As a result of the irregular distribution of freshwater in Mexico (described in section 2.1.2) and that of human settlements, it is important to know the hydrological pressure in the country, which is calculated based on the percentage of extracted water with respect to the mean total natural availability. In this respect Bunge (2010) based on natural water availability data from CONAGUA (2008) on water concessions for agricultural, urban and industrial uses, as well as data on population projections 2005-2030 made by CONAPO (2005), calculated this factor for Mexico, producing the map showed in Figure 4.2.

The analysis showed that 33% of the basins have a strong hydrological pressure and in terms of population pressure (dark red areas on figure 4.2) and that 53% of the people live in basins with this problem. In general it is evident that the same basins that have a low natural availability of water, have higher hydrological pressure. These are found mainly in northern and central Mexico, but northern basins have higher population growth, which in turns means that these will have higher pressure in the future. On the other hand, basins with the lowest pressure are found in south and southeastern Mexico, which are regions with the highest population growth, so planning has also to be made in these regions before things get worse.

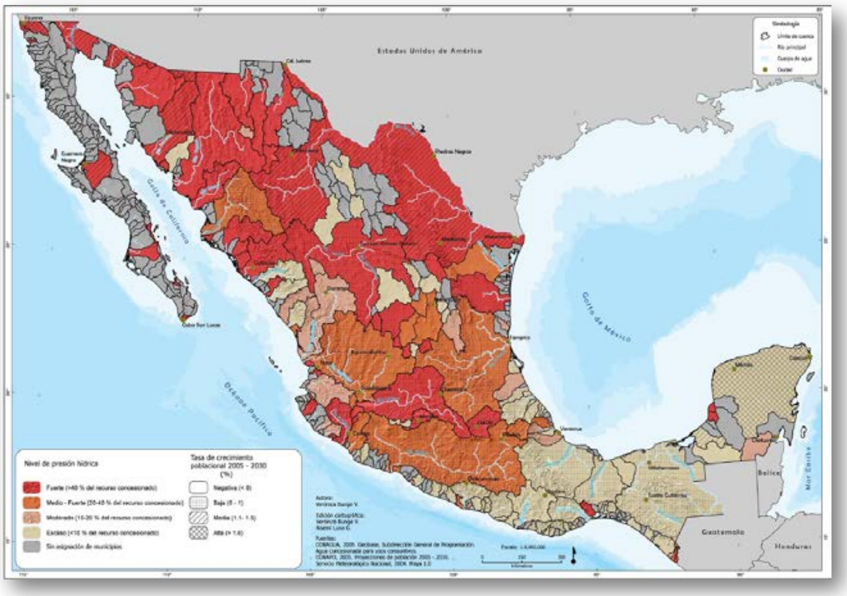


Figure 4.2 *Hydrological pressure on Mexican freshwater basins (Map from Bunge 2010).*

4.1.1.2 Potential diffuse pollution by agriculture

One of the least studied potential threats is related to diffuse pollution that is defined as the introduction of pollutants to a water body through a none-point source, or by an indirect path, like the washing of pollutants through soil, or from sources that can't be pinpointed to a specific site. Diffuse pollution can be continuous of intermittent, being the former the most common because it is related to seasonal agricultural activities, such as the application of fertilizers and pesticides. Diffuse pollution is consequently a result of the cumulative effect of individual sources from different sites, that end up affecting freshwaters of a given basin, subterranean waters and many times marine environments.

Based on data from the Agriculture Census (INEGI 2008) on the amount of pesticides and fertilizers used in every Municipality of Mexico, Cotler & Iura (2010) constructed a hierarchical multi-criteria model to infer the potential diffuse pollution cause by the use of chemicals in agriculture using 1) pollutants used, 2) type of agriculture, and 3) mobility of pollutants, and produced the map shown in figure 4.3 where it is evident that the highest levels of diffuse pollution are present in Northern-Pacific and central basins, as well as those that drain into the Gulf of Mexico. These reflect the extent of agriculture in those regions, which covers from 45 to 60% of the surface area of those basins. It was also found that 35-55% of the surface of those basins use chemical fertilizers.

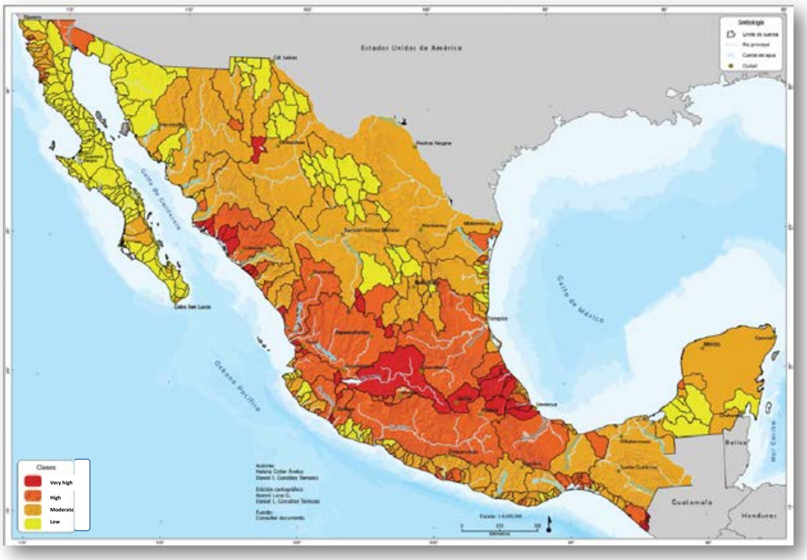


Figure 4.3 *Potential diffuse pollution in Mexican freshwater basins (Map from Cotler & Iura 2010).*

4.1.1.3 Sanitation in Mexican freshwater basins

Sanitation of freshwaters is a well overdue activity in Mexico, in 2008 only 35% of Municipal residual waters and 18% of industrial residual waters received treatment (CONAGUA 2010). In a study that evaluated treatment of Municipal residual waters in Mexico Bunge (2010) found that there were 1,710 water treatment plants in the country and that these only treated 28% of the residual waters generated by industrial and urban activities. When analyzing treatment by basins, it resulted that only a fifth of these treat more than 50% of generated residual waters (Figure 4.4). The same author mentions that those regions that in the map appear without treatment deficit are due to lack or errors in official data, more than true efficiency in the volume of residual water treated.

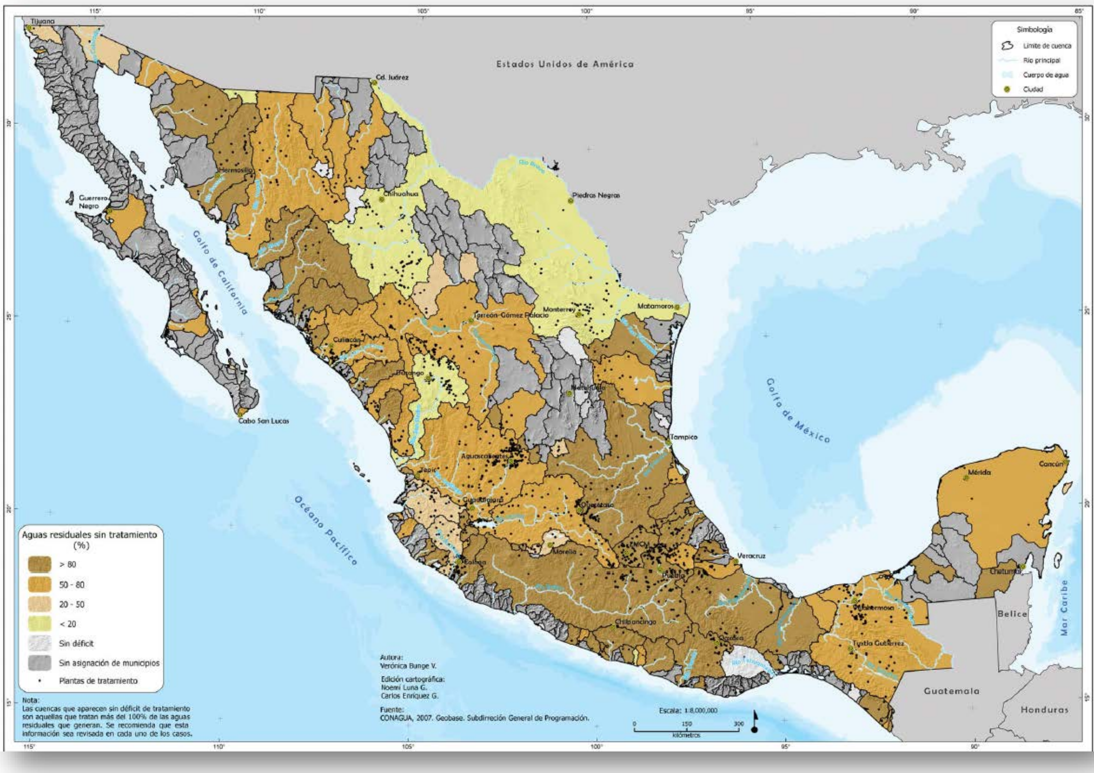


Figure 4.4 *Water sanitation in Mexican freshwater basins (Map from Bunge 2010).*

4.1.1.4 Eco-hydrological alteration of Mexican rivers

By means of the development and implementation of a spatial multi-criteria model consisting of 75 variables that evaluate the cumulative impact of: 1) the presence and operation of hydraulic infrastructure localized in rivers; 2) modification of riparian habitat, and 3) the impact of the territory of basins, Garrido et al. (2010) generated a territorial model related to the eco-hydrological alteration of Mexican rivers (Figure

4.5). As a result of their analysis the authors find that the seven fluvial systems that have the most critical level of eco-hydrological alteration (dark red areas in the map) are the river of the “Cuenca de Mexico”, the Balsas River, rivers of Lake Ciutzeo basin, the Rio Bravo, Rio Santiago, Rio Panuco and the Rio San Luis Potosi. These seven systems represent 31% of the total length of river network in Mexica, as well as 26% of the freshwater river basins of the country.

When considering both high + very high alteration (red + dark red areas in the map) it is evident that 55% of Mexican rivers (313,000 km in length) have been highly modified by human activities. These 29 river systems sustain 81% of the Mexican human population (some 83 million people), and their basins represent 49% of the country. These numbers could show the tight relation between high river alteration and water demand by humans.

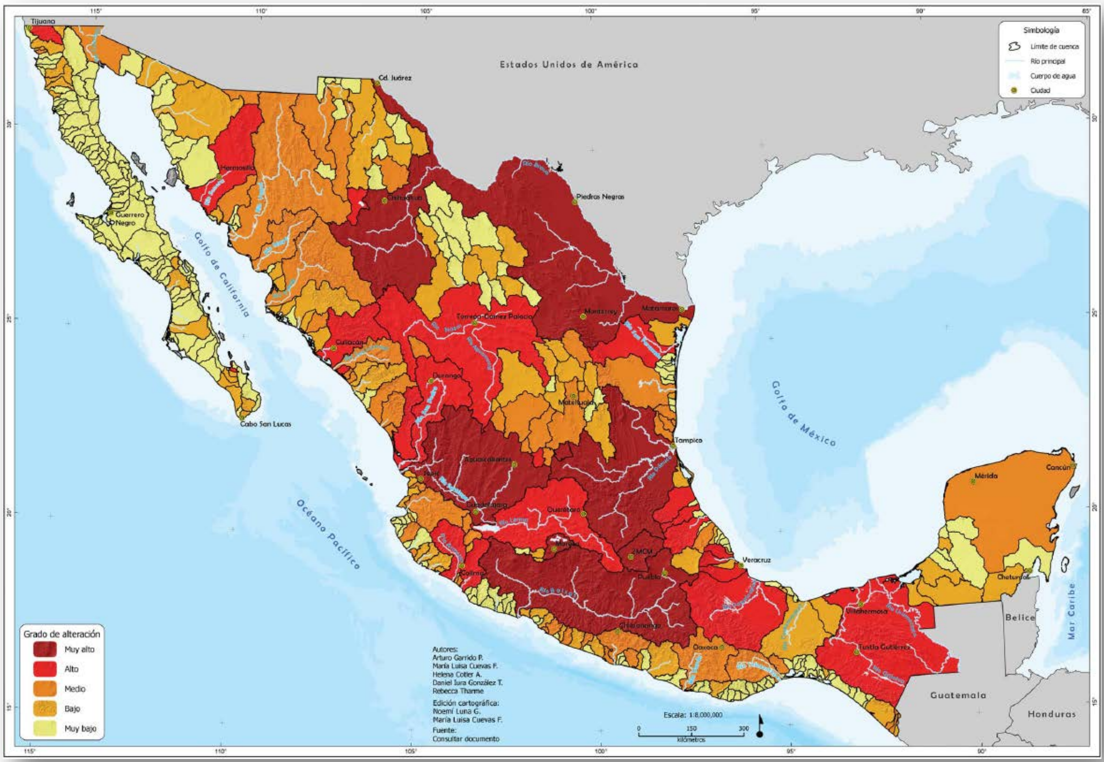


Figure 4.5 *Eco-hydrological alteration of rivers in Mexico (Map from Garrido et al. 2010).*

4.1.1.4 Basin vulnerability to climate change

Climate change is generally causing the world’s waters to warm as well as bringing changes to rainfall patterns, water levels, river flow and water chemistry, this has severe impact on fish species, due to the fact that they cannot control their body temperature. Therefore increasing or decreasing water temperatures will have an impact on growth and reproduction, as will changes of flow and chemistry. Characteristic impacts on fish include stunting, reduced numbers of offspring and even a failure to reproduce at all. Some fish such as salmon, some catfish and sturgeon cannot spawn if winter temperatures do not drop below a crucial level. By contrast, higher temperatures will reduce oxygen levels, making waters uninhabitable for many fishes (Ficke et al. 2007).

With this in mind, using temperature and precipitation projections under climate change scenarios regionalized for Mexico, Murrieta et al. (2010) developed a map for projected anomalies for temperature (Figure 4.6) and another for precipitation (Figure 4.7) using freshwater basins as representation units.

Figure 4.6 *Climate change A2 scenario for temperature 2020s climatology (Map from Murrieta et al. 2010).*

Figure 4.6 shows the geographic pattern of the projection of positive anomalies for temperature which range from 0.5°C to 1.7°C in the Northwestern Mexican basins, in those that flow into the Gulf of California, and in those found in the Southern part of

Baja California Peninsula (red areas on the map), while in Central and Southeastern basins, positive anomalies ranging from 0.4°C to 1.1°C are expected for the 2020's climatology under the A2 scenario for Green House Gases. Which means that Northwestern Mexican basins could experience 0.6°C larger anomalies than other parts of the country.

Figure 4.7 *Climate change A2 scenario for precipitation 2020s climatology (Map from Murrieta et al. 2010).*

In the case of Figure 4.7 related to precipitation, the largest negative magnitude in percentage change are also predicted in the Northwestern Mexican basins, and in the high part of the Gulf of California (darker areas in the map). For the 2020's climatology under the A2 scenario for Green House Gases for these regions, reductions in precipitation of 10% to 20% are predicted. For Central-North and South-Southeastern basins reduction of 5% are expected, while for Central basins and for the Yucatan a 10% reduction are predicted.

These authors conclude that priority basins are those that have a combination of increase in temperature and reduction in precipitation. The impact of these combined factors will increase conflicts between freshwater biodiversity, water extraction, forestry management, among others.

4.2 Aims and objectives

Thus one of the main aim of this study was to assess the extinction risk of each of the Mexican freshwater fish species using IUCN Red List criteria.

Objectives were designed to:

a) Rank individual species according to IUCN categories.

b) Identify patterns of those species deemed to be at risk.

c) Compare the results with those published for freshwater fishes from other regions of the world, and with those previously described for Mexico.

d) Based on species assessments, discus main threats identified

4.3 Study area

(*Described in section 1.5-Chapter 1*)

4.4 Methods

An extensive literature search was carried out in order to gather and collate information for the 616 freshwater fish species known from Mexico, and a database was created with over a thousand references organized by species and families. This information was vital in defining the conservation status of individual species. Spatial data were sourced for the production of distribution maps for each of the 616 species as described in section 4.4. Because of the fact that point data dates back to 1953, and in order to assess current species status most recent distribution data is needed, maps were contrasted against recent freshwater biodiversity surveys provided by CONABIO (Appendix B), and contrasted with publications related to regional and local Mexican freshwater fish distributions (Schmitter-Soto & Gamboa-Pérez 1996, Contreras-MacBeath et al. 1998, Méndez–Sánchez et al. 2002, Ayala-Pérez *et al*. 2003, Guzmán & Lyons 2003, Rodiles-Hernández *et al*. 2005, Mercado-Silva *et al*. 2006, Domínguez-Domínguez *et al*. 2008, López-López *et al*. 2009, Miller *et al*. 2009).

The risk of extinction for each species was assessed according to the IUCN Red List Categories and Criteria: Version 8.1 (IUCN 2010) (Figure 4.8).

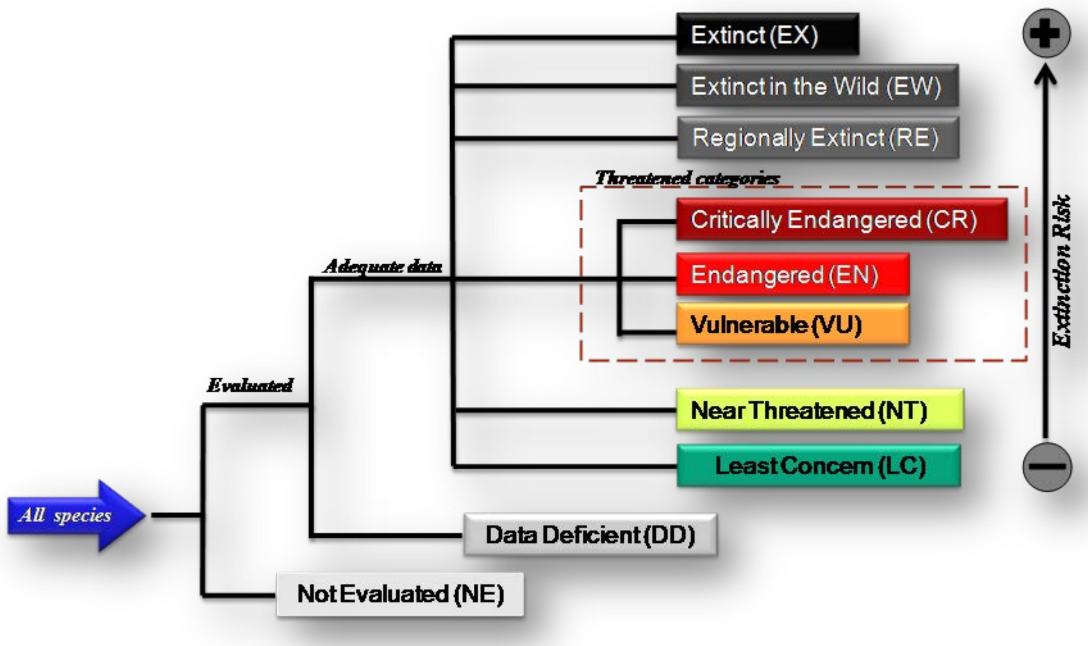


Figure 4.8 *Structure of the IUCN Red List Categories.*

A species is considered **Extinct (E)** when there is no reasonable doubt that the last individual has died. **Extinct in the Wild (EW)** means that the taxon is extinct in its natural habitat but is still kept in captivity, in our case in aquaria. The following three categories, **Critically Endangered (CE), Endangered (E)** and **Vulnerable (Vu)**, are assigned to taxa on the basis of quantitative criteria that are designed to reflect varying degrees of threat of extinction. The category **Near Threatened (NT)** is applied to taxa that do not qualify as threatened now, but may be close to qualifying as threatened. The category **Least Concern (LC)** is applied to taxa that do not qualify (and are not close to qualifying) as threatened or near threatened. The remaining two categories do not reflect the threat status of taxa; the category **Data Deficient (DD)** highlights taxa for which sufficient information is lacking to make a sound status assessment, while the category **Not Evaluated (NE)** applies to taxa that have not yet been evaluated against the Red List Criteria (IUCN 2010).

To distinguish between the categories, there are five criteria with quantitative thresholds reflecting biological indicators of populations threatened with extinction**.** These are summarized in Table 4.2.

It should be stressed that the term ‘population’ is used in a specific sense in the Red List Criteria that is different to its common biological usage (IUCN 2008), thus a ‘population’ is defined as the total number of individuals of the taxon across its global range, and NOT the number of individuals in a given site. This is very important in the evaluation of most species, but especially for those living in aquatic environments, where is very difficult, time consuming and expensive to estimate population numbers across their whole ranges. For instance, in the case of Mexican freshwater fish species the only population estimate available was for the endemic Athrinopsidae, *Poblana Alchichica* (Alcocer *et al*. 2010), for which population numbers were calculated to be between 12,510 and 29,200 organisms, but numbers such as these, that would demonstrate a healthy population for a species such as the black rhino (*Diceros bicornis*), have little to say about the health of a population of small tropical fishes with fecundities that range in the thousands.

Because of this, when applying IUCN Red List criteria in this study, as in other regional evaluations (Kottelat & Freyhof 2007, Darwall *et al*. 2011) population numbers were not considered, so in criterion A1 Population Reduction (Table 4.2) sections (a) direct observation and (b) an index of abundance appropriate to the taxon were never used because of the lack of data, so most of the estimations were based on (c), (d) and (e). Criterion B was also very important, both in the case of (B1) extent of occurrence and (B2) area of occupancy, with sections (a) severely fragmented or number of locations, (b) continuing decline in extent of occurrence, area of occupancy, quality of habitat and number of locations (see numerals i, ii, iii, iv) and (c) extreme fluctuations in extent of occurrence, area of occupancy and number of locations (see numerals i, ii, iii). Criterion C was also not applicable. While criteria D could be applied only in the sense of restricted area of occupancy. Criterion E, quantitative analysis was not applicable.

In order to apply the criteria described above distribution maps were contrasted against known threats as the ones described in sections 2.1.2.1 and 2.1.2.2, as well as published threats related to Mexican freshwater species and ecosystems based on the classification of Salafsky et al. (2008), which include overfishing, pollution, invasive species, dams and other natural system modifications related to water management/use, climate change and aquaculture (Díaz-Pardo 2002, Edwards *et al*. 2002, Orbe-Mendoza *et al*. 2002, Cotler 2004, Contreras-Balderas *et al*. 2005, Contreras-MacBeath *et al*. 2005, Domínguez-Domínguez *et al*. 2005, De la Vega-Salazar 2006, Zambrano *et al*. 2006, Alonso-EguíaLis *et al*. 2007, Contreras-Balderas *et al*. 2008, Domínguez-Domínguez *et al*. 2008, García-Moreno *et al*. 2008, Jelks *et al*. 2008, Lara-Lara *et al.* 2008, Aguirre *et al*. 2009, De la Maza 2009, Aguilar *et al*. 2010, Bunge 2010a, Bunge 2010b, CONAGUA 2010, Garrido *et al*. 2010, Ingol-Blanco E & McKinney 2010, Ruiz 2010, Pedraza 2011, Mejía-Mojica *et al*. 2012, Contreras-MacBeath *et al*. 2013).

Table 4.2 *Summary of the five criteria (A-E) used to determine the category of threat for a species.*

Use any of the Criteria A–E	Critically Endangered	Endangered	Vulnerable
A. Population reduction	Declines measured over the longer of 10 years or 3 generations		
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, based on and specifying any of the following: **(a)** direct observation; **(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.			
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, based on (a) to (e) under AI.			
A3. Population reduction projected or suspected to be met in the future (up to a maximum of 100 years) based on (b) to (e) under AI.			
A4. An observed, estimated, inferred, projected or suspected population reduction (up to a maximum of 100 years) where the time period must include both the past and the future, and where the causes of reduction may not have ceased **OR** may not be understood **OR** may not be reversible, based on (a) to (e) under AI.			
B. Geographic range in the form of either B1 (extent of occurrence) AND/OR B2 (area of occupancy)			
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:			
(a) Severely fragmented, **OR** Number of locations	= 1	≤ 5	≤ 10
(b) Continuing decline 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			
Number of mature individuals	< 250	< 2,500	< 10,000
AND either C1 or C2:			
C1. An estimated continuing decline of at least:	25% in 3 years or 1 generation	20% in 5 years or 2 generations	10% in 10 years or 3 generations
(up to a max. of 100 years in future)			
C2. A continuing decline **AND** (a) and/or (b):			
(ai) Number of mature individuals in each subpopulation:	< 50	< 250	< 1,000
OR	**OR**		
(aii) % individuals in one subpopulation =	90–100%	95–100%	100%
(b) Extreme fluctuations in the number of mature individuals.			
D. Very small or restricted population			
Either:			
Number of mature individuals	< 50	< 250	**D1.** < 1,000
			AND / OR
	Restricted area of occupancy		**D2.** Typically: AOO < 20 km^2 or number of locations ≤ 5
E. Quantitative Analysis			
Indicating the probability of extinction in the wild to be:	≥ 50% in 10 years or 3 generations (100 years max.)	≥ 20% in 20 years or 5 generations (100 years max.)	≥ 10% in 100 years

4.5 Results

4.5.1. General trends

After assessing the 616 species of Mexican freshwater fishes using IUCN Red list criteria (Figure 4.9), 219 species (36%) in 25 families are classified as threatened, 47 are critically endangered (8%), 83 are endangered (14%), 89 are vulnerable (14%). With a total of 160 threatened species, five families compromise 73% of the total, these are Cyprinidae with 55 threatened species, Goodeidae with 38, Poeciliidae with 23, Atherinopsidae with 22 and Cyprinidontidae with 21.

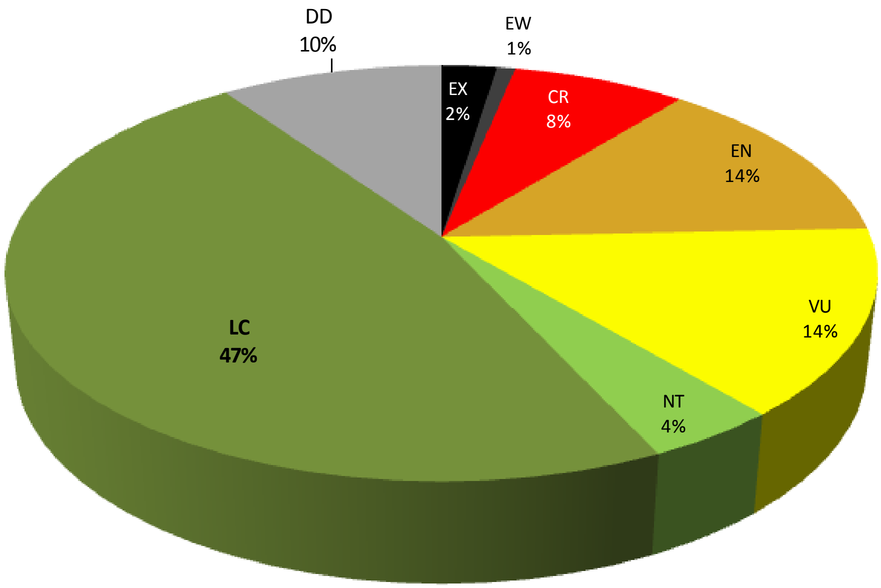


Figure 4.9 *The estimated conservation status of the freshwater fishes of Mexico based on this study. Status as listed in Table.*

Up to 47 % of those species reviewed (n=290) appear to be within the IUCN category of Least Concern. Much of this can be explained by the presence of 197 species of typically marine families with wide distributions that inhabit the brackish waters of the numerous coastal lagoons present in Mexico. The most diverse families within this group are Ariidae and Gerreidae with 19 species each, Gobiidae with 18, Centropomidae with 12 and Clupeidae with 10. Another large segment within this category is composed of 53 species of widely distributed Poecilids and 41 of cichlids. The 291 species resulting from these two groups account for 84% of the total for Least Concerned species.

Lost fishes, both extinct and extinct in the wild represent 3% of the total with 20 species, 15 of which are Mexican endemics. There are only 26 species (4%) classified as Near Threatened, these belong to 11 families, most diverse of which is Poeciliidae with 7 species. Data Deficient species account for only 10% of the total, and this number reflects the amount of knowledge that has been generated in relation to Mexican freshwater fishes.

Some of the most diverse families have high percentages of threatened species (Table 4.3) such as the Goodeidae with 86%, Cyprinidae 68%, Cyprinodontidae 64%, Atherinopsidae 56% and Catostomidae 52%. There al also some groups where all Mexican species are threatened, such as the three Lampreys (*Tetrapleurodon geminis, Tetrapleurodon spadicea and Entospheneus tridentatus*), the sturgeon (*Acipenser oxyrinchus*), the cave fish (*Typhliasina pearsei*), the catfish (*Lacantunia enigmática*) and the sawfish (*Pristis pristis*).

Table 4.3 *Families with high percentages of threatened species.*

FAMILY	Total # *spp*	Threatened *spp*	%
Goodeidae	44	38	86
Cyprinidae	82	55	68
Cyprinodontidae	34	23	64
Atherinopsidae	39	22	56
Catostomidae	19	10	52

4.5.2. Lost species (extinct, extinct in the wild and regionally extinct)

One of the most alarming indicators of the conservation condition of Mexican freshwater fishes, is the one related to lost species, which includes three groups: (1) *extinct*, or those species that have been lost forever, (2) *extinct in the wild*, which have disappeared from the wild, but are now maintained in captivity and (3) *regionally extinct*, that includes species that are now extirpated from Mexico, but can still be found in other countries within their natural distribution range.

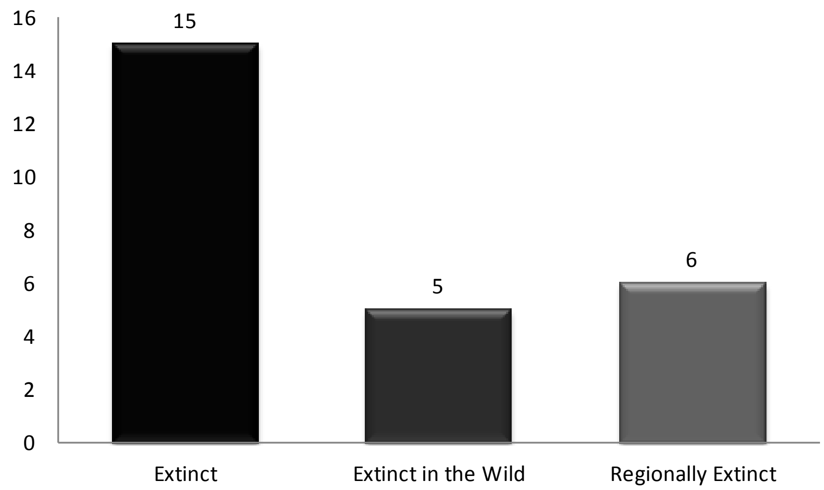


Figure 4.10 *Lost Mexican freshwater fish species.*

An analysis of lost Mexican freshwater fish species (Figure 4.10, Table 4.4) demonstrates that there are 15 extinct species, five extinct in the wild and six that are now regionally extinct. If we analyze lost freshwater fish species by family (Figure 4.11), Cyprinidae clearly dominate with 12 species (46%), followed by Cyprinodontidae with seven species (26%), three Atherinopsidae, two Goodeidae, one Catostomidae and one Poeciliidae.

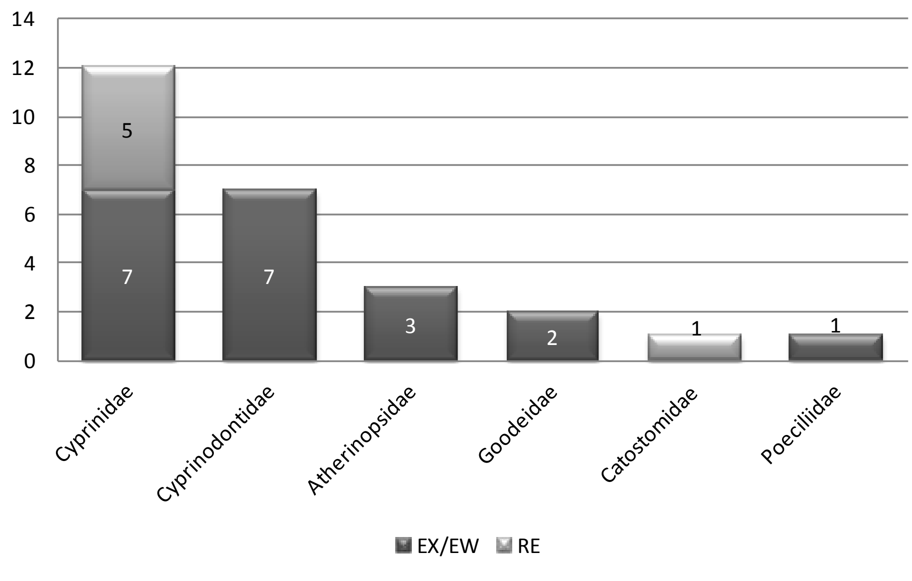


Figure 4.11 *Number of lost Mexican freshwater fish species by family.*

Table 4.4 *Lost Mexican freshwater fish species by category (EW= Extinct in the wild, EX= Extinct, RE= Regionally extinct, e=Mexican endemic, n=Native).*

FAMILY	SPECIES	DISTRIBUTION	STATUS
Cyprinodontidae	*Cyprinodon alvarezi* Miller, 1976	e	EW
Cyprinodontidae	*Cyprinodon longidorsalis* Lozano-Vilano & Contreras-Balderas, 1993	e	EW
Cyprinodontidae	*Cyprinodon veronicae* Lozano-Vilano & Contreras-Balderas, 1993	e	EW
Cyprinodontidae	*Megupsilon aporus* Miller & Walters, 1972	e	EW
Goodeidae	*Skiffia francesae* Kingston, 1978	e	EW
Atherinopsidae	*Chirostoma charari* (de Buen, 1945)	e	EX
Atherinopsidae	*Atherinella callida* Chernoff, 1986	e	EX
Atherinopsidae	*Chirostoma bartoni* Jordan & Evermann, 1896	e	EX
Cyprinidae	*Notropis saladonis* Hubbs & Hubbs, 1958	e	EX
Cyprinidae	*Notropis aulidion* Chernoff & Miller, 1986	e	EX
Cyprinidae	*Evarra bustamantei* Navarro, 1955	e	EX
Cyprinidae	*Evarra eigenmanni* Woolman, 1894	e	EX
Cyprinidae	*Evarra tlahuacensis* Meek, 1902	e	EX
Cyprinidae	*Stypodon signifer* Garman, 1881	n	EX
Cyprinidae	*Notropis orca* Woolman, 1894	n	EX
Cyprinodontidae	*Cyprinodon ceciliae* Lozano-Vilano & Contreras-Balderas, 1993	e	EX
Cyprinodontidae	*Cyprinodon inmemoriam* Lozano-Vilano & Contreras-Balderas, 1993	e	EX
Cyprinodontidae	*Cyprinodon latifasciatus* Garman, 1881	e	EX
Goodeidae	*Characodon garmani* Jordan & Evermann, 1898	e	EX
Poeciliidae	*Priapella bonita* (Meek, 1904)	e	EX
Catostomidae	*Xyrauchen texanus* (Abbott, 1860)	n	RE
Cyprinidae	*Notropis simus* (Cope, 1875)	n	RE
Cyprinidae	*Gila elegans* Baird & Girard, 1853	n	RE
Cyprinidae	*Hybognathus amarus* (Girard, 1856)	n	RE
Cyprinidae	*Ptychocheilus lucius* Girard, 1856	n	RE
Cyprinidae	*Rhinichthys osculus* (Girard, 1856)	n	RE

4.5.3. Critically Endangered species (CR)

From the results above 55 species of fish were found to be critically endangered (Fig. 4.12, Table 4.5). These species were distributed across 13 families. Forty eight (87%) of these species are Mexican endemics and only seven (13%) are native, with distributions extending into the United States. Fish within two families the Goodeidae and the Cyprinidae account for half of the total of CR Mexican freshwater fishes with 27 species.

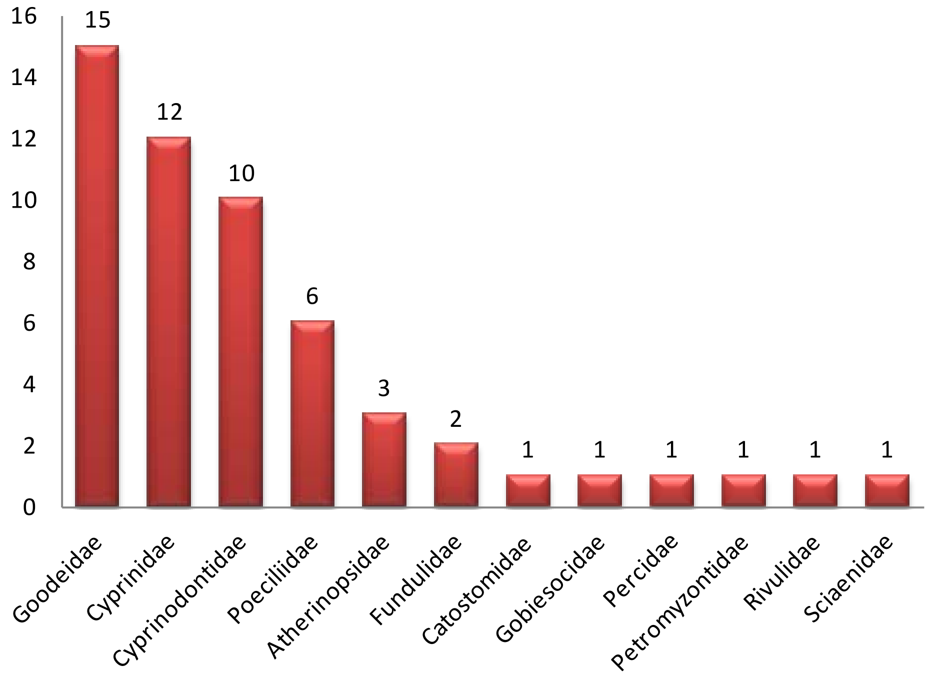


Figure 4.12 *Number of Critically Endangered Mexican freshwater fish species by families.*

Among the 12 Cyprinidae species in this category, six are native to the Mesa del Norte Ichthyofaunal Province (*Cyprinella alvarezdelvillari, C. bocagrande, C. xanthicara, Dionda melanops, Gila modesta, and G. nigrescens*) and thus associated with small springs and streams of this arid region; four are from the Mesa Central (*Algansea barbata*, *Notropis grandis*, *N. marhabatiensis* and *Yuriria amatlana*); while the remaining two species *Tampichthys mandibularis* is from Laguna de la Media Luna in the Tamesí-Pánuco Province, and *Notropis boucardi* is from the Balsas Province (See chapter 3).

Table 4.5 *Critically endangered Mexican freshwater fish species (e=Mexican endemic, n=Native).*

FAMILY	SPECIES	DISTRIBUTION
Atherinopsidae	*Chirostoma riojai* Solórzano & López, 1966	e
Atherinopsidae	*Poblana alchichica* de Buen, 1945	e
Atherinopsidae	*Poblana ferdebueni* Solórzano & López, 1965	e
Cyprinidae	*Algansea barbata* Álvarez & Cortés, 1964	e
Cyprinidae	*Cyprinella alvarezdelvillari* Contreras-Balderas & Lozano-Vilano, 1994	e
Cyprinidae	*Cyprinella bocagrande* (Chernoff & Miller, 1982)	e
Cyprinidae	*Cyprinella xanthicara* (Minckley & Lytle, 1969)	e
Cyprinidae	*Gila modesta* (Garman, 1881)	e
Cyprinidae	*Notropis boucardi* (Günther, 1868)	e
Cyprinidae	*Notropis grandis* Domínguez-Domínguez, Pérez-Rodríguez, Escalera-Velázquez & Doadrio, 2009	e

FAMILY	SPECIES	DISTRIBUTION
Cyprinidae	*Notropis marhabatiensis* Domínguez-Domínguez, Pérez-Rodríguez, Escalera-Velázquez & Doadrio, 2009	e
Cyprinidae	*Tampichthys mandibularis* (Contreras-Balderas & Verduzco-Martínez, 1977)	e
Cyprinidae	*Yuriria amatlana* Domínguez-Domínguez, Pompa-Domínguez & Doadrio, 2007	e
Cyprinodontidae	*Cyprinodon esconditus* Strecker, 2002	e
Cyprinodontidae	*Cyprinodon julimes* de la Maza-Benignos & Vela-Valladares 2009	e
Cyprinodontidae	*Cyprinodon labiosus* Humphries & Miller, 1981	e
Cyprinodontidae	*Cyprinodon maya* Humphries & Miller, 1981	e
Cyprinodontidae	*Cyprinodon meeki* Miller, 1976	e
Cyprinodontidae	*Cyprinodon pachycephalus* Minckley & Minckley, 1986	e
Cyprinodontidae	*Cyprinodon simus* Humphries & Miller, 1981	e
Cyprinodontidae	*Cyprinodon verecundus* Humphries, 1984	e
Fundulidae	*Fundulus lima* Vaillant, 1894	e
Gobiesocidae	*Gobiesox juniperoserrai* Espinosa Pérez & Castro-Aguirre, 1996	e
Goodeidae	*Allodontichthys hubbsi* Miller & Uyeno, 1980	e
Goodeidae	*Allodontichthys polylepis* Rauchenberger, 1988	e
Goodeidae	*Allotoca diazi* (Meek, 1902)	e
Goodeidae	*Allotoca dugesii* (Bean, 1887)	e
Goodeidae	*Allotoca goslinei* Smith & Miller, 1987	e
Goodeidae	*Allotoca maculata* Smith & Miller, 1980	e
Goodeidae	*Allotoca regalis* (Álvarez, 1959)	e
Goodeidae	*Ameca splendens* Miller & Fitzsimons, 1971	e
Goodeidae	*Chapalichthys pardalis* Álvarez, 1963	e
Goodeidae	*Chapalichthys peraticus Álvarez, 1963*	e
Goodeidae	*Characodon audax* Smith & Miller, 1986	e
Goodeidae	*Girardinichthys viviparus* (Bustamante, 1837)	e
Goodeidae	*Hubbsina turneri* de Buen, 1940	e
Goodeidae	*Skiffia bilineata* (Bean, 1887)	e
Goodeidae	*Zoogoneticus tequila* Webb & Miller, 1998	e
Percidae	*Etheostoma lugoi* Norris & Minckley, 1997	e
Petromyzontidae	*Tetrapleurodon spadicea* Bean, 1887	e
Poeciliidae	*Gambusia eurystoma* Miller, 1975	e
Poeciliidae	*Poecilia latipunctata* Meek, 1904	e
Poeciliidae	*Poecilia sulphuraria* (Álvarez, 1948)	e
Poeciliidae	*Poeciliopsis balsas* Hubbs, 1926	e
Poeciliidae	*Xiphophorus couchianus* (Girard, 1859)	e
Poeciliidae	*Xiphophorus milleri* Rosen, 1960	e
Profundulidae	*Profundulus hildebrandi* Miller, 1950	e
Rivulidae	*Millerichthys robustus* (Miller & Hubbs, 1974)	e
Catostomidae	*Xyrauchen texanus* (Abbott, 1860)	n
Cyprinidae	*Dionda melanops* Girard, 1856	n
Cyprinidae	*Gila nigrescens* (Girard, 1856)	n
Cyprinodontidae	*Cyprinodon macularius* Baird & Girard, 1853	n
Cyprinodontidae	*Cyprinodon suavium* Strecker, 2005	n
Fundulidae	*Lucania interioris* Hubbs & Miller, 1965	n
Sciaenidae	*Totoaba macdonaldi* (Gilbert, 1890)	n

As would be expected from the previous account (Chapter 3), all of the critically endangered Goodeidae species are from the Mesa Central Province, four of which are from the Rio Ameca in the State of Jalisco (*Allodontichthys polylepis*, *Allotoca* *goslinei*, *Ameca splendens* and *Zoogoneticus tequila*); four are from the Medio Lerma (*Allotoca diazi*, *A. dugesii*, *Hubbsina turneri* and *Skiffia bilineata*); *Chapalichthys pardalis* and *Chapalichthys peraticus* are from the Balsas river basin in the State of Michoacán; while the remaining five species (*Allodontichthys hubbsi*, *Allotoca maculata*, *Allotoca regalis*, *Characodon audax* and *Girardinichthys viviparous*) are from different individual sites.

Half of the 10 Cyprinodontidae species in this category are part of the *Cyprinodon* species flock from Laguna de Chichancanab in the Yucatan peninsula (*C. simus*, *C. labiousus*, *C. esconditus*, *C. maya* & *C. verecundus*). There are also six Poeciliidae, three Atherinopsidae, two Fundulidae and six families with one species each (Catostomidae, Gobiesocidae, Percidae, Petromyzontidae, Rivulidae and Sciaenidae).

4.5.4. Endangered species (EN)

The analysis showed that there are 78 species in 14 families considered as endangered (Figure 4.13, Table 4.6). Among these 61 (78%) are Mexican endemics and 17 (22%) native. The Cyprinidae family is represented by 27 species (34%), Goodeidae and Atherinopsidae by 12 each (15%), and poeciliidae by six (7%). These five families represent 71% of the total.

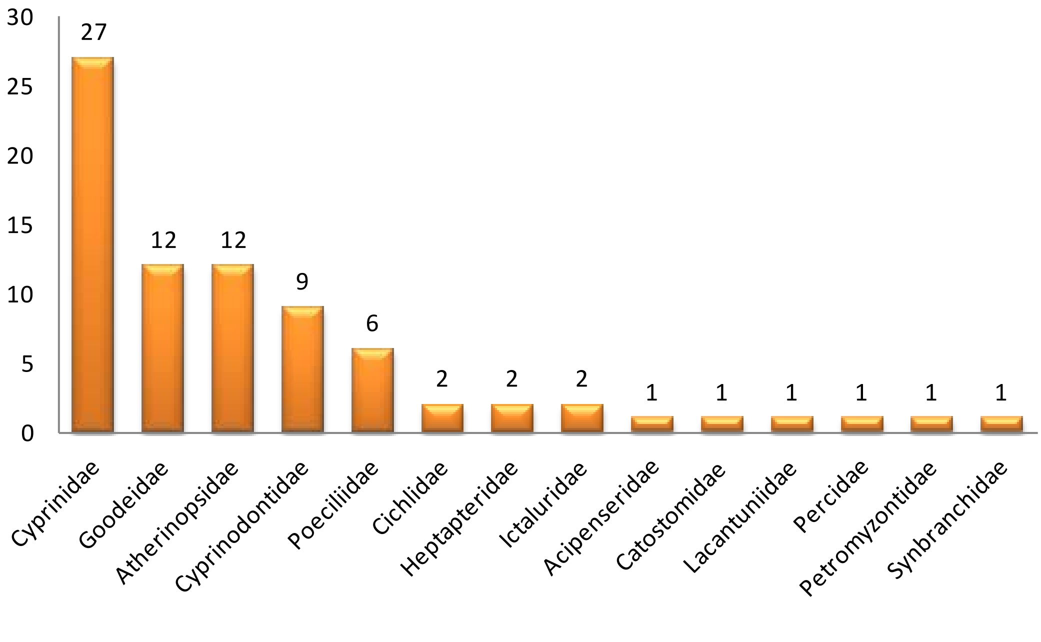


Figure 4.13 *Number of Endangered freshwater fish species by family in Mexico.*

Based on their distribution, two groups can be identified; the first one is integrated by 23 species of the Cyprinidae and Cyprinodontidae families that are distributed in the

Mesa del Norte, among these are *Cyprinella garmani*, *C. rutila*, *Gila conspersa*, *G. eremica*, *Notropis braytoni*, *N. chihuahua*, *Rhinichthys cobitis*, *Cyprinodon albivelis*, *C. bobmilleri*, *C. pisteri* and *C. salvadori*; the second group is composed of 21 species of the Goodeidae and Atherinopsidae families distributed among the Mesa Central, with representative species such as *Chirostoma aculeatum*, *C. contrerasi*, *C. patzcuaro*, *C. sphyraena*, *Allotoca meeki*, *A. zacapuensis*, *Chapalichthys pardalis*, *Girardinichthys ireneae*, *Skiffia lermae*, *S. multipunctata*, *Zoogoneticus purhepechus* and *Z. quitzoensis*.

Table 4.6 *Endangered Mexican freshwater fish species (e=Mexican endemic, n=Native).*

FAMILY	SPECIES	DISTRIBUTION
Atherinopsidae	*Atherinella ammophila* Chernoff & Miller, 1984	e
Atherinopsidae	*Atherinella lisa* (Meek, 1904)	e
Atherinopsidae	*Chirostoma aculeatum* Barbour, 1973	e
Atherinopsidae	*Chirostoma attenuatum* Meek, 1902	e
Atherinopsidae	*Chirostoma contrerasi* Barbour, 2002	e
Atherinopsidae	*Chirostoma lucius* Boulenger, 1900	e
Atherinopsidae	*Chirostoma melanoccus* Álvarez, 1963	e
Atherinopsidae	*Chirostoma patzcuaro* Meek, 1902	e
Atherinopsidae	*Chirostoma promelas* Jordan & Snyder, 1899	e
Atherinopsidae	*Chirostoma sphyraena* Boulenger, 1900	e
Atherinopsidae	*Poblana letholepis* Álvarez, 1950	e
Atherinopsidae	*Poblana squamata* Álvarez, 1950	e
Catostomidae	*Catostomus nebuliferus* Garman, 1881	e
Cichlidae	*Herichthys labridens* (Pellegrin, 1903)	e
Cichlidae	*Rocio ocotal* Schmitter-Soto, 2007	e
Cyprinidae	*Algansea amecae* Pérez-Rodríguez, Pérez-Ponce de León, Domínguez-Domínguez & Doadrio, 2009	e
Cyprinidae	*Algansea aphanea* Barbour & Miller, 1978	e
Cyprinidae	*Algansea avia* Barbour & Miller, 1978	e
Cyprinidae	*Algansea popoche* (Jordan & Snyder, 1899)	e
Cyprinidae	*Cyprinella garmani* (Jordan, 1885)	e
Cyprinidae	*Cyprinella rutila* (Girard, 1856)	e
Cyprinidae	*Gila conspersa* Garman, 1881	e
Cyprinidae	*Gila eremica* DeMarais, 1991	e
Cyprinidae	*Gila minacae* Meek, 1902	e
Cyprinidae	*Gila pulchra* (Girard, 1856)	e
Cyprinidae	*Notropis amecae* Chernoff & Miller, 1986	e
Cyprinidae	*Notropis calabazas* Lyons & Mercado-Silva, 2004	e
Cyprinidae	*Notropis cumingii* (Günther, 1868)	e
Cyprinidae	*Tampichthys dichromus* (Hubbs & Miller, 1977)	e
Cyprinidae	*Tampichthys rasconis* (Jordan & Snyder, 1899)	e
Cyprinidae	*Yuriria chapalae* (Jordan & Snyder, 1899)	e
Cyprinodontidae	*Cualac tessellatus* Miller, 1956	e
Cyprinodontidae	*Cyprinodon albivelis* Minckley & Miller, 2002	e
Cyprinodontidae	*Cyprinodon beltrani* Álvarez, 1949	e
Cyprinodontidae	*Cyprinodon bobmilleri* Lozano-Vilano & Contreras-Balderas, 1999	e
Cyprinodontidae	*Cyprinodon fontinalis* Smith & Miller, 1980	e
Cyprinodontidae	*Cyprinodon macrolepis* Miller, 1976	e

Cyprinodontidae	*Cyprinodon pisteri* Miller & Minckley, 2002	e
Goodeidae	*Allotoca meeki* (Álvarez, 1959)	e
Goodeidae	*Allotoca zacapuensis* Meyer, Radda & Domínguez, 2001	e
Goodeidae	*Ataeniobius toweri* (Meek, 1904)	e
Goodeidae	*Characodon lateralis* Günther, 1866	e
Goodeidae	*Girardinichthys ireneae* Radda & Meyer, 2003	e
Goodeidae	*Skiffia lermae* Meek, 1902	e
Goodeidae	*Skiffia multipunctata* (Pellegrin, 1901)	e
Goodeidae	*Xenoophorus captivus* (Hubbs, 1924)	e
Goodeidae	*Xenotoca eiseni* (Rutter, 1896)	e
Goodeidae	*Xenotoca melanosoma* Fitzsimons, 1972	e
Goodeidae	*Zoogoneticus purhepechus Domínguez-Domínguez, Pérez-Rodríguez & Doadrio, 2008*	e
Goodeidae	*Zoogoneticus quitzeoensis* (Bean, 1898)	e
Heptapteridae	*Rhamdia macuspanensis* Weber & Wilkens, 1998	e
Ictaluridae	*Ictalurus australis* (Meek, 1904)	e
Ictaluridae	*Prietella phreatophila* Carranza, 1954	e
Lacantuniidae	*Lacantunia enigmatica* Rodiles-Hernández, Hendrickson & Lundberg, 2005	e
Percidae	*Etheostoma segrex* Norris & Minckley, 1997	e
Petromyzontidae	*Tetrapleurodon geminis* (Álvarez, 1964)	e
Poeciliidae	*Priapella compressa* Álvarez, 1948	e
Poeciliidae	*Priapella olmecae* Meyer & Espinosa Pérez, 1990	e
Poeciliidae	*Xiphophorus evelynae* Rosen, 1960	e
Poeciliidae	*Xiphophorus gordoni* Miller & Minckley, 1963	e
Poeciliidae	*Xiphophorus meyeri* Schartl & Schröder, 1988	e
Acipenseridae	*Acipenser oxyrinchus* Vladykov, 1955	n
Cyprinidae	*Dionda episcopa* Girard, 1856	n
Cyprinidae	*Cyprinella panarcys* (Hubbs & Miller, 1978)	n
Cyprinidae	*Gila elegans* Baird & Girard, 1853	n
Cyprinidae	*Hybognathus amarus* (Girard, 1856)	n
Cyprinidae	*Macrhybopsis aestivalis* (Girard, 1856)	n
Cyprinidae	*Notropis braytoni* Jordan & Evermann, 1896	n
Cyprinidae	*Notropis chihuahua* Woolman, 1892	n
Cyprinidae	*Notropis jemezanus* (Cope, 1875)	n
Cyprinidae	*Notropis simus* (Cope, 1875)	n
Cyprinidae	*Rhinichthys cobitis* (Girard, 1856)	n
Cyprinidae	*Rhinichthys osculus* (Girard, 1856)	n
Cyprinodontidae	*Cyprinodon eremus* Miller & Fuiman, 1987	n
Cyprinodontidae	*Cyprinodon eximius* Girard, 1859	n
Heptapteridae	*Rhamdia laluchensis* Weber, Allegrucci & Sbordoni, 2003	n
Poeciliidae	*Gambusia speciosa* Girard, 1859	n
Synbranchidae	*Ophisternon infernale* (Hubbs, 1938)	n

In a similar manner, three of the six species of the Poecillidae family are distributed in the Mesa del Norte, *Xiphophorus gordoni*, *X. meyeri* and *Gambusia speciose*. The remaining 12 species from nine families can be found in different sites all over Mexico, but most of them have limited distributions, such as *Poblana letholepis* and *P. squamata* that are endemic to La Preciosa and Quechulac crater lakes, respectively.

4.5.5. Vulnerable species (Vu)

From the assessments 90 species from 18 families were found to be vulnerable. Sixty three of these species are Mexican endemics and 27 native (Figure 4.14, Table 4.7).

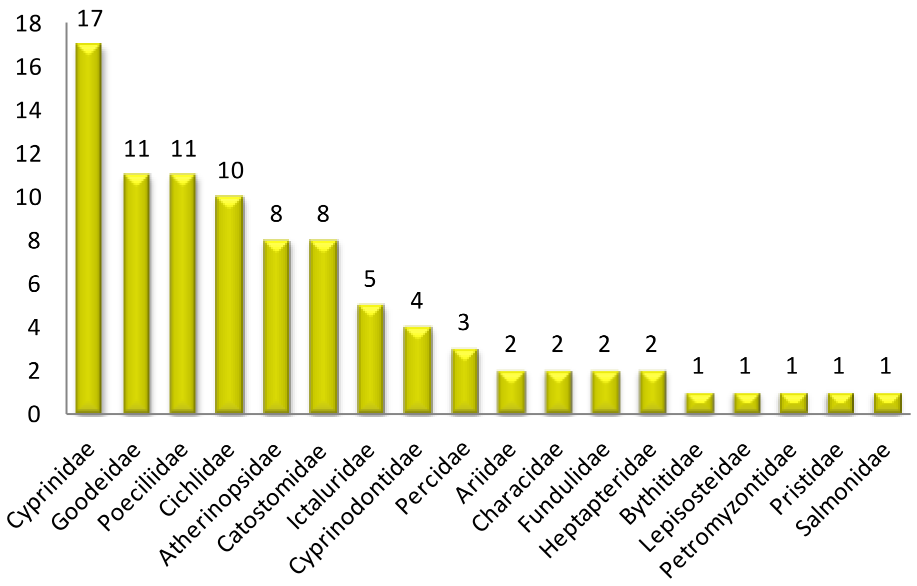


Figure 4.14 *Number of Vulnerable Mexican freshwater fish species by families.*

From figure 4.14 it is evident, that as in other categories, this one is dominated by species from the Cyprinidae (17) Goodeidae and Poeciliidae (11) families. These are followed by Cichlidae (10), Atherinopsidae and Catostomidae with eight species each. These six families represent 72% of the total within this category, with 66 vulnerable species.

Table 4.7 *Vulnerable Mexican freshwater fish species (e=Mexican endemic, n=Native).*

FAMILY	SPECIES	DISTRIBITION
Atherinopsidae	*Atherinella balsana* (Meek, 1902)	e
Atherinopsidae	*Atherinella marvelae* (Chernoff & Miller, 1982)	e
Atherinopsidae	*Atherinella schultzi* (Álvarez & Carranza, 1952)	e
Atherinopsidae	*Chirostoma arge* (Jordan & Snyder, 1899)	e
Atherinopsidae	*Chirostoma estor* Jordan, 1880	e
Atherinopsidae	*Chirostoma grandocule* (Steindachner, 1894)	e
Atherinopsidae	*Chirostoma humboldtianum* (Valenciennes, 1835)	e
Atherinopsidae	*Chirostoma labarcae* Meek, 1902	e
Bythitidae	*Typhliasina pearsei* (Hubbs, 1938)	e
Catostomidae	*Catostomus cahita* Siebert & Minckley, 1986	e
Catostomidae	*Catostomus leopoldi* Siebert & Minckley, 1986	e
Catostomidae	*Catostomus wigginsi* Herre & Brock, 1936	e
Characidae	*Astyanax altior* Hubbs, 1936	e

FAMILY	SPECIES	DISTRIBITION
Characidae	*Bramocharax caballeroi* Contreras-Balderas & Rivera-Teillery, 1985	e
Cichlidae	*Cichlasoma istlanum* (Jordan & Snyder, 1899)	e
Cichlidae	*Herichthys bartoni* (Bean, 1892)	e
Cichlidae	*Herichthys minckleyi* (Kornfield & Taylor, 1983)	e
Cichlidae	*Herichthys pantostictus* (Taylor & Miller, 1983)	e
Cichlidae	*Paraneetroplus hartwegi* (Taylor & Miller, 1980)	e
Cichlidae	*Rocio gemmata* Contreras-Balderas & Schmitter-Soto, 2007	e
Cichlidae	*Thorichthys socolofi* (Miller & Taylor, 1984)	e
Cyprinidae	*Algansea lacustris* Steindachner, 1895	e
Cyprinidae	*Algansea tincella* (Valenciennes, 1844)	e
Cyprinidae	*Gila brevicauda* Norris, Fischer & Minckley, 2003	e
Cyprinidae	*Notropis aguirrepequenoi* Contreras-Balderas & Rivera-Teillery, 1973	e
Cyprinidae	*Notropis calientis* Jordan & Snyder, 1899	e
Cyprinidae	*Notropis imeldae* Cortés, 1968	e
Cyprinidae	*Yuriria alta* (Jordan, 1880)	e
Cyprinodontidae	*Cyprinodon bifasciatus* Miller, 1968	e
Cyprinodontidae	*Cyprinodon atrorus* Miller, 1968	e
Cyprinodontidae	*Cyprinodon salvadori* Lozano-Vilano, 2002	e
Fundulidae	*Fundulus grandissimus* Hubbs, 1936	e
Fundulidae	*Fundulus philpisteri* García-Ramírez, Contreras-Balderas & Lozano-Vilano, 2007	e
Goodeidae	*Allodontichthys tamazulae* Turner, 1946	e
Goodeidae	*Allodontichthys zonistius* (Hubbs, 1932)	e
Goodeidae	*Alloophorus robustus* (Bean, 1892)	e
Goodeidae	*Allotoca catarinae* (de Buen, 1942)	e
Goodeidae	*Chapalichthys encaustus* (Jordan & Snyder, 1899)	e
Goodeidae	*Girardinichthys multiradiatus* (Meek, 1904)	e
Goodeidae	*Goodea gracilis Hubbs & Turner, 1939*	e
Goodeidae	*Goodea luitpoldii (Steindachner, 1894)*	e
Goodeidae	*Ilyodon cortesae* Paulo-Maya & Trujillo-Jiménez, 2000	e
Goodeidae	*Ilyodon whitei* (Meek, 1904)	e
Goodeidae	*Xenotaenia resolanae* Turner, 1946	e
Heptapteridae	*Rhamdia reddelli* Miller, 1984	e
Heptapteridae	*Rhamdia zongolicensis* Wilkens, 1993	e
Ictaluridae	*Ictalurus balsanus* (Jordan & Snyder, 1899)	e
Ictaluridae	*Ictalurus dugesii* (Bean, 1880)	e
Ictaluridae	*Ictalurus mexicanus* (Meek, 1904)	e
Ictaluridae	*Prietella lundbergi* Walsh & Gilbert, 1995	e
Percidae	*Etheostoma australe* Jordan, 1889	e
Percidae	*Etheostoma pottsii* (Girard, 1859)	e
Poeciliidae	*Gambusia alvarezi* Hubbs & Springer, 1957	e
Poeciliidae	*Gambusia hurtadoi* Hubbs & Springer, 1957	e
Poeciliidae	*Gambusia krumholzi* Minckley, 1963	e
Poeciliidae	*Gambusia longispinis* Minckley, 1962	e
Poeciliidae	*Heterandria jonesii* (Günther, 1874)	e
Poeciliidae	*Poecilia catemaconis* Miller, 1975	e
Poeciliidae	*Poecilia chica* Miller, 1975	e
Poeciliidae	*Poecilia velifera* (Regan, 1914)	e
Poeciliidae	*Poeciliopsis catemaco* Miller, 1975	e
Poeciliidae	*Xiphophorus kallmani* Meyer & Schartl, 2003	e
Salmonidae	*Oncorhynchus chrysogaster* (Needham & Gard, 1964)	e
Ariidae	*Potamarius nelsoni* (Evermann & Goldsborough, 1902)	n

FAMILY	SPECIES	DISTRIBITION
Ariidae	*Potamarius usumacintae* Betancur-R. & Willink, 2007	n
Catostomidae	*Catostomus bernardini* Girard, 1856	n
Catostomidae	*Catostomus clarkii* Baird & Girard, 1854	n
Catostomidae	*Catostomus insignis* Baird & Girard, 1854	n
Catostomidae	*Catostomus plebeius* Baird & Girard, 1854	n
Catostomidae	*Moxostoma austrinum* Bean, 1880	n
Cichlidae	*Cichlasoma grammodes* Taylor & Miller, 1980	n
Cichlidae	*Theraps ufermanni* (Allgayer, 2002)	n
Cichlidae	*Thorichthys callolepis* (Regan, 1904)	n
Cyprinidae	*Agosia chrysogaster* Girard, 1856	n
Cyprinidae	*Campostoma ornatum* Girard, 1856	n
Cyprinidae	*Cyprinella formosa* (Girard, 1856)	n
Cyprinidae	*Cyprinella proserpina* (Girard, 1856)	n
Cyprinidae	*Dionda diaboli* Hubbs & Brown, 1957	n
Cyprinidae	*Gila ditaenia* Miller, 1945	n
Cyprinidae	*Gila purpurea* (Girard, 1856)	n
Cyprinidae	*Gila robusta* Baird & Girard, 1853	n
Cyprinidae	*Notropis sallaei* (Günther, 1868)	n
Cyprinidae	*Ptychocheilus lucius* Girard, 1856	n
Cyprinodontidae	*Cyprinodon variegatus* Lacepède, 1803	n
Ictaluridae	*Ictalurus pricei* (Rutter, 1896)	n
Lepisosteidae	*Atractosteus spatula* (Lacepède, 1803)	n
Percidae	*Etheostoma grahami* (Girard, 1859)	n
Petromyzontidae	*Entospheneus tridentatus* (Gairdner , 1836)	n
Poeciliidae	*Poeciliopsis sonoriensis* (Girard, 1859)	n
Pristidae	*Pristis pristis* (Linnaeus, 1758)	n

It is important to note the presence within this category of 16 species belonging to the Catostomidae, Ictaluridae and Percidae families, which are representative from the nearctic region, so most of them are distributed north of the Trans Volcanic Axis.

4.6. Discussion

4.6.1 General trends

As a result of the present study the conservation status of 616 freshwater fish species found in Mexico has been evaluated, this has contributed to the evaluation of 5% of the close to 12,000 freshwater fish species of the world (Nelson 2006), as well as 43% of the 1,411 species of North America (Lévêque *et al*. 2008). Prior to this study only 195 Mexican freshwater fish species had been evaluated using IUCN Red List criteria (IUCN 2011.1). Even though all species were evaluated, including those already in the Red List, this means that the present study contributed to the evaluation of 421 new species. This represents a large step in the ongoing Global freshwater fish assessment (McGregor *et al.* 2010).

Only nine of the 195 species previously assessed suffered changes in their status; four showed negative changes, in this respect *Chirostoma bartoni* stands out due to the fact that it went from Vulnerable to extinct as a consequence of the disappearance of its only known site, the crater lake "La Alberca" West of Valle de Santiago, Guanajuato that dried out (Jelks *et al.* 2008), a similar situation occurred with *Cyprinodon veronicae* that went from Critically Endangered to Extinct in the Wild due to the disappearance of its habitat. *Cyprinodon bifasciatus* went from Least Concern to Vulnerable and *Cyprinodon nazas* from Least Concern to Near Threatened, the first species because its distribution is limited to the Valley of Cuatro Cienegas, that is threatened by invasive species and by the over extraction of water (Souza *et al*. 2006), and the second species due to the level of alteration of the Río Nazas basin, where very low biotic integrity values have been found in terms of metrics such as proportion of native/invasive species, water regime, and habitat health (Contreras-Balderas *et al*. 2005).

In three species there were positive results, *Ameca splendens* was considered Extinct in the Wild, and is now Critically Endangered, due to a small population that has been recorded in a small spring near Tehuchitlán, Jalisco; while the status of two species from the Balsas river Basin also is better, *Ilyodon whitei* whose populations have recovered mainly in the higher part (Contreras-MacBeath 2005) and *Notropis moralesi*, that are now known to have a larger distribution based on genetic data that has established that the species is distributed in the mayor part of the Balsas river basin (Schönhuth *et al.* 2008). Lastly *Atherinella guatemalensis* and *Priapella intermedia* were moved from Least Concern to Data Deficient due to the fact that there was not enough information to evaluate them.

In order to visualise the level of threat of Mexican freshwater fish species Figure 5.9 was constructed based on data published for 546 freshwater fish species from Europe (Kottelat & Freyhof 2007), 2,836 from Africa (Darwall *et al.* 2011), 5,593 currently included in the Red List (IUCN 2011.1), and the 616 from this study.

From Figure 4.15 some interesting patterns become apparent. For example the fact that there are quite similar figures for Mexico and Europe, 36% and 38% for threatened species (this includes Critically Endangered, Threatened and Vulnerable species in red), for Extinct/Extinct in the Wild species 3% and 2% (black), Near

Threatened/Least Concern species 51% and 53% (green), as well as for Data Deficient species 10% and 7% (gray) respectively.

It is well documented that in Europe, after the industrial revolution, there was an accelerated economic growth and in the establishment of industries, but this in turn led to high pollution loads in most of its freshwater resources, and even though there has been considerable efforts towards their restoration, even now about 70% of freshwater ecosystems are in some way affected by pollution (Von der Ohe 2009). Even though industrial development has never been as high in Mexico, the situation is relatively similar, because it has been estimated that 73% of Mexican rivers are altered from pollution and poor water management (Garrido *et al*. 2010). But in Mexico there is a mixed situation, where the central and northern portions of the country are developed, and suffer severely from pollution and water extraction, while the south is less developed, and less impacted (Flores & Bunge 2010, Ruiz 2010, Miguel *et al.* 2011), and fewer threatened species were found in that region.

The percentage of threatened species in Mexico (36%) is much higher than that found for Africa (22%), Darwall *et al.* (2010) mention that maybe the low percentage of threatened species found, mainly in the central portion of Africa and the Congo basin could be explained by the low human development in this region. Mexico also has a higher value than what has been found for freshwater fishes globally (29%).

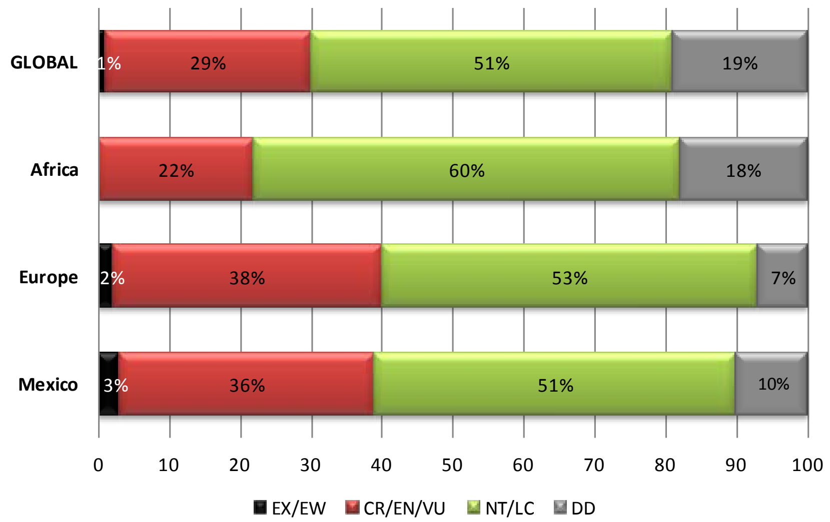


Figure 4.15 *Comparison of the proportion of freshwater fish species by threat category for our data and different regions assessed: data for Europe (Kottelat & Freyhof 2007), from Africa (Darwall et al. 2011), and Global numbers published in the Red List (IUCN 2011.1).*

With respect to lost species (EX/EW), (Figure 4.15) the low value (0.1%) found by Darwall *et al*. (2011) for Africa is worth mentioning, because it contradicts the alleged massive extinction of 200-400 Haplochromine Ciclids from Lake Victoria as a consequence of the introduction of the Nile Perch (*Lates niloticus*) in the 50s (Ogutu-Ohwayo 1990, Witte *et al.* 1992, Harrison & Stiassny 1999). The authors only found three extinct species for the whole of Africa, but explain, that many of these have resurged, and that some of the species extinctions were of species not scientifically described.

With regards to extinct species, there appears to be only a slight difference between Mexico with 3% (20 species) and Europe 2% (15 species), never the less, by comparing the data with the 67 freshwater fish global extinctions (IUCN 2011.1), extinctions in Europe represent 22% and México an alarming 30% of the total. By considering that 19 of these species were Mexican endemics, it is clear that more effort had to be put forward by the Mexican authorities for their conservation.

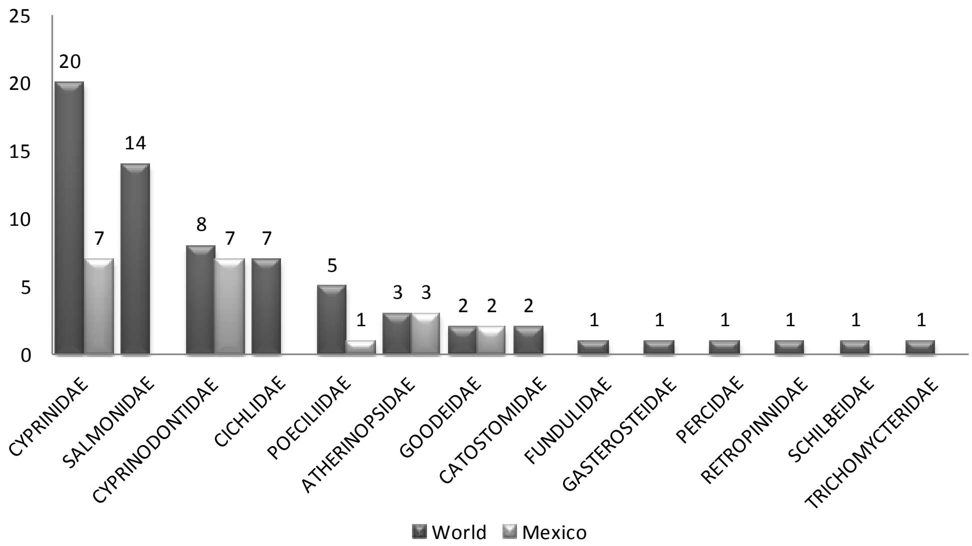


Figure 4.16 *Number of freshwater fish species extinct by family for Mexico and the rest of the world.*

In figure 4.16 data on global extinctions (black) and those for Mexico (gray) are presented by family, the dominance of Cyprinidae is evident with 20 species (29%), 7 of which are Mexican species, moreover, of the 8 extinct Cyprinodontidae 7 were Mexican species (87%), as well as all the extinct Atherinopsidae and Goodeidae.

4.6.2 Lost species

One of the most important aspects of Red List assessments relates to the changes that can be seen over time with regards to the status of species (Butchart *et al*. 2004, Rodrigues *et al*. 2006), even though this is the first time that most of the Mexican freshwater fish species have been evaluated using IUCN Red List criteria, and consequently there is no previous evaluation to which compare most species, there is data from three previous assessments using Mexican official criteria from the periods 1994-2001-2010 (SEMARNAP 1994, SEMARNAT 2002, SEMARNAT 2010), and by analyzing these it is evident that in 1994 there were no recognized extinctions, while in 2010 there are 13, and in this study 20 were found, so in the last 17 years it becomes clear that there is an increase in the tendency towards extinction.

It is becoming more frequent to carry out comparative studies related to the patterns of species extinction risk, because these can offer important information on conservation practice (Cardillo y Meijaard 2011), but what is less common is to find studies evaluating recent extinctions in order identify when a threat becomes a cause, in other words, to find patterns among extinction drivers that have caused recent extinctions, the way that palaeontologists have effectively investigated the massive extinctions of the past (Raup & Sepkoski 1984, Labandeira & Sepkoski 1993, Schulte *et al.* 2010).

It is well known that in the extinction of freshwater fish species several drivers can act progressively and synergistically (Brook *et al*. 2008), among these are natural systems modifications such as the construction of dams and water extraction/use, overfishing, pollution, invasive species, aquaculture and climate change (Salafsky *et al.* 2008). In order to find patterns associated with the main causes of extinctions, based on data published by several authors (Miller *et al.* 1989, Langhammer 1995, Harrison & Stiassny 1999, Soto-Galera *et al.* 1999, Abell *et al.* 2000, Jelks *et al.* 2008, Miller *et al.* 2009) figure 4.17 was constructed, where it is evident that the main driver of species extinctions and extirpations is natural systems modifications with 19 species (74% of the total).

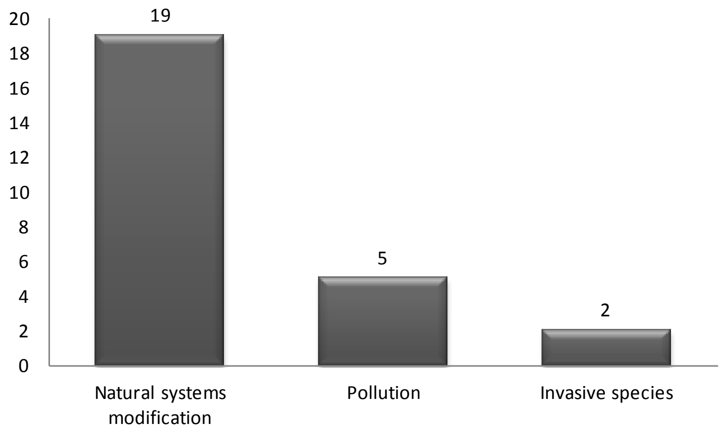


Figure 4.17 *Number of Lost Mexican Freshwater fish species by main causes.*

Most of these extinctions were caused by excessive water extraction in arid areas that resulted in drying up, for example small springs that were the only localities for endemic species such as *Characodon garmani*, *Megupsilon aprorus*, *Cyprinodon alvarezi*, *C. veronicae*, *C. longidorsalis*, *C. inmemoriam*, *C. ceciliae* and *Chirostoma bartoni,* all of the members of the genus *Evarra* (*Evarra bustamantei, E. eigenmanni, E. tlahuacensis*) from the "Valle de México", where in the second half of the last century springs in Mexico City started to dry up and then pollution also occurred. A similar situation happened with Regionally Extinct species from Río Bravo (*Hybognathus amarus*) and Colorado (*Gila elegans, Ptychocheilus lucius* y *Rhinichthys osculus*) basins, where dam construction and the introduction of invasive species are threatening them in all their distribution area in the United States , but have eliminated them from sites in Mexico where they once inhabited. Pollution has accounted for five extinctions (19% of the total) such was the case with *Chirostoma charari* from Río Grande de Morelia, as well as *Priapella bonita* from El Refugio and Motzorongo rivers form the Río Papaloapan basin. There are also two documented extinctions caused by invasive species, one of these was *Skiffia francesae* (EW) from the río Ameca in Jalisco, while the other is *Xyrauchen texanus* (RE) (Miller *et al*. 2009).

The high percentage of extinct species, as well as the tendencies found clearly demonstrates that there is a severe extinction crisis in Mexico related to fresh water fishes.

4.6.3 Analyses of direct threats

Based on what was described in sections 1.5.2 and 4.1.1 regarding the potential threats to Mexican freshwater fish species, it is not surprising to have found that 36% of them are threatened, this reinforces the idea that freshwaters are perhaps the most impacted ecosystems of Mexico as they have been the focus for human settlement and are heavily exploited for water supplies, irrigation, electricity generation, and waste disposal (Mittermeier *et al.* 2010).

Data show that based on the classification proposed by Salafsky *et al.* (2008) direct threats or the proximate human activities or processes that have caused and are causing the destruction, degradation, and/or impairment of freshwater fish species in Mexico are: dams and other natural system modifications related to water management/use, pollution, invasive species, aquaculture, and overfishing. Even though it is well known that stressors act in synergy to impact freshwater species (Strayer 2010), each of these threats is discussed in the following sections with respect to these findings.

4.6.3.1 Overfishing

Overfishing is commonly the first disturbance in the historical progression when a fisheries collapses, followed by other factors including pollution and eutrophication, mechanical habitat destruction, introduced species, and climate change. Despite the challenge of evaluating the effects of fishing owing to complex system responses and the presence of other pressures, there is ample evidence that overfishing is a significant factor in the decline of numerous species and fisheries (Allan *et al*. 2005).

There are only a few well documented examples of the impact of overfishing on Mexican freshwater fishes, little is known with regards to the state of fish populations in 56 (86%) of the 65 large Mexican lakes and reservoirs (Naranjo & Dirzo 2009) and data on river fisheries is lacking. Moreover, interpretation of fisheries statistics is difficult since records refer to species groups, rather than single species and most of the available information relates to introduced species (Contreras-Balderas *et al*. 2008).

One the best-known and well-studied inland fisheries in Middle America, is that of Lake Pátzcuaro, located in the highlands of central México. This 97.5 km^2 lake has been intensively fished for eight native species since long before the Spanish conquest of México, and more recently four exotics have been incorporated to the fishery (Orbe-Mendoza *et al.* 2002). Native fishes in the fishery include four species of the genus *Chirostoma* in the family Atherinopsidae. The "pez blanco" (*Chirostoma estor* Vu*)* is the largest and most valuable. The remaining three species are usually caught and marketed together (*C. grandocule* Vu, ***C.*** *patzcuaro* EN and *C. attenuatum* EN), these are known as "charales" and are endemic to the lake. Three species of Goodeidae contribute to the fishery, the "tiro" *Goodea atripinnis* (NT), "chegua" *Alloophorus robustus* Vu, and "choromu" *Allotoca diazi* CR. The last one is a species of Cyprinidae, the "acúmara" *Algansea lacustris* Vu. In 1981 total landings of all species were estimated at 737 metric tons. Landings and fishing effort grew steadily until 1988, when yield peaked at 2,524 tons. Since then landings have dropped dramatically to a low of 392 tons 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* (*C. grandocule*, ***C.*** *patzcuaro* and *C. attenuatum*), *Algansea lacustris* and *Allotoca diazi* are considered as threatened by Jelks *et al.* (2008), but only this last species is considered as threatened by the Mexican Environmental Authority (SEMARNAT 2010), this has been due to pressures by local fishermen, who opposed the listing of these species clamming that this would affect their livelihoods. 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 a legal instrument the "Carta Nacional Pesquera" (SAGARPA 2006), with limited results.

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* NT, *C. chapalae* NT, *C. labarcae* Vu, *C. arge* Vu, *C. consocium* NT and *C. contrerasi* EN) and three of "pescado blanco" (*C. lucius* EN, *C. sphyraena* EN and *C. promelas* EN). During the 30's the fishery in the lake was estimated at 1,000 metric tons, with a sustained increase reaching its peak in 1981 at 17,700 tons, but since that date overfishing along with habitat loss through water extraction, and pollution decreased production to 3,200 tons annually (SAGARPA 2004). This has taken its toll on native fish populations to an extent that by 2000 fishery statistics do not consider what was once the main fishery (*Chirostoma*), due to the fact that it has not been registered since 1990 (Rojas 2005). Out of all of these only *Chirostoma labarcae* and *C. promelas* are considered as threatened by the Mexican Environmental authority (SEMARNAT 2010).

One of the best documented Mexican examples of threat due to overfishing is that of the Totoaba (*Totoaba macdonaldi* CR) which is endemic to the Gulf of California. It is the largest sciaenid fish measuring up to 2m long reaching a weight of 135 kg. This species has important ontogenic habitat shifts, using freshwaters of the estuary of the Colorado River as nursery ground. Juveniles feed on benthic invertebrates and adults mainly on small pelagic fishes captured in salt waters of the Gulf (Cisneros-Mata *et al*. 1997). The fishery of this species is recognized since the 1920s, with a marked increase in fishing intensity until 1942, when about 2300 metric tonnes were caught. Catch followed a systematic decrease until 1958 when catch was only 280 tonnes, but reaching a minimum catch of only 59 tonnes in 1975 (Lercardi & Chávez 2007). The Totoaba is listed as critically endangered by the IUCN Redlist (IUCN 2011) and the fishery is currently closed by the Mexican environmental agency.

4.6.3.2 Pollution

The pollution of freshwaters, destruction of their fish communities (and those of other biota) is a worldwide problem created by humans. Whether as a result of industrial, domestic or agricultural activities, the outcome is often catastrophic and can result in the elimination of fish species and dead rivers and lakes (Richter *et al.* 1997). One of the most severe environmental problems in Mexico is related to freshwater pollution associated to the lack of wastewater treatment (Perevochtchikova 2010). The National Water Commission (CONAGUA), governmental agency in charge of water management in Mexico, mentions that in 2008 only 35% of municipal and 18% of industrial wastewaters were treated. Another important fact is that 64% of water treatment plants dispose of their waters in rivers, lakes, lagoons and the sea, but due to the fact that most of the water treated does not eliminate pathogens nor reduces suspended solids to meet national standards, aquatic ecosystems become highly polluted (Bunge 2010).

Even though there are pollution problems in 80% of Mexico’s hydrological basins, according to Torres-Orozco & Pérez Hernández (2011) four rivers receive 50% of residual water discharges: Pánuco, Lerma, San Juan and Balsas, and the most polluted aquifers are in the “Comarca Lagunera”, Valle de Mexico, the Bajío region and Mezquital valley, mainly due to leachate pollution from agriculture. But the worst case of freshwater pollution in Mexico is in the Mesa Central and more specifically in the Lerma-Chapala basin (IMTA 2009), as well as in the high portion of the Río Baslas basin (CONAGUA 2008), that are localized where the water quality monitoring stations show the highest pollution levels (see section 1.5.2). Several authors have studied freshwater ecosystems alterations in this region (Bernal-Brooks 1998, Fisher *et al.* 2003, von Bertrab 2003, Cotler et al. 2006, Sedeno-Diaz & Lopez-Lopez 2007), and its impact on freshwater fishes (Soto-Galera *et al*. 1991, Lyons *et al*. 1995, 1998, Soto-Galera *et al*. 1998, Contreras-MacBeath *et al*. 1998, Soto-Galera *et al*. 1999, Lyons *et al*. 2000, Mercado-Silva *et al.* 2002, Méndez–Sánchez *et al.* 2002, Domínguez-Domínguez *et al.* 2005, Contreras-MacBeath 2005, Mercado-Silva *et al.* 2006, De la Vega-Salazar 2006, Domínguez-Domínguez *et al.* 2006a, Domínguez-Domínguez *et al.* 2008, Mercado-Silva *et al*. 2009, Magurran 2009), they all agree that pollution in both lentic and lotic systems is one of the main causes of threat for up to about 100 fish species from the region, as well as for the local extinctions of many of them.

Some critical examples of this situation are those of *Algansea barbata* (CR) which was thought to be extinct, but that was rediscovered in 2000 in one site close to a fish farm (Figueroa-Lucero y Ontiveros-López 2000), *Chirostoma riojai* (CR) also from the high Lerma, that has been extirpated from 85% of its natural range due to several causes, but mainly by pollution (Soto-Galera & Alcántara-Soria 2007, Méndez-Sánchez *et al.* 2008). Another example is that of *Allotoca dugesii* (CR) originally considered as one of the most widely distributed species in the Lerma Basin, but that can currently only be found in 50% of its original range (Díaz-Pardo 2002). There is also the case of *Notropis boucardi* (CR) from the high part of the Balsas basin, in the state of Morelos, that due to the growth of the city of Cuernavaca and the pollution of the streams it inhabits, has disappeared from 60% of its native range (Contreras-MacBeath & Rivas 2008). This species has become the flagship of an important restoration project led by the current federal government (CONAGUA 2008).

Maybe the best documented example of the impact of pollution on fish communities in Mexico is the one published by Soto-Galera *et al*. (1999) for the Cuenca del Río

Grande de Morelia-Lago de Cuitzeo, in central Mexico, who found pollution to be the main cause of extinction of *Chirostoma charari*, as well as the extirpation of *Notropis calientis* (Vu), *Notropis sallei* (Vu) and *Hubbsina turneri* (CR).

The oil industry in the coast of the Gulf of Mexico, where 78% of the oil is extracted, and in states such as Tabasco and Chiapas where the remaining 22% comes from, as well as the sulfur an petrochemical industries have had a negative impact both in coastal-marine and freshwater ecosystems (De la Maza & Bernárdez 2003), but maybe due to the abundance of water in this region, there has not been a considerable impact in freshwater fishes. Nevertheless Botello (1996) conducted a study to evaluate metal concentration in freshwater fishes in Laguna "El Yucateco", Tabasco, where he found that the concentrations of lead in *Parachromis friedrichsthalii* (LC) were the highest found in fishes (15.68 μg g−1), values that were much higher than those permitted for human consumption which is 2.5 μg g−1. In the same study he found concentrations of Cd, Cr, Pb y Ni in *Parachromis friedrichsthalii*, *Paraneetroplus bifasciata* (LC) and *Cichlasoma urophthalmus* (LC) above permitted limits. It is important to mention that these species are captured for human consumption.

4.6.3.3 Dams and other natural system modifications related to water management/use

Dams have made an important and significant contribution to human development, and the benefits derived from them have been considerable. But in to many cases an unacceptable and often unnecessary price has been paid to secure those benefits, especially in social and environmental terms, by people displaced, by communities downstream, by taxpayers and by the natural environment (World Commission on Dams 2000). Currently 77% of the total water discharge of the 139 largest river systems in the northern third of the world is strongly or moderately affected by fragmentation from dams, inter-basin diversions and irrigation withdrawal. Humans currently appropriate half of the estimated 40,700 km^3 annual global runoff (Stiassny 2002). This has taken a heavy toll on the world's freshwater biota in general creating many endangered species of freshwater fish.

As previously described (section 1.5.2), this is one of the main threats to the freshwater fishes of Mexico, considering that 19 of the documented extinctions have it as the main driver. The level of alteration has been described in detail in section 1.5.2, where it is evident that even though it is present in most of the country, except in south-eastern

Mexico, where most of the water is concentrated (Bunge 2010a), it is in Mesa del Norte where the situation is critical and thus an important threat to freshwater fishes. To put in perspective the magnitude of the problem, it is sufficient to mention that there are more than 4,462 dams and water retention berms in Mexico, 667 of which are classified as large dams, according to the definition of the International Commission on Large Dams (CONAGUA 2010). This represents a very high number if we compare it to the 1,207 dams, and 135 large dams existing in the African Continent (Darwall *et al.* 2011).

But along with the problem of dam construction, another important driver is water stress (section 1.5.2), that even though has its highest values in the metropolitan area of Mexico City and the Lerma-Chapala basin, due to human population concentration, some 45 million people, this represents a very important problem in the arid regions of Mexico (Mesa del Norte), where there is little water availability (Bunge 2010a, Bunge 2010b). In 1993 Contreras-Balderas & Lozano-Vilano mentioned that 92 springs and 2500 km of river had dried in this area, which is a very alarming situation, because of the fact that the richness and endemism analysis (Chapter 3), demonstrated that this region hosts one of the centers of richness, the Bravo-Conchos, where there are 122 species (section 3.5.3), as well as 5 of the 7 centers of endemism (section 4.5.3), as well as one of the centers of richness + endemism (section 3.5.5).

In the case of the Rio Bravo basin, water extraction for agriculture and domestic uses, and the construction of Falcón dam have been identified as the main causes of disruption of natural water flow, which has consequently affected the integrity of freshwater ecosystems (Small *et al.* 2009). This river that in 1962 had a runoff of over 12,000 million cubic meters/year, in 2002 had less than 2% of that figure, and was dry for months in the delta region, both in 2002 and 2004 (Contreras-Balderas *et al.* 2008). In this respect, surveys have demonstrated that the original freshwater fish fauna has been retreating from the lower reaches and is being replaced by brackish and marine invaders (Contreras-Balderas *et al.* 2002,). Some endangered species due to this situation are *Dionda episcopa* (CR), *Gila modesta* (CR), *G. nigrescens* (CR), *Cyprinella rutila* (EN), *Hybognathus amarus* (EN), *Macrhybopsis aestivalis* (EN), *Notropis braytoni* (EN), *N. chihuahua* (EN), *N. jemezanus* (EN), *Prietella* *phreatophila* (EN), *Etheostoma segrex* (EN), *Gambusia speciosa* (EN) and *Xiphophorus meyeri* (EN).

There is a similar situation in the Rio Conchos, which is the main tributary of the lower Bravo, (see figure 2.1) and where drought with increased water demand and low irrigation efficiencies, the competition for water resources is high on both sides of the border (Ingol-Blanco & McKinney 2010), this has had severe impacts on freshwater fish species (Edwards *et al.* 2002). Among threatened species by this situación are *Xiphophorus couchianus* (CR), *Cyprinodon julimes* (CR) y *Cyprinella panarcys* (EN).

Maybe the most severe case is that of the Colorado river, where there are close to 100 dams and water diversions, including 11 dams in the main river channel and in its main tributary the Río Verde (Adler 2007). This situation is so severe that the Colorado Delta does not receive any freshwater and the estuary has been converted into an inverse-estuary that is saltier at its back than its mouth due to the lack of freshwater inflow (Carriquiry *et al.* 2011). This situation has extirpated freshwater fish species (Torres-Orozco & Pérez-Hernández 2011). The most conspicuous examples are those of *Gila elegans* (RE), *Rhinichthys osculus* (RE) and *Ptychocheilus lucius* (RE), this last one represented the biggest Cyprinid endemic to the Colorado, which reached 1.8 meters and weighed up to 36 Kilos (Miller 1961).

Water extraction has affected the centers of endemism of this region, the most extreme example is that of the disappearance of two springs included in two endorheic basins in Southwestern Nuevo León; El Potosí and Ojo de Agua la Presa in Bolsón de Sandia (Contreras-Balderas & Lozano-Vilano 1996), which led to the extinction of six species *Cyprinodon alvarezi* (EW), *Megupsilon aprorus* (EW), *Cyprinodon veronicae* (EW), *Cyprinodon longidorsalis* (EW), *Cyprinodon inmemoriam* (E) and *Cyprinodon ceciliae* (E).

In the case of Cuatro Cienegas, currently water extraction for cattle is has affected 70% of the springs (Cabral & Cruz 2007), with negative impacts o all the freshwater biodiversity, including fish species such as *Cyprinella xanticara* (CR), *Cyprinodon bifasciatus* (Vu), *Etheostoma lugoi* (CR), *Gambusia longispinis* (Vu), *Herichthys minckleyi* (Vu), *Lucania interioris* (CR) and *Xiphophorus gordoni* (EN).

Species that define the other centers of endemism in this arid region for example *Gambusia krumholzi* (Vu), *Prietella phreatophila* (Vu), *Gambusia alvarezi* (EN), *Cyprinodon fontinalis* (EN), *Cyprinella bocagrande* (CR) and *Gobiesox juniperoserrari* (CR), may also suffer the effects of natural system modifications due to water extraction.

4.6.3.4 Invasive species

The issue of invasive species has gained much interest in Mexico in recent years, to the extent that there is a National Invasive Species Strategy (Comité Asesor Nacional sobre Especies Invasoras 2010) and a book dealing with freshwater invasive species has recently been published (Mendoza & Koleff 2014). As part ot that publication, and using the database created for this study, a chapter dealing with invasive fish species for Central Mexico was produced (attached publication), which accounts for 25 invasive species (Contreras-MacBeath *et al.* 2014).

There are though to be 115 invasive species within the fish fauna of Mexico (Contreras-Balderas *et al.* 2008). Introductions of alien species are among the most important, least controlled, and least reversible of human impacts on the world's ecosystems, strongly affecting their biodiversity, biogeochemistry, and economic uses (Strayer 2010) they add to the physical and chemical impacts of humans on fresh waters, in part because exotics are most likely to successfully invade fresh waters already modified or degraded by humans (Dudgeon *et al.* 2006). The impacts from invasive species go far beyond those to the environment; for instance in the United States alone a total of 138 alien fish species have been introduced, and the conservative economic losses they cause is in the order of $5.4 billion annually (Pimentel *et al.* 2005). Introductions in aquatic systems can be intentional, such as in extensive aquaculture or with introductions of top predators for recreational fishing, or incidental, such as escape from aquaculture facilities or via shipping ballast water (Zambrano *et al.* 2006). This has been found to be true for Mexican freshwaters (Contreras-MacBeath *et al*. 1998, Contreras-Balderas *et al*. 2008, Contreras-Balderas *et al*. 2013).

The problem of invasive fish species in Mexico is considered as one of the worst, and the least controlled, due to the fact that the number of invasives has grown in recent years; in 1904 only 4 invasives were recognized, 7 were found in 1969, 55 in 1983, 94 in 1997, 113 in 2008 (Contreras-Balderas *et al*. 2008), and 118 in 2009 (Aguirre & Mendoza *et al.* 2009). The same authors based on data by Contreras-Balderas (1999), mention that invasive species are the main threat to 76 species listed by the Mexican Authority.

The impacts of invasive species are not limited to a specific region, as was found in the results presented in section 3.5.1, where it was found that *Oreochromis mossambicus* is among the 10 most widely distributed fish species in Mexico. The same was true for two native species *Micropterus salmoides* and *Gambusia affinis*, whose distributions have been extended due to sport fishing and mosquito larvae control (Contreras-MacBeath *et al.* 1998, Miller *et al.* 2009).

It is not easy to come across well documented examples that clearly show the impact of invasives on native fishes, this situation has led to an intensive debate (Gurevitch & Padilla 2004, Clavero & Garcia-Berthou 2005). But for Mexico, besides the two extinctions that have already been described, has no other good examples.

In the case of Tilapias, there are many examples of their impact all over the world (Canonico *et al.* 2005). In Mexico this group is composed of five species and a hybrid (Aguirre & Mendoza *et al.* 2009). One of the best documented cases of the impact of the introduction of *Oreochromis sp.* in a natural system is the one described by Stecker (2006) in Laguna Cichancanab, who found an increase of parasite loads in the Cyprinodon flock after their introduction. He also documents the disappearance of the large schools (50-1000 individuals) of *Cyprinidon simus* (CR) that could be seen in 1981, he even suggests that the possible cause of threat is due to food competition for zooplankters with juvenile cichlids also rely on. He also suggestes that the reduction in the size of *Cyprinodon maya* (CR) is due to the reduction of ostracods as a consequence of the death of Chara vegetation within large areas due to bioturbation and deposition of large amounts of faeces produced by Tilapias. It is important to mention that the invasion of the Lake by *Astyanax fasciatus* has also had an impact in the Cyprinodon species flock.

Another example related to Tilapia is that of *Fundulus lima* (CR), which is endemic to several oases in the Baja California Peninsula, and that is threatened by the introduction of 4 exotics *Cyprinus carpio*, *Poecilia reticulata*, *Xiphophorus hellerii*, but mainly by *Tilapia* cf. *zillii* (Ruiz-Campos *et al*. 2006). The last example is the possible extinction in nature of *Allotoca goslinei* (CR) as a consequence of the introduction of *Xiphophorus helleri* in 2002-2004, which has substituted it in all of its native range, and has not been collected since 2004 (Helmus *et al*. 2009).

4.6 Conclusion

In conclusion therefore these results clearly show that when the current levels of threat are reexamined in terms of the IUCN criteria new insights in to the situation of Mexican freshwater fishes are generated.

After assessing the 616 species of Mexican freshwater fishes using IUCN Red list criteria, 219 species in 25 families are classified as threatened, 47 are critically endangered, 83 are endangered, and 89 are vulnerable. These proportions are very similar to those found for European freshwater fishes (Kottelat & Freyhof 2007).

With a total of 160 threatened species, five families compromise 73% of the total, these are Cyprinidae with 55 threatened species, Goodeidae with 38, Poeciliidae with 23, Atherinopsidae with 22 and Cyprinidontidae with 21.

There are 26 lost freshwater fish species for Mexico, 15 extinct species, five extinct in the wild and six that are now regionally extinct. Globally extinct fishes, both extinct and extinct in the wild represent 3% of the total with 20 species, 15 of which are Mexican endemics. If we consider that there are 67 documented freshwater fish global extinctions (IUCN 2011.1), Mexican extinctions represent 30% of the global total. This high number, as well as the tendencies found towards things getting worse clearly demonstrates that there is a severe extinction crisis in Mexico related to fresh water fishes.

Most of these extinctions (19) were caused by excessive water extraction in arid areas that resulted in drying up of the aquatic habitat. One of the most severe examples of this is that of *Chirostoma bartoni*, a species that went from Vulnerable to Extinct as a consequence of the disappearance of its only known site, the crater lake “La Alberca” West of Valle de Santiago, Guanajuato that dried out (Jelks *et al.* 2008). Five extinctions are recognized to be produced by pollution and two by invasive species.

Data shows that based on the classification proposed by Salafsky *et al.* (2008) direct threats or the proximate human activities or processes that have caused and are causing the destruction, degradation, and/or impairment of freshwater fish species in Mexico are: dams and other natural system modifications related to water management/use, pollution, invasive species, aquaculture, and overfishing. Even though it is well known that stressors act in synergy to impact freshwater species (Strayer 2010).

Chapter 5: Assessment of the effectiveness of current Mexican conservation strategies with regards to freshwater fish species.

5.1 Introduction

As most countries, Mexico suffers from a large part of the environmental problems associated with unsustainable human development, such as resources overexploitation, pollution, loss of its natural capital and consequently, loss of the environmental services that biodiversity provides (Naranjo & Dirzo 2009, Bunge 2010a, Ruiz 2010, Miguel 2011, OCDE 2013). It is not an exaggeration to state that aquatic ecosystems are possibly the most affected by human activity; thus rivers, lakes and lagoons receive a great quantity of contaminants from large cities, from industrial parks, and from livestock and agricultural activity (Domínguez-Domínguez *et al*. 2005, Mercado-Silva *et al*. 2006, Cabral & Cruz 2007, CNA 2008, Contreras-Balderas *et al*. 2008, Bunge 2010, CONAGUA 2010, Perevochtchikova 2010).

Mexico has a long history of environmental policy, which according to Pérez (2010) can be divided in three periods: the first one, that had a "sanitary" focus, started in 1841 with the creation of the Superior Sanitary Council of Mexico (Consejo Superior de Salubridad del Departamento de México), and with the establishment of a sanitary code that dealt with the sanitary conditions of the natural environment associated with humans. This went on until the late 70s, decade when the Sub-Ministry of Environmental Improvement (Subsecretaría de Mejoramiento del Ambiente), which was a part of the Health Ministry. In the second period environmental policy attained a more integrated approach directed towards the protection and restoration of environmental equilibrium. In 1982 the Federal Environmental Protection Law was created, and in 1983 the Ministry for Urban Development and Ecology (Secretaría de Desarrollo Urbano y Ecología), that had the responsibility to protect forest resources, flora and fauna and to reduce the impacts of industrial development. In the third stage that begins in the mid 90s to this date, environmental policy acquires a sustainable development focus, thus views things in a integrative manner, trying to articulate economic, social and environmental goals. In 1995 the Ministry of the Environment, Natural Resources and Fisheries (Secretaría de Medio Ambiente, Recursos Naturales y Pesca), and the Environmental Program were created. In 2000 Fisheries were moved to the Agriculture Ministry, and the current Ministry of the Environment, and Natural

Resources (Secretaría de Medio Ambiente y Recursos Naturales) and the National Program for the Environment and Natural Resources dealing with environmental policies were created.

Seeking to protect its biodiversity, Mexico has carried out a series of important initiatives in response to the adoption of the Convention on Biological Diversity (CBD), such as the creation of the National Biodiversity Commission in 1992 (Sarukhán & Dirzo 2012) and the elaboration of the National Biodiversity Strategy (CONABIO 2000), regional action plans (CEAMA-CONABIO 2003, CONABIO *et al*. 2007) as well as conservation strategies for terrestrial and marine species and environments (March *et al*. 2009).

Because the overarching purpose behind environmental policies is to improve environmental conditions (Mickwitz 2003, Bennear & Coglianese 2004), or to protect species and their habitats (Hockings et al. 2000, Male & Bean 2005, Figueroa *et al.* 2011) it is important to evaluate how these policies are benefiting specific groups, especially when there is a situation like the one presented in chapter 5 for freshwater fish species in Mexico where the results with respect to the percentage of threatened presented, not only do not show any improvement, but clearly show that things are getting worse. In this respect, it is important to assess the Mexican legal and institutional framework related to freshwater fish species conservation, as well as the effectiveness of ongoing biodiversity conservation strategies, in order to propose amendments or changes that could benefit freshwater fish species.

5.2 Aims and objectives

Aim

The main aim of this chapter is to assess the effectiveness of current Mexican conservation strategies with regards to freshwater fish species conservation.

The specific goals were:

a) To describe the legal and Institutional framework of Mexico related to freshwater fish conservation.
b) To evaluate the impact of official conservation programs on freshwater fish species by means of *ex-post* analysis.

c) To discuss the results in the framework of institutional gap analysis

5.3 Study Area

(Described in section 1.5-Chapter 1)

5 .4 Methods

5.4.1 Description of the Legal Framework

A qualitative and systematic description of the Mexican legal framework in relation to freshwater fish conservation was carried out following the policy analysis method used by Gonzalez *et al.* (2010). Laws, Normatives and Regulations were reviewed in a hierarchic manner, starting with the Mexican Constitution (Constitución Política de los Estados Unidos Mexicanos), Environmental Law (Ley General del Equilibrio Ecológico y Protección al Ambiente 2007), Wildlife protection law (Ley general de vida silvestre 2000), National Water Law (Ley de Aguas Nacionales 2004), among others.

5.4.2 Description of the Institutional and policy Framework

In the same manner, the Institutional framework and the governmental programs implemented in Mexico with regards to the conservation and sustainable management of freshwater fishes were evaluated. In this respect, The main Institutions reviewed were those related to the environmental branch of the Mexican government, such as the National Environmental Agency (Secretaria de Medio Ambiente y Recursos Naturales, SEMARNAT), the National Commission for Protected Areas (Comisión Nacional de Áreas Naturales Protegidas, CONANP), and the National Commission for Biodiversity (Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, CONABIO)

5.4.3 Policy evaluation

Policy evaluation was based on *ex-post* analysis described by Bennear & Coglianese (2004) but adapted to the needs of this study. This method is based on a retrospective analysis of the results of specific environmental programs and policies, thus one starts with the outcome, and goes back in each step of the policy (orange lines figure 5.1). The end result leads to the development of a conservation strategy as the one proposed in chapter 6.

Even though there are many governmental programs related to the restoration and management of freshwater ecosystems (CONAGUA 2010), *ex-post* analysis was based on the two Mexican governmental policies related to ecosystem and biodiversity conservation, which are those related to Protected Areas and Conservation of species at risk, implemented by the National Commission on Protected Areas (Green agenda of figure 5.1).

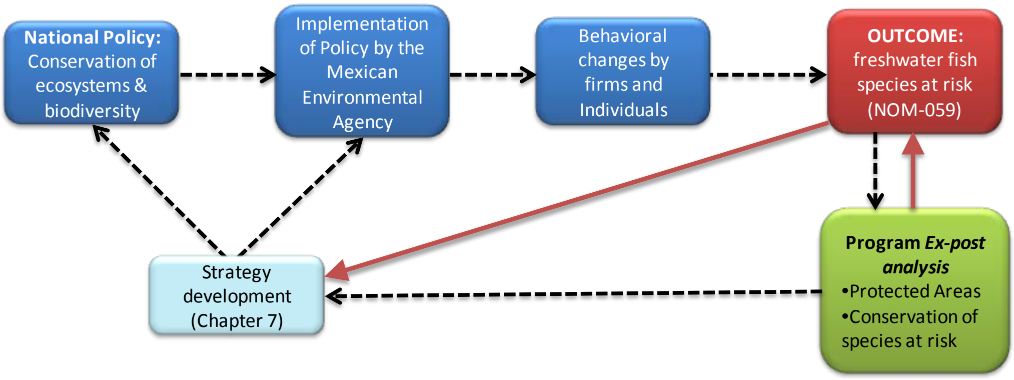


Figure 5.1 *Flow chart of the ex-post analysis used for policy evaluation.*

It is important to mention that even though in this thesis the IUCN Red List is used as the method to determine species at risk (Chapter 4), due to the fact that there is not a complete historical assessment of all Mexican freshwater fish species that could provide a picture of how the situation has changed over the years, a decision was made to use as the outcome of conservation policies, the changes in threatened species status based on the Mexican endangered species Norm that regulates the protection of native Mexican species in threat categories (red box figure 5.1). Changes in the list were analyzed since its first publication in 1994 (NOM-059-SEMARNAT-1994), the one published in 2001 (NOM-059-SEMARNAT-2001), and the most recent one published in 2010 (NOM-059-SEMARNAT-2010). This Norm represents the most important legal document in the Mexican legal system related to the protection of species. Even though it is a document published by the Federal Government, in its construction academic institutions, scientific societies, governmental agencies from all states, and different social organizations participate (Tambutti *et al.* 2001).

Once it was clear what the tendency is in relation to the conservation status of fresh fishes of Mexico, each public environmental policy and was reviewed and discussed based on the framework for *institutional gap analysis* described by Angestalm *et al*. (2003), following the diagram presented in Figure 5.2 in a bottom-up sequence, answering the following questions:

1. Are the economic resources sufficient?
2. Is the institutional framework consolidated?
3. Are the policies consistent?
4. Are there clear objectives?
5. Are the issues of concern relevant?

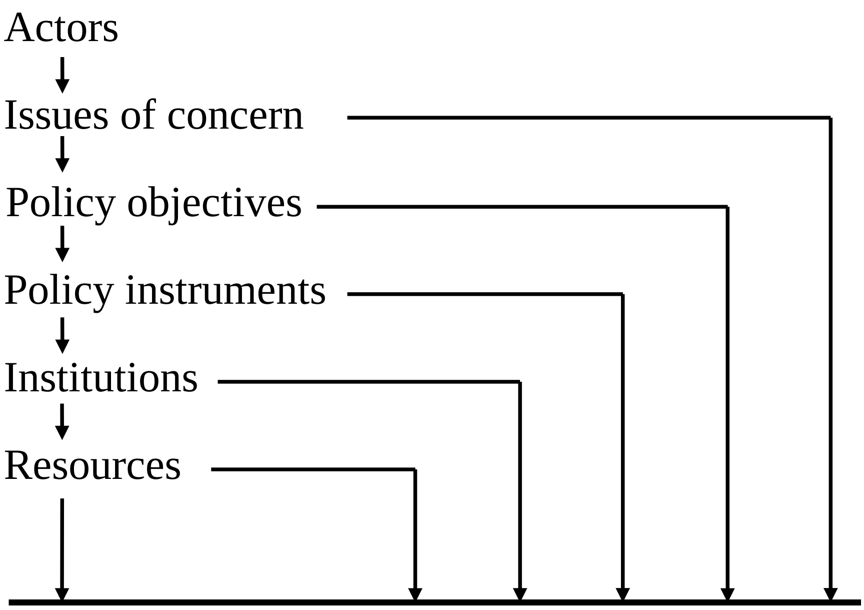


Figure 5.2 Framework for institutional gap analysis based on Angestalm *et al*. (2003).

5.5 Results

As established by the Political Constitution of the United Mexican States published in 1917, Mexico has a framework of a federal presidential representative democratic republic whose government is based on a congressional system, whereby the president of Mexico is both head of state and head of government, and of a multi-party system. The federal government represents the United Mexican States (31 states and a Federal District) and is divided into three branches: (1) *executive*, who's power is exercised by the President, and advised by a cabinet of secretaries that are independent of the legislature. Presidents are directly elected by a simple majority of registered voters in the thirty-one states and the Federal District. The president holds the formal titles of chief of state, head of government, and commander in chief of the armed forces. Once a new president is elected, he is obligated to develop a National Development Plan that defines the governmental structure and postulates the general strategies for development. (2) The *legislative* branch of the Mexican government consists of a bicameral congress (Congreso de la Unión) divided into an upper chamber, or Senate (Cámara de Senadores), and a lower chamber, or Chamber of Deputies (Cámara de Diputados). As in the United States, both chambers are responsible for the discussion and approval of legislation and the ratification of high-level presidential appointments. (3) The *judicial*, branch of the Mexican government is divided into federal and state systems. Mexico's highest court is the Supreme Court of Justice, located in Mexico City. It consists of twenty-one magistrates and five auxiliary judges, all appointed by the president and confirmed by the Senate or the Permanent Committee.

5.5.1 Legal framework

The Mexican legal framework is composed of three normative levels: (1) the Federal Constitution; (2) Treaties and statutory law issued by federal and local legislatures; and (3) administrative provisions, which include regulations issued by the federal executive power, as well as other rules created by administrative agencies such as technical norms, directives and other sector-specific binding instruments.

The Mexican Constitution (1917)

The Constitution of Mexico (Constitución Política de los Estados Unidos Mexicanos) published in 1917 represents the basis of the country's legal system (Figure 5.3). The Constitution establishes the overarching rules and principles pertaining to the structure of the Mexican federal government, and determines the competence and legal authority of the distinct branches of government within their specific jurisdictions. The Constitution also sets out the principles for the validity of laws made by government institutions; the salient principle is that all the acts and norms issued by such institutions must comply with the Constitution in order to be valid and enforceable. The statutory laws issued by federal Congress provide the legal fundamentals for activities while the administrative rules and regulations provide greater detail of laws' scope, limitations, and legal sanctions.

It is important to mention that environmental issues are considered in the Mexican Constitution: article 4° states that "*every person has a right to a healthy natural environment for his wellbeing*". Article 25°, which deals with economic development states that "*economic development must consider environmental protection*". Article 27° is very important for the regulation of natural resources; it states that "*lakes, lagoons, rivers, among other systems are property of the nation*".

International Treaties and Agreements

Mexico is a signatory to several international treaties dealing with the environment, among which are: the Convention on Wetlands (Ramsar), the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), the United Nations Framework Convention on Climate Change (UNFCCC) and its protocol, the Convention on Biological Diversity (CBD), among many others.

Ecological Equilibrium and Environmental Protection Law of 1987 (LGEEPA)

The general purpose of the Environmental Protection Law is to ensure the preservation and restoration of the country's ecological balance, as well as environmental protection throughout its territory, including areas subject to national jurisdiction and sovereignty.

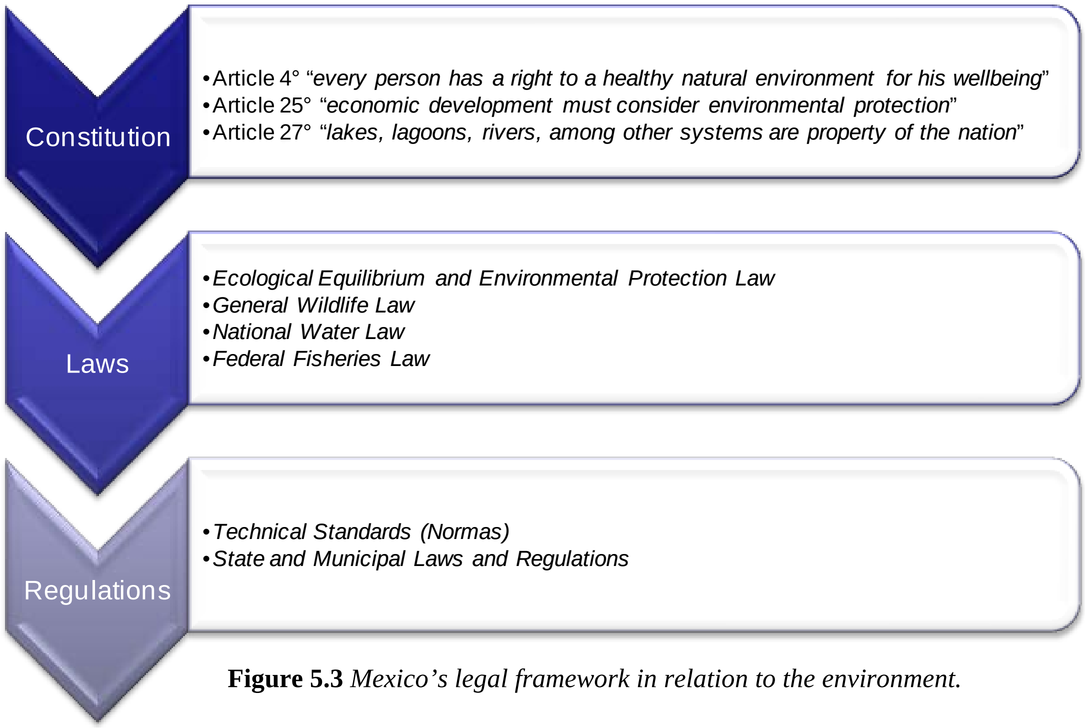


Figure 5.3 *Mexico's legal framework in relation to the environment.*

The Environmental Protection Law also promotes sustainable development. It establishes basic rules to ensure the sustainable use, preservation and restoration of soil, water and other natural resources in such a way that activities to achieve economic benefits and social activities are compatible with environment preservation.

The law also sets out the jurisdictions of each level of government (federal, state and municipal). The federal government has jurisdiction over environmental impact assessments, and has the authority to authorize public works or other activities such as hydraulic and oil works, and petrochemical, chemical, steel, paper, sugar, cement and electricity industries. The federal government is also responsible for regulating the sustainable use, protection and preservation of national waters, biodiversity, fauna and all other natural resources within its jurisdiction and to issue laws regarding the sustainable use of energy resources.

General Wildlife Law (Ley General de Vida Silvestre or *LGVS* in Spanish*)*

The general wildlife Law has 130 articles. Its main goal 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 habitat within the Mexican territory.

Article 1° of this law states that the sustainable use of wood from forests and of species whose total lifespan is spent on water, will be regulated by forestry and fisheries laws, except for those species considered as threatened.

The National Water Law (Ley de Aguas Nacionales or *LAN* in Spanish*)*

The National Water Law establishes that the use of the nation's waters will be carried out through the allocation of concession deeds by the Federal Executive Branch, through the CONAGUA, by means of the River Basin Councils, or directly by the CONAGUA when appropriate, according to the rules and conditions laid down within the National Water Law and its By-Laws. Similarly, for wastewater discharges, it is necessary to have a discharge permit issued by the CONAGUA.

Since the issuing of the National Water Law in 1992, the concession and discharge permit deeds are recorded in the Public Registry of Water Duties (REPDA).

Federal Fisheries Law (Ley de Pesca in Spanish*)*

The highest ranking, and more specific instrument of Mexican fisheries legislation is the Federal Fisheries Law (Ley de Pesca). It gives general guidelines to regulate fisheries and can be modified through the intervention of the Chamber of Deputies and the Senate. From this general law stems the Fisheries Regulation (Reglamento de la Ley Federal de Pesca) made by the Executive on the basis of the general guidelines given in the Federal Law. It deals with more particular aspects and can be modified without the intervention of the Legislature, which results in some degree of flexibility.

State and Municipal Laws and Regulations

Generally speaking, there should be approximately eight or more state laws on the books that partially or wholly address environmental matters. These laws concern: State Constitution, ecology, urban development, subdivisions, water treatment, planning, sanitation, public administration, and others that may exist, such as transportation, human settlements, and public works. It is important to note that local (state) regulatory authorities for such laws may vary from state to state with regard to the exact name of the office that enforces a law; however, each state government's administrative office would have this information. Regulations might accompany these laws.

Municipalities derive their authority over certain environmental matters directly from the State Ecology or Urban Development Laws, but indirectly from the Constitution and the Federal Ecology Law which set the framework for concurrent jurisdiction and decentralization. Municipal legislation that exists may include such titles as Organic Law of the Free Municipality of (Name of City), etc. Municipal laws may addresses the municipal government's authority in general as to the regulation of drinking water and sewage treatment, sanitation, human settlements, economic development, public participation, etc. Regulations at the municipal level are also plentiful in Mexico, and Mexico's major municipalities have begun to enact their own municipal ecology regulations. Another type of legislation that may cover environmental matters is a municipal ordinance regarding police and governance.

Technical Standards (Normas)

Mexico's Federal environmental standards are contained in three different types of norms (Normas in Spanish). These include: (1) Normas Oficiales Mexicanas (NOMs), (2) Normas de Emergencia, and (3) Normas Mexicanas. The first category included in this database consists of a collection of all NOMs enforced by various agencies of government, and they are identified by alphanumeric characters and a date in the "title". The capital letters in the title indicate the agency or authority responsible for enforcement. Some of these included in this website are ECOL (Environment Secretariat - SEMARNAP), PESC (previously a Sub-Secretariat of SEMARNAP known as PESCA, which has subsequently been moved to another agency), CNA (Within SEMARNAP, the National Water Commission), RECNAT (within SEMARNAP), SSA (Health Secretariat), NUCL (Energy Secretariat), STPS (Labor Secretariat), SCT (Communications and Transportation Secretariat), FITO and ZOO (Agriculture Secretariat), and TUR (Tourism Secretariat).

5.5.2 Institucional Framework

The current National Development Plan (Plan Nacional de Desarrollo 2006-2012) defines Human Sustainable Development as the basic premise for the integrated development of Mexico, but in reality there is a sectorized management of the country, in which each Governmental Agency tries to reach its own objectives and goals, and not only do they not coordinate with each other to try to reach a sustainable development, they implement programs that contradict each other. The federal Agency that tries to give a sense of sustainability to Mexican public policies is the Mexican Environmental Agency (Secretaría de Medio Ambiente y Recursos Naturales, SEMARNAT). This Agency, as well as its associated organizations are described below:

Mexican Environmental Agency (Secretaría de Medio Ambiente y Recursos Naturales, SEMARNAT). It is the governmental agency that has as its main purpose to promote the protection, restoration and conservation of ecosystems, natural resources and assets, as well as ecosystem services, all of this to achieve sustainable development. SEMARNAT has a territorial organization composed of 32 state delegations and several regional offices. Its main goal is to promote in all aspects of the Mexican society and of government, criteria and instruments that contribute to its purpose of environmental protection and sustainable natural resources management. It also has seven associated organizations that cover different aspects of its public policy.

National Water Commission (CONAGUA), the mission of CONAGUA is to administrate and preserve Mexican National waters with the participation of society, in order to achieve its sustainable use. The Commission considers that the participation of society is essential to achieving the goals it has proposed for each water basin, because it is the inhabitants of these basins who can keep track and further these goals even if the government changes.

National Commission of Protected Areas (CONANP), its mission is to preserve Mexico's natural capital by means of protected areas and other forms of conservation. It also promotes conservation awareness and the sustainable development of communities living in protected areas.

National Commission for the Knowledge and Use of Biodiversity (CONABIO), it is an inter-agency commission dedicated mainly to maintain and increase the National Biodiversity Information System (SNIB). It also finances projects and researches related to the expansion of knowledge on biodiversity and its use. It advises to other Ministries and sectors in issues related to biodiversity, and it also participates in international treaties. Its main mission is thus to promote, coordinate and support activities related to the knowledge of biodiversity, its conservation and sustainable use for society.

National Forest Commission (CONAFOR), it is a government organization that has as its main goal to promote productive activities, the conservation and restoration of forests, as well as to develop plans and programs related to sustainable forest use.

National Ecology and Climate Change Institute (INECC), its mission is to generate, integrate and distribute knowledge and information, through scientific research and capacity building, in order to support national environmental policies and decision making for sustainable development.

Federal Environmental Protection Agency (PROFEPA), it has as its main activity to increase in all sectors of society the compliance to environmental laws and regulations in order to contribute to sustainable development.

National Water Technology Institute (IMTA), its main goal is to develop research, and new technologies related to sustainable water management.

5.5.3 Policy framework

Figure 5.4 *A representation of Mexico's environmental-related policy framework.*

The National Development Plan represents Mexico's main planning instrument that contains the government's development guiding principles, as well as objectives and strategies to achieve them. It is the central document for the whole federal public administration and is legally approved by Congress. National Development Plans are six-year programs established by the Mexican President at the beginning of the presidential term (Figure 5.4). The Plans are intended to provide systematic and coordinated economic, social, political and cultural development.

Every Secretariat develops a national sector-based program consistent with the President's National Plan and based on its own long-term (25-year) strategic outlook. Sector-based programs serve as policy guides, specifying goals and strategies in each sector to be implemented during the following six years.

For the purpose of this thesis the environmental component of the current National Development Plan (PND 2007-2012) is described, but due to the fact that with respect to environmental issues it is basically an extension of the previous one (PND 2000-2006), conclusions are drawn from this 12 year period.

National Development Plan 2007-2012

In the National Development Plan 2007-2012 human sustainable development is defined as the main premise for the integrated development of Mexico, as well as for the goals and priorities that would guide the present federal administration. The plan has five chapters that correspond to the five central points of the governments public policies:

1. Civil rights and security
2. Competitive economy for the generation of jobs
3. Equal opportunities
4. Environmental sustainability
5. Effective democracy and responsible international policies

Chapter four of the plan "environmental sustainability" that relates to the present study, has nine goals. Goal four and its strategies deal with biodiversity conservation:

Goal 4: to conserve ecosystems and their biodiversity

Strategy 4.1: to promote the generation of knowledge related to biodiversity, and its diffusion.

Strategy 4.2: to increase the territorial land under protection, management and sustainable use.

Strategy 4.3: to give special attention to threatened Mexican species.

All of these strategies are implemented through the Environmental and Natural Resources Sector Plan coordinated by SEMARNAT, strategy 4.1 through the National Commission for the Knowledge and Use of Biodiversity (CONABIO), and strategies

4.2 and 4.3 through the National Commission of Protected Areas (CONANP). All of these are described below:

Environmental and Natural Resources Sector Plan 2007-2012

In accordance to the National Development Plan, the Environmental and Natural Resources Sector Plan has as its main goal the promotion of sustainable development, considering that a sustainable environment is indispensable for the benefit and opportunities of current and future generations. In this sense a healthy environment is an integrated part of Mexico's future, so the Plan that is divided in 10 main issues and goals that have 48 strategies, contemplates the promotion of a culture that respects and protects nature.

In the application of the Plan all of the governmental organizations described above participate. For operational purposes SEMARNAT's policies are sectorized in three so called Agendas: (1) The green agenda that deals with conservation and sustainable use of terrestrial ecosystems, their biodiversity and their ecosystem services, (2) the blue agenda, that deals with integrated water management and (3) the Grey Agenda, that deals with pollution prevention and control (Table 5.1).

Table 5.1 *The three "agendas" that SEMARNAT divides its activities, showing objectives and strategies.*

GREEN AGENDA	BLUE AGENDA	GRAY AGENDA
Goal: to conserve and to promote the sustainable use of ecosystems in order to stop the erosion of Mexico's natural capital, to conserve our national patrimony and to generate income and jobs mainly in rural areas, and to contribute to environmental sustainability and national development. ***Strategies:*** 1. *In situ* conservation of ecosystems and their biodiversity. 2. Recuperation of species at risk. 3. Biosecurity and agricultural biodiversity 4. Generation of knowledge, analysis and monitoring of ecosystems and their biodiversity	***Goal:*** to achieve an appropriate management and preservation of water in basins and aquifers to promote social wellbeing, economic development and environmental protection. ***Strategies:*** 1. Increase the access to potable water and the quality of services related to treatment by inducing sustainable use. 2. Promote the integrated and sustainable management of water in basins and aquifers. 3. Improve the productivity of water in the agriculture sector.	Goal: consolidate laws and regulations and to apply policies to prevent, reduce and control pollution. To carry out an integrated management of pollutants and to remediate polluted sites to achieve and adequate quality of air, water and soil. ***Strategies:*** 1. Prevent, reduce and control the emission of atmospheric pollutants in order to guarantee an adequate air quality to protect the health of human populations and ecosystems, by means of better laws and regulations, based on the best scientific information. 2. Achieve and integrated management of pollutants by means of applying of legal instruments, actions

5. Sustainable use of ecosystems, species and natural resources. 6. Valuation of ecosystems, biodiversity and environmental services. 7. Restoration of ecosystems and soils.		and strategies, as well as the generation of statistical information needed to evaluate progress. 3. To attain an integrated and transversal restoration of polluted sites. 4. To update the legal instruments that regulates high risk activities and materials, as well as chemical substances.

Environmental programs

As described in Table 6.1, there are three strategies of the blue and green agenda that are directly related to freshwater fish species conservation and consequently to this analysis: (1) the integrated and sustainable management of water in basins and aquifers, (2) *in situ* conservation of ecosystems and their biodiversity, and (3) recuperation of species at risk. These are described below:

Integrated and sustainable management of water in basins and aquifers

This strategy, that is part of the *Blue Agenda*, is implemented by the National Water Commission (CONAGUA). Its main goal is *to achieve an appropriate management and preservation of water in basins and aquifers in order to promote social wellbeing, economic development and environmental protection* (Table 6.1), it is important to recognize the attention that the current government has placed on water treatment, and the importance that this has in the restoration of freshwater habitats and their biota, but, as was described in section 2.1.2, the results are still minimal (Contreras-Balderas *et al.* 2008, Bunge 2010, CONAGUA 2010).

The integrated water resources management program has three strategies and 15 actions, but none of those is directly related to freshwater biodiversity conservation, even though that in the justification paragraph it clearly states that…..”*It is equally important to increase the efficient use of water by means of implementing modern techniques in agriculture, which in turn will allow us to liberate important water flows for the conservation of ecosystems*”.

Due to the fact that CONAGUA has no specific actions related to the conservation of freshwater biodiversity, it is not further described in this document (CONAGUA 2008, 2010).

Conservation and sustainable use of ecosystems

The main goal of this strategy is the conservation and sustainable use of ecosystems in order to stop the depletion of Mexico's natural capital, by means of generating income and jobs for people living in natural areas. It has seven strategies and 50 actions, none of which are designed specifically for freshwater ecosystems or their biodiversity, even though there are some which refer to to mangroves, costal and marine environments. Never the less there are two general strategies and four actions that should include freshwater fish species:

Strategy 1: *In situ* conservation of ecosystems and their biodiversity.

Actions:

- To increase the surface of Mexico incorporated as Protected Areas, in ecoregions and ecosystems best preserved and of high diversity, that are most representative of the country.
- To monitor threatened and priority ecosystems and species.

Strategy 2: Recuperation of species at risk

Actions:

- To operate the program for the conservation of species at risk 2007-20012, as well as the Action Plans derived from it.
- To procure the recuperation of species by means of their reproduction, translocation, stocking and reintroduction in the framework of the System of Units for the Conservation and Management of Wildlife (UMAs).

Both of the strategies described above are implemented through the National Program for Protected Areas and the Program for the Conservation of Threatened Species, implemented by the National Commission on Protected Areas (CONANP). The activities carried out by the present administration are described below:

National Program for Protected Areas 2007-20012

The National Program for Protected Areas 2007-20012 has the task of strengthening the *Green Agenda* in order to move towards sustainable development. It consists of six strategic goals, those that directly relate to this study are:

- To preserve the most representative ecosystems of Mexico and their biodiversity, with the responsible participation of all sectors.
- To develop, promote, direct, manage and supervise programs and projects in Protected Areas that deal the protection, management and restoration.
- To promote the application of the strategy of conservation for development, as a means to support the wellbeing and quality of life of the people living in protected areas, and to mitigate negative impacts on ecosystems and their biodiversity.
- To achieve the conservation of species at risk on the basis of national priorities and by means of the implementation of the national program for the conservation of species at risk 2007-20012

National Program for the Conservation of Species at Risk (PROCER) 2007-20012

From the above Program stems out the National Program for the Conservation of Species at Risk 2007-20012 that has as its main goal to establish the basis, coordinate, articulate and promote governmental efforts, as well as those carried out by different sectors of society towards the conservation and recuperation of Mexican threatened species, seeking to attain immediate results, and setting the basis for a mid and long term effort.

In order for PROCER to be successful, a series of specific goals that must be carried out with the inclusion of different stakeholders have been defined. Those that are relevant to this study are mentioned below:

- To elaborate and execute Action Programs for Species Conservation (PACE).
- To preserve environmental services and the biodiversity of Mexico.

5.5.3 Evolution of the environmental budget

The best way to measure the effort that a government makes towards a specific goal is to evaluate the changes of the budget allocated to it. Based on a revision of the Mexican federal budget (Presupuesto de Egresos de la Federación) from 2001 to 2011 allocated to SEMARNAT (light green line Figure 5.5) it is evident that there has been an important increase in this 10 year period that went from £706,143,290 in 2001 to £ 2,511,714,168 in 2010, which represents a 350% increase in the period.

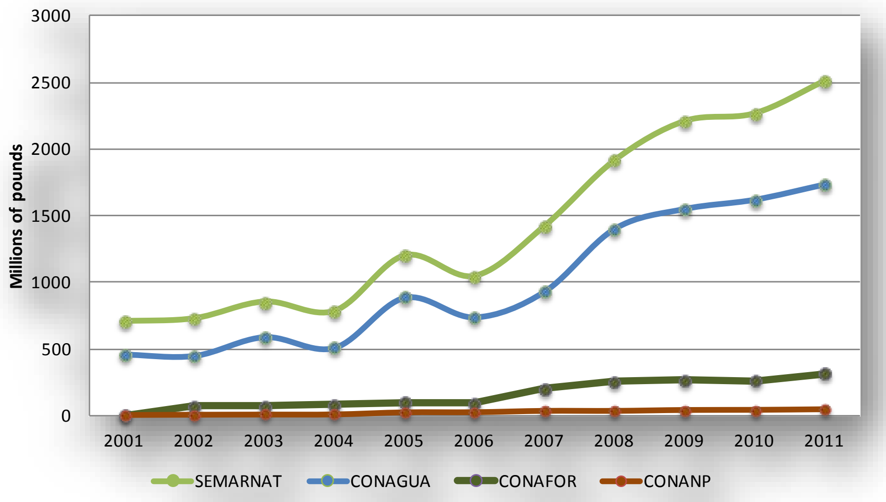


Figure 5.5 *Changes in Mexican Federal Budget related to SEMARNAT and its three main environmental branches of government CONANP, CONAFOR and CONAGUA.*

Budget allocation among the different agendas operated by SEMARNAT reflects the attention that the government places on each of them, in this respect it is evident that most of the resources are directed towards the "blue agenda" (blue line Figure 5.5). Just to give an example, in 2011 CONAGUA, that promotes integrated watershed management and sustainable water use, received 71% of the Federal environmental budget, while the "green agenda" that includes both CONAFOR (dark green line Figure 5.4) that promotes sustainable forest use received 12.6% of the budget, and CONANP (red line Figure 5.4) that manages protected areas and endangered species only received 1.9%. The remaining 4.5% of the budget was destined towards the "gray agenda" and operational costs.

It is worth mentioning that in every case there has been a considerable increase in budget over the past ten years, CONAGUA 370%, CONAFOR that did not exist in 2001 had an increase of 310%, and CONANP, although with a much smaller budget, had an increase of 580%. All these figures demonstrate that there has been at least an economic intention to support environmental issues in Mexico.

5.5.4 Policy evaluation

Following the proposed method, a retrospective analysis of the changes in species conservation status for the freshwater fishes was done. The results are discussed below.

5.5.4.1 OUTCOME: Threatened freshwater fishes of Mexico

In order to evaluate if conservation policies and programs described above have had a positive impact on freshwater fish conservation in Mexico, the Mexican Official Norm on endangered species was used (NOM-059-SEMARNAT-2010), the list includes 204 fish species, 188 of which are freshwater species (92%) and 16 marine.

There are 21 species in the category of Special Protection (Pr), which are "*those that could become endangered due to factors that negatively affect their viability*". There are 73 Threatened (A), which are "*those that could be in threat of disappearing in the short or medium term if the factors that affect them continue to do so*". There are 81 Endangered species (E), which are "those whose distribution areas and population numbers in Mexico have been dramatically reduced in a way that their biological viability is at risk in their whole natural habitat". There are also 13 recognized extinctions.

The current list (SEMARNAT 2010), has had two previous versions, the first one published in 1994 (SEMARNAP 1994), and the second one in 2001 (SEMARNAT 2002). This has been done in order to keep an updated version due to the advance in threatening factors, new scientific information, changes in taxonomy or due to upgrades in the classification system.

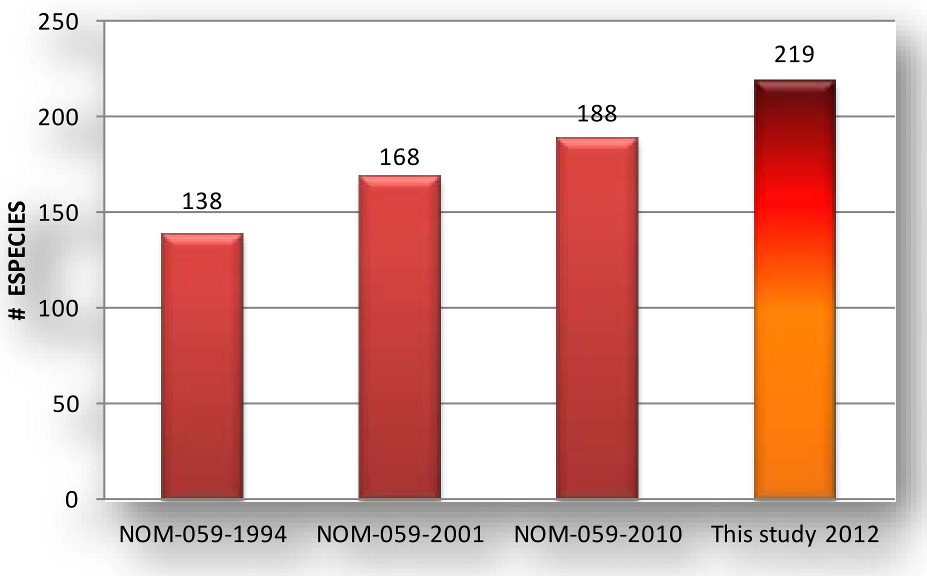


Figure 5.6 *Number of freshwater fish species considered in each version of the NOM-059, with the inclusion of the results of the present study.*

Because there are two previous versions of the list, it is possible to analyze the changes that have occurred, and from this to see if environmental policies have worked. In this sense, the first important aspect to consider is the increase in threatened species over the years (Figure 5.6), thus in 1994 there were 138 threatened freshwater fish species, 168 in 2001 and in 2010 there were 188, and this represents an increase of 31% in 16 years. This number does not consider the results of this study, in which 219 species were found to be threatened (section 4.5.1). In spite of the possibility that a percentage of the changes in numbers could be due to taxonomy, or better evaluations, the fact remains that there is a clear tendency towards things getting worse for fresh water fishes in Mexico, to an extent that currently one out of every three species is at risk.

A more detailed analysis of the changes within each category among the three versions of the list reflects some interesting patterns (Figure 5.7), such as that the number of species under special protection (Pr) has remained relatively constant; there has been a slight increase in threatened species that went from 62 in 1994 to 73 in 2010; but the highest increase has been in Endangered species (P) that went from 55 in 1994 to 81 in 2010, which represents an increase of 32%. Another very dramatic result is the fact that in 1994 no extinctions were recognized, but in 2010 there were 13.

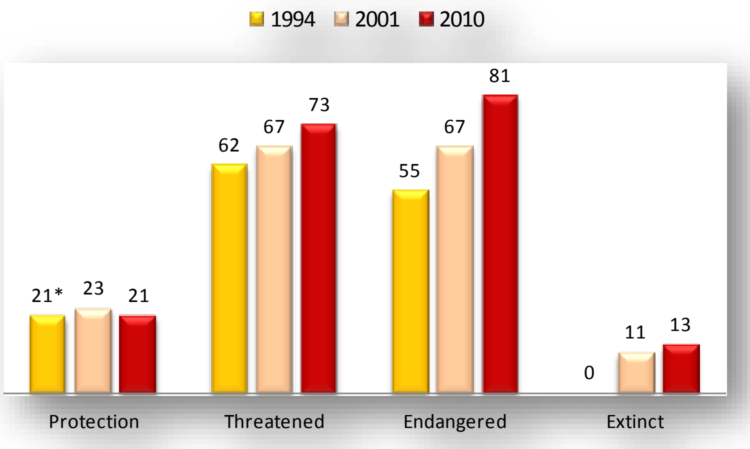


Figure 5.7 *Number of freshwater fish species by threatened category in each of the versions of the NOM-059 (* in 1994 these were considered as rare species).*

After reviewing the species listed in 1994 and comparing them to the two other lists (2001 & 2010) it was found that 48 of them changed their status, 34 (70.8%) of which have now worst situations: five went from Special Protection (Pr) to become Threatened (A), while 18 went from Pr or A to endangered.

The most outstanding result found is that 13 species that were considered as endangered became extinct in this 16 year period, a situation that is worse if it is considered that in this study there are 20 documented extinctions and six regionally extinct species (for details see section 4.5.2).

On the other hand, there are 10 species that improved their status *Cyprinella panarcys*, *Herichthys labridens*, *Notropis moralesi*, *Poecilia butleri*, *Priapella intermedia*, *Rhamdia guatemalensis*, *Typhliasina pearsei*, *Xiphophorus clemenciae* and *Zoogoneticus tequila*.The only species delisted was *Cichlasoma urophthalmus*, that since 2001 does not appear in the list, but it is likely that its inclusion in 1994 was an error, due to the fact that this is a species with a wide distribution in southeastern Mexico (Miller *et al*. 2009). There are also four species with variable results (two went from A-P-A, and the other two from P-Pr-P), this must be due to different interpretations on the part of the reviewers.

All of these results show that over the past 16 years there is a tendency of more freshwater fish species being imperiled. So it is fair to say that conservation programs have not had a positive impact on freshwater fishes. Much of this can be attributed to two fundamental situations: (1) the first one is related to the fact that fishes are still considered as resources, and not as wildlife (Contreras-MacBeath1997), a situation not privative of Mexico, as demonstrated by the fact that today, fishing remains the largest extractive use of wildlife in the world, with an annual capture of 93.8 million tonnes, 9,712,551 tones of which correspond to production from inland waters, mainly freshwater fishes (FAO 2012). This leads to interpretations such as what is established in Article 1° of the Mexican General Wildlife Law, stating that *"the sustainable use of wood from forests and of those species, whose total lifespan is spent on water, will be regulated by forestry and fisheries laws, except for those species considered as threatened"*. The impact that Article 1° has had on the conservation status of freshwater fishes, and freshwater biodiversity in general is devastating, as shown by the figures presented above, and is caused by relegating them to areas of government that apply policies with an economic focus, that don't consider species without commercial value, which is the case of most freshwater fish species. This situation also leads to the implementation of governmental policies that promote the introduction of exotic species in natural freshwater systems, as a way to increase economic growth, with severe consequences on the native freshwater fish fauna (Contreras-MacBeath 2005, Contreras-Balderas *et al*. 2008, Reid *et al*. 2013, Contreras-MacBeath *et al*. 2013).

(2) The second situation is related to the way that the "*green, blue and gray policy Agendas*" applied by SEMARNAT (Table 6.1), sectorizes attention to environmental issues in such a way that it generates confusion and judicial inefficiencies, promotes rivalry among governmental agencies (Cañas *et al.* 2009), and creates gaps like the one that leaves freshwater fishes greatly unattended.

In the following sections, the two main strategies applied by the Mexican environmental authority related to the conservation of its natural capital are reviewed in relation to the goals of the National Development Plan 2006-2012, and to the conservation status of its freshwater fish species:

5.5.4.2 Strategy 1: *in situ* conservation of ecosystems and their biodiversity

As in many other countries, in Mexico *in situ* conservation by means of establishing protected areas has been the main strategy for the protection of biodiversity as a whole and endangered species in particular. The goal established in the National Development Plan 2006-2012 was to increase the number of Federal Protected Areas in order to cover 2.5% of marine and insular ecosystems and 10% of terrestrial, aquatic and costal ecosystems, this represents an increase of three million hectares. Official data obtained from CONANPs Web Page (www.conanp.gob.mx consulted november 2012) show that the protected area surface went from 22 million to 25.3 million hectares in the period considered, thus attaining the proposed goal (Figure 5.8).

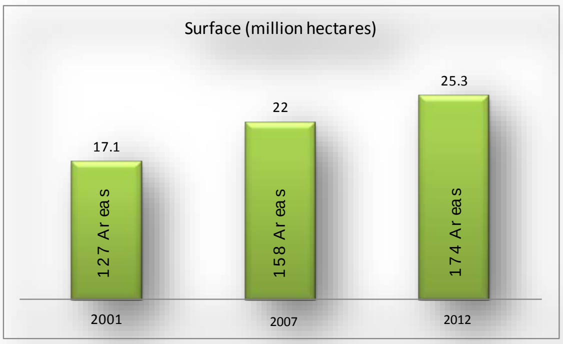


Figure 5.8 *Increase in the number and surface of protected areas in México in the period 2001-2012 (source: CONANP 2012).*

The total protected area surface of Mexico (25.3 million hectares, a surface slightly larger than the 24.19 million hectares of the whole United Kingdom) is an important conservation effort that represents 11.8% of the nation's territory. This percentage is very close to the 12% reached globally in 2010 (IUCN & UNEP-WCMC 2011).

This conservation effort has 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 this study and what has been published by several authors (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) demonstrate that this has not been the case of freshwater fish species. Much of this has to do with the fact that protected areas in Mexico have been designed and designated with a terrestrial focus, a situation considered by many authors as having little impact on the conservation of freshwater species (Saunders *et al*. 2002, Abell *et al*. 2007, Suski & Cooke 2007, Lawrence *et al*. 2011, Williams et *al*. 2011), and even though many freshwater fish species are distributed in freshwater habitats within protected areas, there are almost no conservation actions directed towards them (Contreras-MacBeath 1997, Contreras-MacBeath 2005, Pino-Del-Carpio *et al*. 2010).

Ramsar Sites

One of the main components of *in situ* conservation in Mexico related to freshwater ecosystems is related to Ramsar sites. A strategy that has been at the core of Mexico´s conservation actions, according to the report presented by the Mexican government at the 11th Meeting of the parties celebrated in Rumania (2011), Mexico has 134 Ramsar sites that sum a surface of 8,911,455 hectares, a number that makes it the second largest in the world after the United Kingdom. 57 of these sites are also federal protected areas, 14 are state and municipal protected areas and 63 sites are protected under other modalities. During the past few years there has been a considerable increase in this number, between February 2009 and the same month of 2011, 22 new Ramsar sites were declared which in turn increased the protected surface of wetlands in 797,484.04 hectares.

Unfortunately, as in the case of protected areas, Ramsar sites do not have clear conservation strategies directed towards freshwater fishes (see section 7.5.5.3), in this respect, a revision of the official data published by SEMARNAT (www.conanp.gob.mx consulted december 2012) showed that of the 134 Ramsar sites, 57 are said to have their corresponding management plan, which corresponds to 42% of the total, but they are to those of protected areas which are also Ramsar sites, and as mentioned earlier, they do not have formal conservation strategies directed towards freshwater fish species.

5.5.4.3 Strategy 2 Recuperation and monitoring of species at risk

Action 1 Recuperation and monitoring of species at risk.

Within the Program for the Conservation of Species at Risk (PROCER 2006-2012) there are 49 priority species (Table 5.2) that have been selected by a prioritization process that includes the following criteria:

a) Its importance for the conservation of habitats and other species.
b) The importance of the species or its population in maintaining biodiversity and the structure and functionality of an ecosystem, or part of it.
c) Its endemicity when recognized as an endangered species.
d) Its social, cultural, scientific or economic value.

Based on those criteria, the Mexican priority species strategy is related to the *"proxy species"* concept (Caro 2010) that directs conservation efforts in order to optimize resources and maximize results. By reviewing the criteria described above it is clear that in the Mexican strategy threatened species are considered, but are not a determining factor, due to the fact that the main goal of this strategy is to promote the conservation of other species and critical habitats.

Table 5.2 *List of species in the program for the conservation of species at risk (PROCER).*

Common name	Scientific name	PACE
Black Zapote	***Diospyros xolocotzii***	**2011**
Loggerhead Sea Turtle	***Caretta caretta***	**2011**
Kemp's ridley sea turtle	***Lepidochelys kempii***	**2011**
California Condor	***Gymnogyps californianus***	**2011**
Primates	***Ateles geoffroyi*** & ***Alouatta spp.***	**2011**
Green sea turtle	***Chelonia mydas***	**2011**
Olive Ridley Sea Turtle	***Lepidochelys olivacea***	**2011**
Manatee	***Trichechus manatus***	**2011**
Jaguar	***Panthera onca***	**2009**
Mexican Grey Wolf	***Canis lupus baileyi***	**2009**
Leatherback sea Turtle	***Dermochelys coriacea***	**2009**
Pronghorn	***Antilocapra americana***	**2009**
Tapir	***Tapirus bairdii***	**2009**
Thick-billed Parrots	***Rhychopsitt pachyrhyncha*** & ***R. terrisi***	**2009**

Common name	Scientific name	PACE
Black Bear	***Ursus americanus***	**2009**
Scarlet Macaw	***Ara macao***	**2009**
Blue Whale	***Balaenoptera musculus***	**2009**
Humpback Whale	***Megaptera novaeangliae***	**2009**
Hawksbill Sea Turtle	***Eretmochelys imbricata***	**2009**
Horned Guan	***Oreophasis derbianus***	**2009**
Bison	***Bison bison***	**2009**
Staghorn corals	***Acropora cervicornis*** & ***A. palmata***	**2009**
Golden Eagle	***Aquila chrysaetos***	**2008**
Vaquita Porpoise	***Phocoena sinus***	**2008**
Prairie dogs	***Cynomys mexicanus*** & ***C. ludovicianus***	**-**
Worthen Sparrow	***Spizella wortheni***	**-**
Military Macaw	***Ara militaris***	**-**
Yellow-naped Parrots	***Amazona auropalliata*** & ***A. oratrix***	**-**
Neotropical Birds of Prey	***Harpia harpyja, Spizaetus ornatus, S. tyrannus*** & ***Spizastur melanoleucus***	**-**
Mexican mountain rabbit	***Romerolagus diazi***	**-**
White-lipped peccary	***Tayassus pecari***	**-**
Guadalupe Fur Seal	***Arctocephalus towsendi***	**-**
Fin Whale	***Balaenoptera physalus***	**-**
Desert Fishes	***Herichthys minckleyi, Xiphophorus gordoni, Gambusia longispinis, Etheostoma lugoi, Cyprinella xanthicara*** & ***Cyprinodon bifasciatus***	**-**
Mexican Long-nosed Bats	***Leptonycteris nivalis*** & ***Leptonycteris yerbabuenae***	**-**

From the list (Table 5.2) some interesting facts emerge, first that it is dominated by mammals with 20 species, 14 birds, six reptiles (all of them sea turtles), two corals and one plant. It is important to state that there are no amphibians and that all fish species considered are from the same site, the springs of Cuatro Ciénegas, but there are no other threatened Mexican freshwater fishes included. This bias towards charismatic species has been reported for the United States (Male & Bean 2005). Trying to correct this situation, in December of 2011 a workshop to broaden the species included in PROCER was organized by CONABIO, and for the first time a group of ichthyologists were invited. This resulted in the proposal of 119 freshwater fish species that should be included, but the Mexican environmental authority, wrongly interpreting Article 1° of the General Wildlife Law, did not include them, with the argument that these should be managed by other government ministries. This represented a huge setback, because in countries such as the United States, is has been found that the Endangered Species Act benefits the conservation status of species (Ferraro *et al.* 2007, Schwartz 2008, Gibbs & Currie 2012).

But having species in a list is not enough, because in order to achieve their conservation, management actions have to be implemented. In this respect, in order to achieve conservation of selected species and their habitats, the PROCER program 2006-2012 had as a goal to elaborate and publish 30 Action Plans for Species Conservation (PACE). In each PACE critical activities for the conservation of species are included, that can be related to protection, management, recuperation, generation of knowledge and communication. But even this small goal was not attained as it can be seen in table 6.2, where to this date only 24 PACE have been published. Considering that in Mexico there are 2556 threatened species (SEMARNAT 2010) there is much work to be done.

Action 2. To procure the recuperation of species by means of their reproduction, translocation, stocking and reintroduction in the framework of the System of Units for conservation, management and sustainable use of wildlife (UMAs).

The Units for conservation, management and sustainable use of wildlife *(UMAs)* is the most ambitious conservation strategy employed in recent years by the Mexican Government with the purpose of biodiversity protection. This strategy integrates environmental, economic, social and legal instruments towards the sustainable management of wildlife, that promote a wide range of incentives for local communities and private land owners who set aside land for this activity. Since the program was launched in 2000, these have grown exponentially, to an extent that in the past 12 years, the number grew from 3,531 to 11,655 *UMAs* with an area that went from 14.7 to 37.6 million hectares (CONABIO 2012). In some cases this strategy has surpassed traditional protected areas, as has happened in the northern state of Coahuila, where there are 833 registered *UMAs* that extend over 28.4% of its territory, while the nine protected areas the state has cover only 15.3% (Cantú *et al*. 2011).

Most *UMAs* are destined for sustainable use (64%), most of these are game preserves for species like white tailed deer (*Odocoileus virginianus*) and the Collared Peccary (*Pecari tajacu*), or sites for the extraction of palms (*Chamaedorea pochutlensis*) of which 2,935,840 specimens where extracted in these 12 years. There are also UMAs for species protection (12%) and recreation (6%), among others. There are 5,560 UMAs that manage animal species, 201 for plants and even 19 for fungi (CONABIO

2012), but there is not one that protects or manages freshwater fish species, so these organisms have not benefited from this governmental strategy.

5.6 Discussion

Following the method proposed by Angestalm *et al*. (2003) for institutional gap analysis in this section results are discussed in relation to Mexican policies and their specific impact on the conservation of freshwater fish species. This is done by answering the questions postulated in section 5.4.3, and a series of recommendations intended to promote chance are presented.

5.6.1 Are the economic resources sufficient?

This is considered to be one of the most difficult questions to respond, nevertheless, it is generaly said that there will never be enough economic resources for biodiversity conservation if we compare the existing amounts, to what is in those activities that have negative impacts on ecosystems and their species (Brooks *et al.* 2006, Vörösmarty *et al.* 2010), this has led to the development and publication related to the priorization of conservation investment, nearly all such literature justifies itself with references to the need for efficiency in the face inadequate resources (Balmford & Whitten 2003, Joseph *et al*. 2009) for a large problem such as biodiversity loss (Mace *et al.* 2007).

The Mexican economy is considered as occupying the 10th place in the global ranking by the International Monetary Fund, a spot very close to the United Kingdom that ranks 9th. So the 0.9% of the GDP invested by Mexico in the environment could be considered as high if we compare it to other countries such as Italy that also spends 0.9%, and higher to the 0.8% spent by France or the 0.6% spent by Belgium (INEGI 2013).

On the other hand, by focusing on the distribution of environmental spending in Mexico, the fact that 71% is destinated towards the "*blue agenda*" operated by CONAGUA, that promotes integrated watershed management and sustainable water use, should be encouraging, nevertheless, water quality results, as well as the environmental situation of freshwater basins in Mexico, described in section 4.1.1, lead us to the conclusion that to date resources have been insufficient to contain and resolve water quality problems in Mexico.

This situation could be explained by the existence in Mexico of perverse incentives that work against the environment (OCDE 2013), specialy in the productive sector such as aquaculture. This situation has been identified in Mexico's fifth National Report to the CBD as one that needs urgent attention (CONABIO 2014). In this respect in the 2011 Mexican budget, there were 29 million dollars destinated towards fomenting aquaculture, exclusively with exotic fishes.

Specifically for threatened species, in 2011 Mexico destinated 5.1 million dollars for the priority species program, which seeks to improve the status of threatened species. This amount is much lower than the 32 million dollars that New Zeeland spends in this same activity (Joseph *et al*. 2009). Moreover, 85% of the Mexican budget was spent on one species the "Vaquita porpoise" (*Phocoena sinus*), and unfortunately nothing was spent on any freshwater fish species. A situation that reinforces the need to raise the budget and distribute them in a better way.

It has been estimated that costs associated with environmental degradation and loss of natural resources represents 7% of Mexico's GDP, and its expenditure in the environment is only 0.9% of this same indicator (OECD 2013), so more economic resources should be put into environmental programs.

Recommendations:

1. Due to the lack of clarity in financial information, is seems necessary to produce precise data on environmental spending, but specifically on species conservation. This will make it possible to contrast biodiversity conservation spending, against money spent on those policies that negatively impact freshwater fishes, and their environments.
2. Based on the result from the previous section, a periodization program that would promote "smart" spending and better results should be carried out, and contradicting monetary spending policies should be aligned in favor of the conservation of threatened species.
3. It is fundamental to reduce or eliminate perverse incentives that work against biodiversity conservation.

5.6.2 Is the institutional framework consolidated?

Based on the analysis of the Mexican Environmental Institutional Framework described in section 5.5, it can be appreciated, that in concordance with what has happened globally (Meine 2010) from the 80s environmental institutions in Mexico have grown and consolidated to a certain extent, so what was originally an activity operated by the health or agricultural sector, has now transformed into a series of institutions coordinated by SEMARNAT (Simonian 1999, DOF 2013). This situation has been recognized by the CBD, when it mentions that CONABIO and the other environmental institutions of Mexico are leaders in biodiversity conservation (CONABIO 2014).

In Mexico's fifth national report to CBD (CONABIO 2014), there is also a good description on the advances towards inter-ministerial coordination among Mexican institutions and their policies. In the same document, a description is made of the four main Commissions that deal in a coordinated mater matters related to biodiversity: (1) Inter-ministerial Commission on Biosecurity and Genetically Modified Organisms; (2) Inter-ministerial Commission on Climate Change, (3) Inter-ministerial Commission on the Management of Seas and Coastlines; and (4) Inter-ministerial Commission on Biodiversity). In spite of this institutional arrangement progress, the OCDE (2013) states that more national efforts are needed to consolidate Mexican environmental institutions, and to allow their goals to affect other governmental sectors.

The same could be said for environmental institutions at the State level, which have grown in the last decades, although most of these focus mainly on topics related to waste management and water treatment, and rarely focus on biodiversity conservation issues. In fact only two of the 32 Mexican states have Biodiversity Commissions, in spite of the fact, that it is at this governmental level that specific conservation actions are supposed to be implemented by developing state biodiversity strategies (CONABIO 2014). This situation is worst at the Municipal level, where conservation work is practically non-existent.

In conclusion, even though there has been much progress in consolidating institutions at the Federal level, there is still much to do at the State and Municipal levels in relation to biodiversity conservation, and more specifically with regards to freshwater fishes. This is very important, because current successful fish conservation examples in Mexico are at the local scale, *Cyprinodon julimes* from the "Balneario El Pandeño de los Pando" in the Chihuahuan desert (De la Maza *et al.* 2010), *Profundulus hildebrandi* in the State Protected Area "Humedales Maria Eugenia" (SMAVeHN 2011) and *Notropis boucardi* in the highlands of the Rio Balsas (Contreras-MacBeath & Rivas 2007).

Recommendations:

4. It is necessary to strengthen Federal and State and Municipal environmental institutions, specialy those related to biodiversity conservation.

5. Strengthen and promote the integration of decision structures that coordinate efforts among different levels of government, and among ministries.
6. It is fundamental to promote the production and implementation of State Biodiversity strategies, and that these put special emphasis on the conservation of species at the local level, including freshwater fish species.

5.6.3 Are the policies consistent?

In recent years, Mexico has made a huge effort to align its biodiversity conservation policies with those of the CBD (Sarukhán *et al*. 2012), and the country is recognized as one of the world's first countries of adopt the Aichi Goals (Secretaría del Convenio de Diversidad Biológica 2014), so it can be argued that Mexican conservation policies are at least consistent with those accepted globally.

Conservation efforts by the Mexican government have been effective in protecting many terrestrial species and habitats in Mexico (Dirzo *et al.* 2009, Figueroa *et al*. 2011, Halffter 2011), but unfortunately, *ex-post* analysis and data from section 5.5.4.1 demonstrates that this has not been the case of freshwater fish species.

Designation of protected areas has been the cornerstone of Mexican conservation initiatives and there are now 25.3 million hectares protected (11.8% of the nation's territory), but these have been designed and designated with a terrestrial focus, a situation considered by many authors as having little impact on the conservation of freshwater species (Saunders *et al*. 2002, Abell *et al*. 2007, Suski & Cooke 2007, Lawrence *et al*. 2011, Williams et *al*. 2011), and even though many freshwater fish species are distributed in freshwater habitats within protected areas, there are almost no conservation actions directed towards them (Contreras-MacBeath1997, Contreras-MacBeath 2005, Pino-Del-Carpio *et al*. 2010). So these have only been marginally benefited by this conservation policy.

The Program for the Conservation of Species at Risk currently has 49 priority species, most of which are terrestrial all fish species considered are from the springs of Cuatro Ciénegas. In December of 2011 a workshop was held in Mexico City to produce a new list, and for the first time a group of ichthyologists were invited. The result from this workshop was a list of 119 freshwater fish species that should be introduced, but the Mexican environmental authority, wrongly interpreting Article 1° of the General Wildlife Law, did not include them, with the argument that these should be managed by the Fisheries sector of SAGARPA, something that won't happen, because the basic strategy of this sector is based on the introduction of exotic species into natural systems, instead of managing sustainably and with an ecological perspective traditional fisheries, as suggested by several authors (Rueda-Jasso & Campos Mendoza 2009, Beard *et al.* 2011).

Much of this can be attributed to two fundamental situations: (1) the first one is related to the fact that fishes are still considered as resources, and not as wildlife, (2) The second situation is related to the way that the "*green, blue and gray policy Agendas*" applied by SEMARNAT, sectorizes attention to environmental issues in such a way that it generates confusion and judicial inefficiencies, promotes rivalry among governmental agencies (Cañas *et al.* 2009), and creates gaps like the one that leaves freshwater fishes greatly unattended.

Recommendations:

7. Consolidate information systems related to the management and conservation of biodiversity, so it can be posible to evaluate its impacts.
8. Review conservation policies so special attention can be put on species in imminent risk of extinction, with special focus on freshwater fishes.
9. Change article 1° of the National Wildelife Law in a way that freshwater fishes are included.
10. Change the way in which freshwater fisheries are managed.

5.6.4 Are there clear objectives?

Because of the fact that national conservation objectives are alligned with the strategic goals and their corresponding Aichi Targets (see Appendix D), described in the CBD (Sarukhán *et al*. 2012, Secretaría del Convenio de Diversidad Biológica 2014), it can be said that these are very clear. These are as follows:

Strategic Goal A: Address the underlying causes of biodiversity loss by mainstreaming biodiversity across government and society

Strategic Goal B: Reduce the direct pressures on biodiversity and promote sustainable use

Strategic Goal C: To improve the status of biodiversity by safeguarding ecosystems, species and genetic diversity

Strategic Goal D: Enhance the benefits to all from biodiversity and ecosystem services

Strategic Goal E: Enhance implementation through participatory planning, knowledge management and capacity building

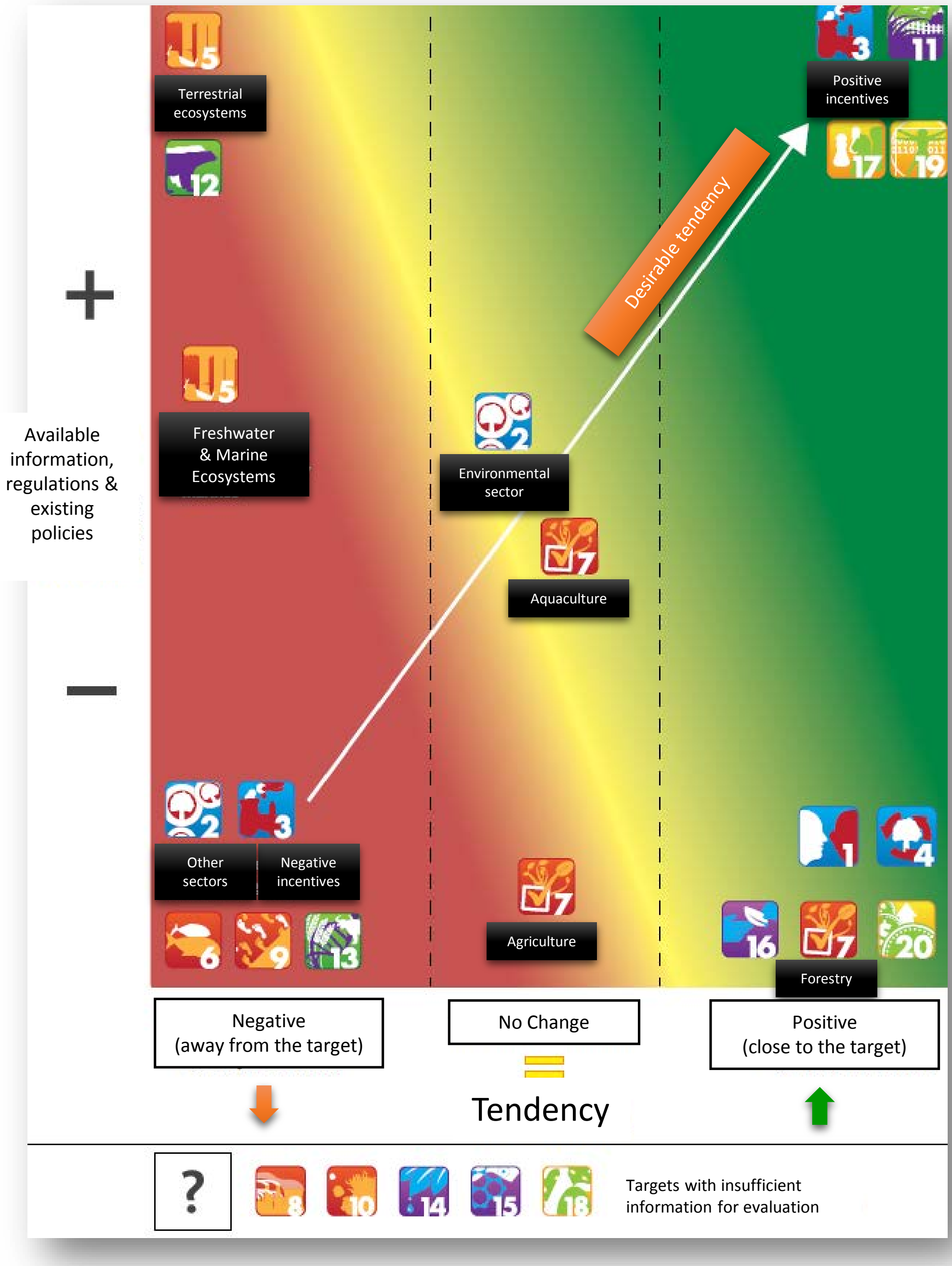


Figure 5.9. *Advances of Mexico with regards to Aichi targets (from CONABIO 2014).*

Mexico has put much effort in the evaluation of its environmental policies towards reaching the Aichi targets. In figure 5.9 taken from Mexico's Fifth National Report towards CBD (CONABIO 2014), results related to each target are displayed in a graphic manner, with those with a positive tendency localized in the upper green part of the grap, while those with negative tendencies on the red lower part. It is evident in the graph that those related to freshwater fishes have all negative tendencies. Target 5

“By 2020, the rate of loss of all natural habitats, including forests, is at least halved and where feasible brought close to zero, and degradation and fragmentation is significantly reduced” has a negative tendency, that is mainly influenced by the environmental problems associated with freshwater and marine ecosystems. In the case of target 6 “By 2020 all fish and invertebrate stocks and aquatic plants are managed and harvested sustainably, legally and applying ecosystem based approaches, so that overfishing is avoided, recovery plans and measures are in place for all depleted species, fisheries have no significant adverse impacts on threatened species and vulnerable ecosystems and the impacts of fisheries on stocks, species and ecosystems are within safe ecological limits” this target has the worst of the results, something that is consistent with the results of this study. In the case of target 7 “By 2020 areas under agriculture, aquaculture and forestry are managed sustainably, ensuring conservation of biodiversity”, it in a mid point, mainly because of the negative influence of freshwater aquaculture. Target 12 “By 2020 the extinction of known threatened species has been prevented and their conservation status, particularly of those most in decline, has been improved and sustained”, even though there is some progress in relation to terrestrial ecosystems, it is still in the negative side of the graph due to the influence of freshwater species, including fishes.

In conlusion, the objectives are clear, but the strategies implemented to reach them have not benefited freshwater fish species, a situation that is in urgent need of attention.

Recomendaciones:

11. Even though the general goals and targets are clear, specific targets need to be put in place to focus on priority species such as freshwater fishes.
12. As in other cases (Marine environments, invasive species, amongst others) a strategy to focus on freshwater species should be implemented.

5.6.5 Are the issues of concern relevant?

Today the intrinsic value of biodiversity is an established international norm (Mace *et al*. 2012) and researchers recognize that it is crucial to human well-being (Díaz *et al.* 2006, Duffy 2009, Hooper *et al.* 2012) so the issue of biodiversity conservation is particulary relevant. This has led to the global conservation effort coordinated by the

Convention on Biological Diversity (Secretaría del Convenio de Diversidad Biológica 2014) and countries such as Mexico, to further efforts to protect their natural capital.

Considering what was described in section 1.2.1 with regards to the values and importance of freshwater fishes, information that is further described in the attached paper (Reid *et al.* 2013), conservation of freshwater fishes should be a highly relevant issue in Mexico. Both because of the important of subsistence fisheries for the diet of poor people in Mexico (which reach 45 million), who by fishing in local rivers and lakes, have acces to free animal protein (Contreras-MacBeath 1995), and because of the fact that they are part of our natural heritage, and they deserve at least as much attention as terrestrial species. In this sence, what is realy surprising, is the lack of attention given to their conservation by Mexican authorities, and by the general public of Mexico, because even though freshwater species conservation seems neglected if we compare it to terrestrial and marine species (Ricciardi & Rasmussen 1999, Dudgeon *et al*. 2006), in other regions there are at least some ongoing conservation efforts for these organisms (Minckley et al. 2003, Williams et al. 2011, Hermoso & Clavero 2011), something which is not occurring in Mexico.

These results demonstrate, that even though freshwater fish conservation is in the mind of Mexican public oficials, it has not been relevant enough to take action, with the consequences that have been described in chapter 4.

Recommendations:

13. Develop a communication strategy aimed at making freshwater fishes relevant to public oficials and to the general public.
14. Develop a conservation evidence based strategy associated to freshwater fishes and their ecosystems.

5.7 Conclusions

The assessment of the Mexican legal and institutional framework related to freshwater fish species conservation, as well as the effectiveness of ongoing biodiversity conservation strategies demonstrated that there is a robust framework and a commitment by the Mexican government towards biodiversity protection and the transition towards sustainable development, something that is backed by the federal budget which had a 350% increase in the period between 2001 and 2011. Currently £ 2,511,714,168 are spent on environmental programs, which represents 0.9% of GDP, a figure that is equal to the 0.9% spent by Italy, and higher to the 0.8% spent by France or the 0.6% spent by Belgium (INEGI 2013).

Conservation efforts by the Mexican government have been effective in protecting many terrestrial species and habitats in Mexico (Dirzo *et al*. 2009, Figueroa *et al*. 2011, Halffter 2011), but unfortunately, *ex-post* analysis and data from Chapter 5 demonstrates that this has not been the case of freshwater fish species.

Designation of protected areas has been the cornerstone of Mexican conservation initiatives and there are now 25.3 million hectares protected (11.8% of the nation's territory), but these have been designed and designated with a terrestrial focus, a situation considered by many authors as having little impact on the conservation of freshwater species (Saunders *et al*. 2002, Abell *et al*. 2007, Suski & Cooke 2007, Lawrence *et al*. 2011, Williams et *al*. 2011), and even though many freshwater fish species are distributed in freshwater habitats within protected areas, there are almost no conservation actions directed towards them (Contreras-MacBeath1997, Contreras-MacBeath 2005, Pino-Del-Carpio *et al*. 2010).

The Program for the Conservation of Species at Risk currently has 49 priority species, most of which are terrestrial all fish species considered are from the springs of Cuatro Ciénegas.

Much of this can be attributed to two fundamental situations: (1) the first one is related to the fact that fishes are still considered as resources, and not as wildlife, (2) The second situation is related to the way that the "*green, blue and gray policy Agendas*" applied by SEMARNAT (Table 6.1), sectorizes attention to environmental issues in such a way that it generates confusion and judicial inefficiencies, promotes rivalry among governmental agencies (Cañas *et al.* 2009), and creates gaps like the one that leaves freshwater fishes greatly unattended.

Even though progress in Mexican institutions an policies is evident, due to the fact that all the answers to the questions put forward in the institutional gap analysis were negative with respect to freshwater fish species, fourteen recommendations are given in order tomove towards an institutional arrangement that better promotes the conservation of these species.

1. Due to the lack of clarity in financial information, is seems necessary to produce precise data on environmental spending, but specifically on species

conservation. This will make it possible to contrast biodiversity conservation spending, against money spent on those policies that negatively impact freshwater fishes, and their environments.

2. Based on the result from the previous section, a priorization program that would promote “smart” spending and better results should be carried out, and contradicting monetary spending policies should be aligned in favor of the conservation of threatened species.
3. It is fundamental to reduce or eliminate perverse incentives that work against biodiversity conservation.
4. It is necessary to strengthen Federal and State and Municipal environmental institutions, specialy those related to biodiversity conservation.
5. Strenghthen and promote the integration of decision structures that coordinate efforts among different levels of government, and among ministries.
6. It is fundamental to promote the production and implementation of State Biodiversity strategies, and that these put special emphasis on the conservation of species at the local level, including freshwater fish species.
7. Consolidate information systems related to the management and conservation of biodiversity, so it can be posible to evaluate its impacts.
8. Review conservation policies so special attention can be put on species in imminent risk of extinction, with species focus on freshwater fishes.
9. Change article 1° of the National Wildelife Law in a way that freshwater fishes are included.
10. Change the way in which freshwater fisheries are managed.
11. Even though the general goals and targets are clear, specific target need to be put in place to focus on priority species such as freshwater fishes.
12. As in other cases (Marine environments, invasive species, amons others) a strategy to focus on freshwater species should be implemented.
13. Develop a communication strategy aimed at making freshwater fishes relevant to public oficialas and to the general public.
14. Develop a conservation evidence strategy associated to freshwater fishes and their ecosystems.

Chapter 6: Strategy Development

6.1 Introduction

More generally conservation biology has a poor record of translating research into action because most research has been theoretical (Salafsky *et al*. 2002), but the generation of knowledge by itself is of little use for conservation without its acceptance, legitimacy, and subsequent adoption by user agencies (Roux *et al*. 2008). In consequence a wide gap between research and practice hinders the implementation of biodiversity conservation recommendations (Braunisch *et al*. 2012). In this respect, a study carried out by Knight *et al*. (2008) showed that documented cases of conservation assessments successfully being translated into conservation action are relatively rare in the peer-reviewed literature, they found that almost 70% of conservation assessments were formulated primarily to improve research techniques, with little or no intention to implement action. One of the main drivers of this situation is that most research is funded by national science agencies that value conceptual novelty above conservation relevance. This disconnect promotes misconceptions among many academic conservation scientists about how conservation works and what practitioners actually need, and too few scientists are taking proactive steps to bridge the gulf (Laurance *et al*. 2012).

Mexico is not the exeption to this rule, because even though there have been several conservation assessments related to freshwater species (Carrillo-Rivera *et al.* 2007, Koleff *et al.* 2009), none have resulted in coordinated conservation actions. One of the most recent assessments is the work carried out by Aguilar *et al.* (2010), that based on Gap analyses related to freshwater biodiversity, the database from CONABIO (including the one used for this study), and the participation of 260 experts, propose a series of conservation priorities for Mexican freshwater basins (Figure 6.1).

In their basin analyses, they identify 20 basins of extreme priority (dark blue areas of the map), that cover 35.74% of the country. Within this category are some of the largest Mexican basins (Bravo, Panuco, Grijalva-Usumacinta, Balsas, Lerma-Chapala, Santiago and Papaloapan, among others), as well as basins of some of the most important lakes (Cuitzeo, Zirahuén y Pátzcuaro).

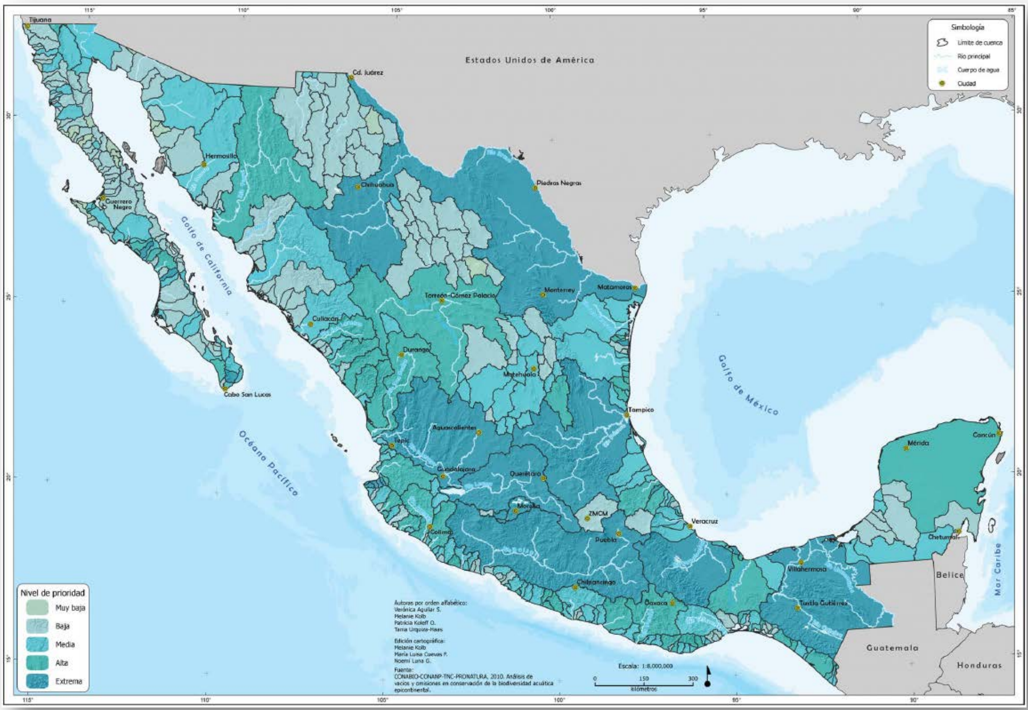


Figure 6.1 *Priority basins for freshwater species conservation in Mexico (Map from Aguilar et al. 2010)*

Unfortunately, all these assessments have not resulted in practical conservation innitiatives, maybe because of the magnitude of the problem. In this respect, due to the extinction crisis related to freshwater fish species found un chapter 4, as well as the tendency towards things getting worse described in chapter 5, immediate actions must be put in place in order to protect Mexico's rich freshwater fish fauna, thus the main goal of this chapter is to develop an operational strategy, based on the adaptive management model described by Salafsky *et al*. (2002). In this model conservation targets, their main threats and contributing factors are identified, then a suite of actions, as well as the people in charge of their implementation are identified (Figure 6.2).

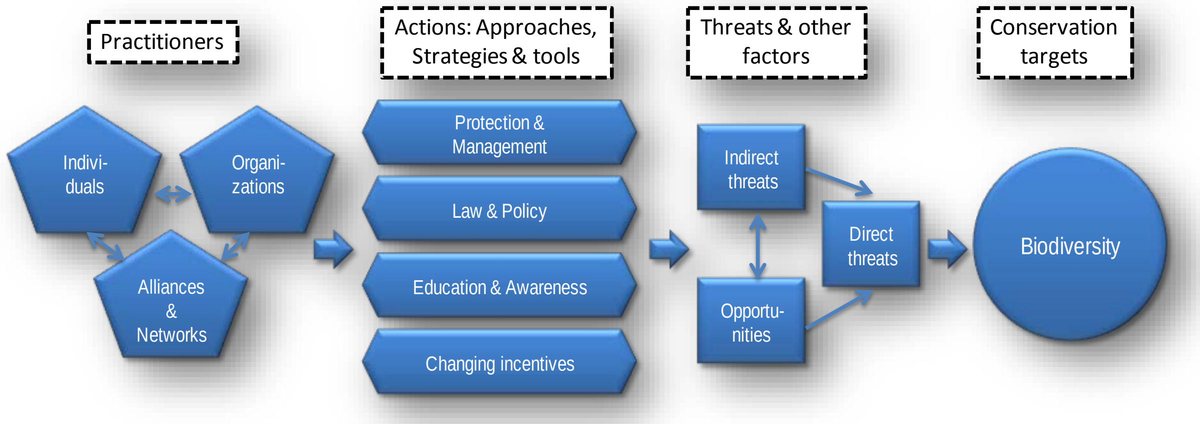


Figure 6.2 *A generalized model of a conservation Project (redrawn from Salafsky et al. 2002).*

6.2 Aims and objectives

The main aim of this chapter is to develop a conservation strategy for species with imminent risk of extinction.

Objectives were designed to:

c) Identify priority sites with species in imminent risk of extinction

d) Identify a series of concrete actions aimed at reducing threats.

6.3 Study Area

(Described in section 1.5-Chapter 1)

6.4 Method

For strategy development the Open Standards for the Practice of Conservation Version 2.0 (CMP 2007) developed by the Conservation Measures Partnerships was used. Due to the scope of this study only the two first steps were completed, which include conceptualization and planning. In this respect, having as a framework the Mexican Biodiversity Strategy (CONABIO 2000), from step one scope, vision and objectives were defined. Subsequently, due to the large number of threatened freshwater fish species found (219), within such a large country (1,964,375 km^2), with limited economic resources for species conservation actions, a decision was made to identify targets for this proposal towards those species with imminent risk of extinction, thus a prioritization method was employed based on the work of Ricketts *et al*. 2005, but with slight changes to fit it to the conservation aims of this study. Criteria were as follows: (1) the site had to contain at least one endangered or critically endangered freshwater fish species based on the data presented in chapter 4 (sections 4.5.3 and 4.5.4), (2) the site had to be the sole area where an endangered or critically endangered species currently occurs, and (3) the site had to have a definable boundary, within which habitats, biological communities, or management issues share more in common with each other than they do with those in adjacent areas (e.g., a single lake, spring, or river stretch). The boundary of the area was defined to correspond to the most practical conservation unit, including considerations of contiguous habitat, management units, and the potential for significant gene flow among populations, but limited to the aquatic environment.

Distribution data for critically endangered and endangered species were based on the findings of chapter 3, where distribution maps for each species were produced. When a species met the criteria, management and protection status of its distribution site was assessed by reviewing the Mexican Protected Area Database held by CONANP (www.conanp.gob.mx), that contains federal protected areas as well as Ramsar sites, and then a further review of state databases for each specific case. Other uses or managements of the areas were also identified. Sites were then assigned within three management categories: no management or protection, water parks, and protected areas.

Stakeholder analysis was based on the methods described by Sutherland (2000) and WWF (2005), but adjusted to fit this study. In this respect the method used has four steps that are described below: (1) identification of all the individuals, groups and institutions whose lives may be affected by the project, who hold influence or who may be capable of affecting it. This included both those who support the project and those who oppose it, (2) for each stakeholder, the interests that relate to the objectives of the project or the problems it addresses were listed, (3) a consideration was made on whether the project is likely to have a positive (+1), negative (-1), neutral (0) or uncertain (?) impact on each interest and (4) a decision was made on which stakeholders should be given priority (1= highest, 3= lowest) in meeting these interests while bearing in mind their influence and power. Thus the outcome of the analysis is a table with columns listing stakeholder, interests, impact and priority.

All the information obtained was then processed using *Miradi*™ 3.3.2 (2011) planning software, by means of which a conceptual model (Figure 7.6) was developed. The model integrates all the information including direct threats affecting sites that were drawn from the literature, using the classification of Salafsky *et al.* (2008). Based on this information result chains were then constructed in relation to each target, and from these, priority actions were identified based on the classification proposed by the same author.

In order to show how these actions can be implemented to actually protect species, the results of a case study that has been developed to conserve *Notropis boucardi* from the higher balsas river basin is presented.

6.5 Results and Discussion

6.5.1 Context

Due to the fact that this study aims to stimulate Mexican authorities towards freshwater fish conservation action, a decision was made to frame it as a subcomponent of the Mexican Biodiversity Strategy (CONABIO 2000), which is the main Mexican framework related to the protection and sustainable use of its natural capital. A similar approach was used when developing the protection strategy for coastal and marine biodiversity (SEMARNAT 2008) as well as the invasive species strategy (SEMARNAT-CONABIO 2010).

The Mexican Biodiversity Strategy (CONABIO 2000), which was elaborated in a participatory manner by consulting numerous experts, members of the civil society, the business sector and governmental agencies, is structured in four fundamental strategic lines (Figure 6.3):

1. ***To protect and preserve the different components of biodiversity***, with which the Mexican government seeks to recuperate and guarantee the presence in quality and quantity of the greatest possible components of its rich biodiversity, and to reduce the incidence of adverse factors that have negative impacts upon it.
2. ***To evaluate the different components of biodiversity***, where criteria for policies that the people of Mexico must adopt to ensure the correct valorization of the importance of existing biodiversity and its conservation. This in order to support a fair distribution of the benefits and costs related to the protection and sustainable use of biodiversity.

3. ***The advancement in knowledge and information management,*** in order to rescue and systematize current knowledge, generation of new information and communication of findings with a broad audience. In this way, information will be useful for capacity building, environmental education and communication, as well as for better decision making for the protection and sustainable use of biodiversity.
4. ***To stimulate the diversification of sustainable uses of the different components of biodiversity***, in order to stop unsustainable practices and promote new and diverse uses as a way to generate income and jobs. It will be essential to stimulate, based on the best available scientific information, a wider sustainable use of genes, species, communities and ecosystems.

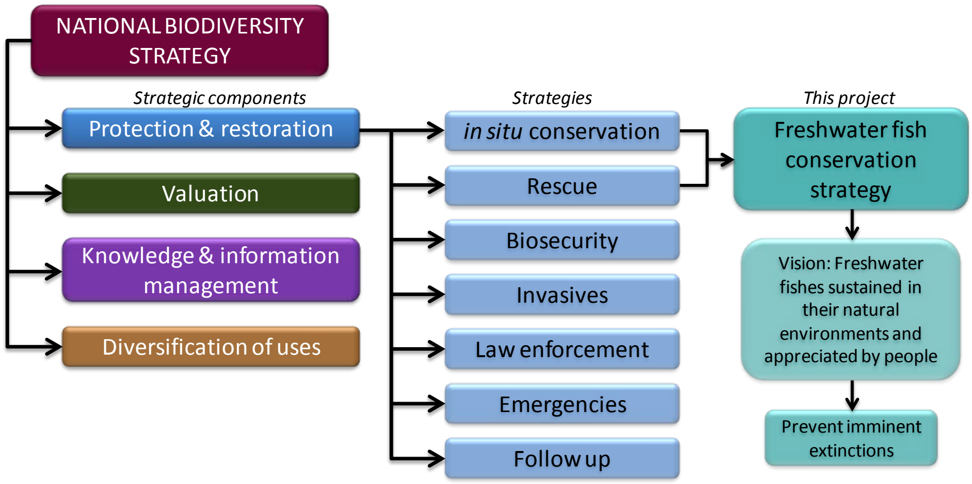


Figure 6.3 *Components of the Mexican biodiversity strategy (CONABIO 2000), and its relationship with this study.*

Even though all the components of the Mexican Biodiversity Strategy are important, in order to achieve the conservation of freshwater fishes, most of the present study has been related to information generation and systematization (Chapters 3 & 4), thus the strategy here described is centered on the protection and restoration components, and more specifically with the ones related to *in si*tu conservation and species rescue (Figure 6.3).

As it is described in the Mexican Biodiversity Strategy, *in situ* conservation has as its main goal to promote and consolidate protection initiatives such as the establishment of protected areas and other modalities for the management of ecosystems such as territorial planning of biome specific management strategies (UANL 2008, SEMARNAT-CONABIO 2010). While species rescue seeks to intensify actions directed towards the rehabilitation and recuperation of ecosystems, communities, species and genetic resources (SEMARNAT-IMTA 2009).

6.5.2 Scope definition

When the Mexican Biodiversity Strategy was published 12 years ago (CONABIO 2000), specific actions were defined in order to consolidate the country's conservation policies related to priority groups, but as demonstrated by the findings presented in chapters 4 & 5, these have not had a positive impact on freshwater fish species. That is why it is necessary to prepare the current strategy that has as its main scope to protect the ***Freshwater Fishes of Mexico***, in other words, the 616 species listed in chapter 3.

6.5.3 Vision statement

Strategy development requires the definition of a vision statement, to serve as an inspirational goal, and as the framework for all subsequent strategic planning. Traditionally the vision is constructed by the group of planners or stakeholders related to the resource in question, but since this was not possible in this case, the proposed vision statement was taken from the one discussed and agreed upon by the IUCN SSC/WI Freshwater Fish Specialist Group (IUCN 2007), but adapted to meet the scope of this project. It is as follows: ***"Mexican freshwater fishes sustained in their natural environments and appreciated by people"***

6.5.4 The Goal

Even though as it was stated in the vision, the aim is the conservation of Mexican freshwater fishes in general, due to the lack of institutional attention towards their conservation, the magnitude of the problem, and the limited economic resources available for this activity, a decision was made to focus on the worst problem identified, which is the high proportion of extinct freshwater fish species. So the main goal is ***"to prevent any further extinction of endemic Mexican freshwater fish species"***.

6.5.5 Priority setting (species with imminent risk of extinction)

Priority setting is common in conservation, whether it is for areas (Brooks *et al*. 2006, Wilson *et al.* 2006, Sarkar & Pressey 2006) or for species (Mace *et al*. 2007, Wilson *et al*. 2009), and in cases like this, when there are many conservation objects, it is necessary to do so. In this respect once the goal described in the section above was established, the next step required setting priorities of intervention, which was done by identifying species with imminent risk of extinction. As a result of this analysis 45 species within nine families were identified as those with the highest extinction risk (see tables below). The list is dominated by Cyprinodontidae with 11 species, followed by Goodeidae with 10, Cyprinidae with 8, Atherinopsidae with 7, Poeciliidae with 5 and Profundulidae, Petromyzontidae, Percidae and Heptapteridae with one species each (Figure 6.4). This is a relatively high number, due to the fact that it represents 7.3% of the freshwater fish species registered for Mexico (Chapter 3), as well as 20% of those that are threatened (Chapter 4, section 4.5.1).

The Mesa Central hotspot harbors 18 of these species (10 Goodeidae, four Cyprinidae, three Atherinopsidae and one Petromizontidae), this result fits with what was described in section 4.5.5, where this region was identified as one of the most impacted by human activities, which severe impacts on freshwater fish species (Garrido *et al.* 2010, Fisher *et al.* 2003, De la Vega-Salazar 2006, Domínguez-Domínguez *et al.* 2006, Domínguez-Domínguez *et al.* 2008, Mercado-Silva *et al*. 2009).

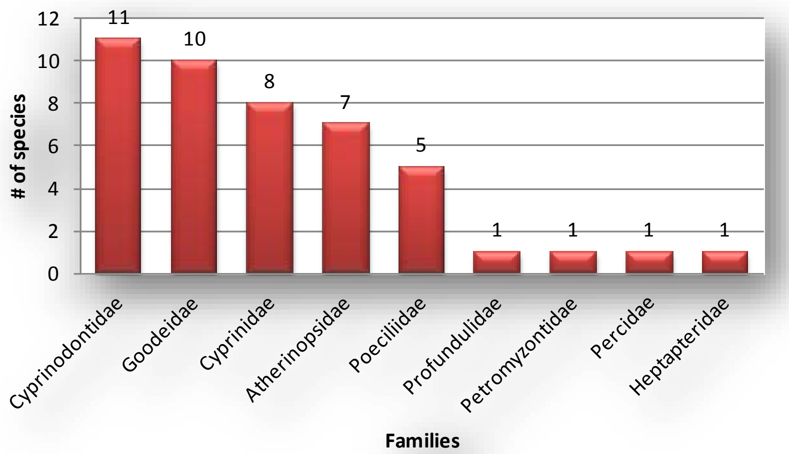


Figure 6.4 *Number of species with imminent risk of extinction grouped by families.*

Of the Cyprinodontidae, most are distributed in Northern Mexico, where diversity is low and water is scarce, so most species live in small desert habitats, except for the species flock from "Laguna de Chichancanab" in the Yucatan composed of six endemic species of Cyprinodonts (*Cyprinodon beltrani*, *C. simus*, *C. maya*, *C.*

labiousus, C. esconditus & *C. verecundus*) which all are in imminent risk of extinction (García-Moreno *et al.* 2008).

The 45 species are distributed in 30 different sites along Mexico with no apparent geographic pattern. Among these the six species from Lake Chichancanab described in the previous section stand out, followed by lake Chapala with four, Cuatro Ciénegas with three, as well as Lake Zacapu, Water Park El Rincón en Tehuchitlán in Jalisco, Lake Patzcuaro, Baños de Azufre in the Grijalva River and the Bolsón de los Muertos in Chihuahua with two species each. There are seven other sites with one species each (Figure 6.5).

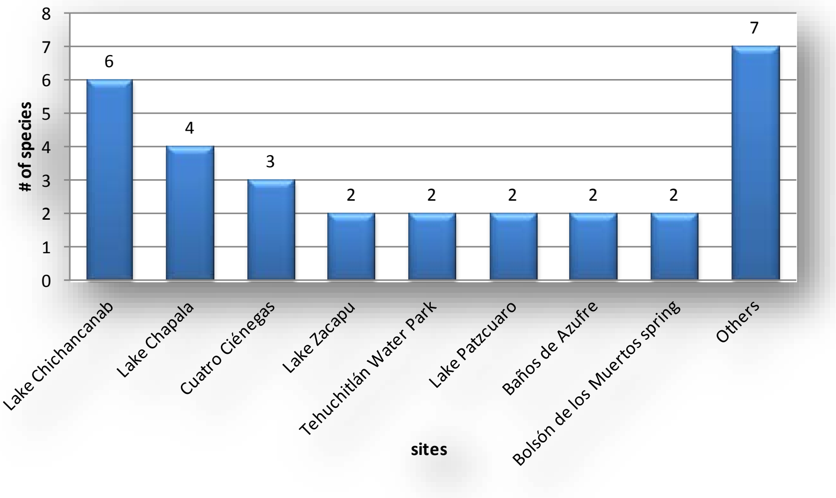


Figure 6.5 *Number of species with imminent risk of extinction grouped by sites.*

The rationale behind selecting areas is related to the Key biodiversity area principles of vulnerability and irreplaceability (Eken *et al*. 2004, Holland *et al*. 2012, Foster *et al*. 2012) but more precisely to the globally significant sites or Areas of Zero Extinction (AZE) described by Butchart *et al*. (2012), as those that represent networks of sites that are identified on the basis of current knowledge as the most important places for conserving biodiversity.

Because the idea is to identify specific conservation actions for each site, once species and sites were identified, these were grouped according to their level of protection and/or management. As a result of this classification, it was found that there are 12 sites with no management or formal protection, six which are water parks, and 12 which have some type of protection, including four sites that have more than one category of protection, such as the “Parque Estatal El Texcal”, which is a State protected area as well as a Ramsar site.

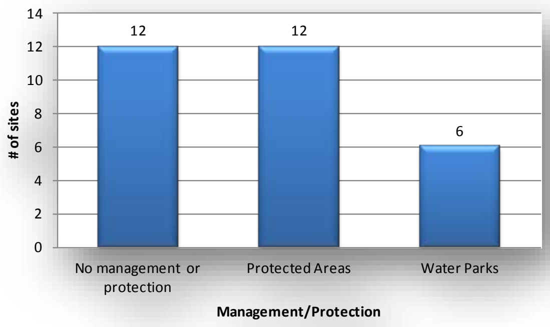


Figure 6.6 *Number of sites species with imminent risk of extinction grouped by level of management or protection.*

In this respect, there are four state protected areas, three federal protected areas, five Ramsar sites and three protected areas which are also Ramsar sites (Figure 6.6).

6.5.5.1 Sites with no management or protection

Before analyzing the data, it is important to mention that stating that there are aquatic sites in Mexico with no management is not entirely true, due to the fact that because of the scarcity of this resource in many parts of the country, most of the water has some kind of management and use, most of which is unsustainable (Sainz & Becerra 2003, Cotler 2004, CONAGUA 2010).

Sites in this category were grouped by State, because most are small areas, and because of the fact that along with Federal protection, it is feasible that each Mexican State could “adopt” its species, as priorities in their governmental programs (Table 6.1).

Table 6.1 *List of species with imminent risk of extinction in sites with no management or protection.*

FAMILY	SPECIES	STATE	DISTRIBUTION
Cyprinidae	*Cyprinella bocagrande*	Chihuahua	Ojo Solo Spring
Cyprinodontidae	*Cyprinodon fontinalis*		
Goodeidae	*Characodon audax*	Durango	El Toboso spring
Goodeidae	*Allotoca maculata*	Jalisco	Lake Magdalena
Cyprinidae	*Algansea barbata*	México	Los Reyes stream
Goodeidae	*Chapalichthys pardalis*	Michoacán	Tocumbo spring
Goodeidae	*Chapalichthys peraticus*	Michoacán	Lake San Juanico
Goodeidae	*Allotoca regalis*	Michoacán	Stream near Los Reyes
Atherinopsidae	*Poblana alchichica*	Puebla	Crater Lake Alchichica
Atherinopsidae	*Poblana letholepis*	Puebla	Crater Lake La Preciosa
Atherinopsidae	*Poblana squamata*	Puebla	Crater Lake Quechulac
Atherinopsidae	*Poblana ferdebueni*	Puebla	Lake Almoloya

In the 11 sites 12 species are found, because in Ejido Rancho Nuevo spring of the State of Chichuahua there are two species *Cyprinella bocagrande* and *Cyprinodon fontinalis*. The states of Michoacán and Puebla have three and four species respectively, the first one with three species of Goodeidae (*Chapalichthys pardalis*, *C. peraticus* and *Allotoca regalis*) which represent the most characteristic fish family of Michoacan (Domínguez-Domínguez *et al.* 2006, Pedraza 2011), while Puebla has four species of Atherinopsidae all belonging to the genus *Poblana* (*Poblana alchichica*, *P. letholepis, P. squamata* and *P. ferdebueni*) which are distributed in three crater lakes of the Cuenca Oriental and a small lake (Lira-Guerrero *et al*. 2008, Alcocer *et al*. 2010). In the Northern state of Durango there are *Characodon audax* which can only be found in "El Toboso" spring (Martínez-Aquino et al. 2007), while in Jalisco there are *Allotoca maculata* in the remains of Lake Magdalena (Domínguez-Domínguez *et al.* 2006), and in the State of Mexico there is a vestigial population of *Algansea Barbata*, that is difficult to find, but occasionally some specimens end up in a fish farm in the locality of "Los Reyes" (Figueroa-Lucero & Ontiveros-López 2000).

6.5.5.2 Water Parks

One of the most common uses given to large springs in Mexico is related to the construction of water parks, most of which are not managed with sustainable criteria, in consequence water is normally conduced into traditional swimming pools, but in some cases the original spring and the resulting stream is relatively unaffected, a situation that has turned these into sanctuaries for critically endangered fish species. This is the case of the six springs presented in Table 6.2, that constitute the remaining sites for eight species with imminent risk of extinction.

Table 6.2 *List of species with imminent risk of extinction in water parks.*

FAMILY	SPECIES	STATE	WATER PARK
Cyprinodontidae	*Cyprinodon macrolepis*	Chihuahua	Balneario ejidal Ojo de Hacienda Dolores
Cyprinodontidae	*Cyprinodon julimes*	Chihuahua	Balneario El Pandeño de los Pando
Goodeidae	*Ameca splendens*	Jalisco	Balneario el Rincón, Tehuchitlán
Goodeidae	*Zoogoneticus tequila*		
Cyprinidae	*Notropis marhabatiensis*	Michoacán	Balneario San Miguel
Poeciliidae	*Xiphophorus couchianus*	Nuevo León	Parque Fundadores de Apodaca
Poeciliidae	*Gambusia eurystoma*	Tabasco	Balneario El Azufre, Teapa
Poeciliidae	*Poecilia sulphuraria*	Tabasco	

There are two species of Cyprinodontidae in the northern state of Chihuahua, *Cyprinodon macrolepis* in "Balneario ejidal Ojo de Hacienda Dolores" (De la Maza 2009) and *Cyprinodon julimes* in "Balneario El Pandeño de los Pando", this last one is in the process of being declared as a state protected area (De la Maza in: Carabias *et al.* 2010). Another species from northern Mexico is *Xiphophorus couchianus* that inhabits "Parque Fundadores de Apodaca" in Nuevo León (Aguilera-González 1998). There are two species of Goodeidae *Ameca splendens* and *Zoogoneticus tequila* in the " Balneario el Rincón de Tehuchitlán" in Jalisco, this last species has not been seen in recent years, so it could be extinct in the wild, but further field surveys are needed in order to confirm this situation (De La Vega-Salazar *et al*. 2003, Magurran 2009, Pedraza 2011). In "Balneario San Miguel", Michoacán there is the Cyprinidae *Notropis marhabatiensis* (Domínguez-Domínguez *et al*. 2009), while in the sulphidic waters of "Balneario El Azufre", in the locality of Teapa in the southern state of Tabasco there are two species of Poeciliidae *Gambusia eurystoma* and *Poecilia sulphuraria* (Tobler et al. 2008).

6.5.5.3 Protected Areas

In this category there are 24 species that are found in 12 Protected Areas (Table 6.3). In the state of Chiapas there is *Profundulus hildebrandi* in the State Protected Area "Humedales Maria Eugenia", that was declared as such in part for the conservation of this species, that is why in its management plan there are specific actions for this species conservation (SMAVeHN 2011). There are eight Ramsar Sites, among which only Hueyapan spring (which is also part of the State protected area El Texcal) in the state of Morelos, has a management plan and specific actions for the conservation of *Notropis boucardi* (see case study in section 6.5.8). So none of the other Ramsar sites like Chichancanab in the state of Quintana Roo, which is crucial for the conservation of six species of Cyprinidontidae, nor Lake Chapala in the state of Jalisco, where there are at least four species *Chirostoma contrerasi, Yuriria chapalae, Algansea popoche* and *Tetrapleurodon spadicea* in imminent risk of extinction, this last one due to its complex life cycle that is dependent on host species, as well as on the conservation of Duero river, a tributary of the lake, where the larvae live (Díaz-Pardo *et al.* 2012). The same situation happens in the state of Michoacan where Lake Zacapu which has two species (*Notropis grandis* and *Allotoca zacapuensis*), nor the "Humedales del Lago de Patzcuaro" where there are two other species (*Allotoca diazi* y *Chirostoma patzcuaro*) have a management plan. This is also true for the "Río Sabinas" of the state of Coahuila where there is *Xiphophorus meyeri*, "Ciénegas del Lerma" in the state of Mexico México which holds the last populations of *Chirostoma riojai*, and "Baño de San Ignacio" in Nuevo León, where there is still *Cyprinodon bobmilleri*. There are also no management plans for the Federal Protected Areas such as the "Zona Protectora Forestal Bosque de Aldamas" in the state of Chihuahua, where there is *Cyprinodon pachycephalus* or the state protected area in Tabasco "Agua Blanca", where there is *Rhamdia macuspanensis.*

Table 6.3 *List of species with imminent risk of extinction in protected areas.*

FAMILY	SPECIES	STATE	PROTECTED AREA
Profundulidae	*Profundulus hildebrandi*	Chiapas	Zona Sujeta a Conservación Ecológica Huedales Maria Eugenia
Cyprinodontidae	*Cyprinodon pachycephalus*	Chihuahua	Zona Protectora Forestal Bosque De Aldamas
Cyprinidae	*Cyprinella xanthicara*	Coahuila	RAMSAR, Área de Protección de Flora y Fauna Cuatro Ciénegas
Percidae	*Etheostoma lugoi*		
Poeciliidae	*Xiphophorus gordoni*		
Poeciliidae	*Xiphophorus meyeri*	Coahuila	RAMSAR Río Sabinas
Petromyzontidae	*Tetrapleurodon spadicea*	Jalisco	RAMSAR Lake Chapala
Atherinopsidae	*Chirostoma contrerasi*		
Cyprinidae	*Yuriria chapalae*		
Cyprinidae	*Algansea popoche*		
Atherinopsidae	*Chirostoma riojai*	México	RAMSAR Ciénegas del Lerma, Área de Protección de Flora y Fauna
Cyprinidae	*Notropis grandis*	Michoacán	Zacapu RAMSAR
Goodeidae	*Allotoca zacapuensis*		
Goodeidae	*Allotoca diazi*	Michoacán	RAMSAR Humedales del Lago de Pátzcuaro
Atherinopsidae	*Chirostoma patzcuaro*		
Cyprinidae	*Notropis boucardi*	Morelos	RAMSAR Hueyapan, Parque Estatal El Texcal
Cyprinodontidae	*Cyprinodon bobmilleri*	Nuevo León	Baño de San Ignacio RAMSAR, Zona Sujeta a Conservación Ecológica del Estado de Nuevo León
Cyprinodontidae	*Cyprinodon beltrani*	Quintana Roo	Chichancanab RAMSAR
Cyprinodontidae	*Cyprinodon esconditus*		
Cyprinodontidae	*Cyprinodon labiosus*		
Cyprinodontidae	*Cyprinodon maya*		
Cyprinodontidae	*Cyprinodon simus*		
Cyprinodontidae	*Cyprinodon verecundus*		
Heptapteridae	*Rhamdia macuspanensis*	Tabasco	Parque Estatal "Agua Blanca"

The only federal Protected Area (also a Ramsar site) that has a management plan that includes specific activities directed towards the conservation of aquatic species is the "Área de Protección de Flora y Fauna Cuatro Ciénegas" in the state of Coahuila (INE

1999), where three species with imminent risk of extinction were identified *Cyprinella xanthicara, Etheostoma lugoi* and *Xiphophorus gordoni.*

6.5.6 Stakeholder analysis

Once conservation priorities were established, it was important to identify stakeholders that are critical for the development of conservation programs. Table 6.4 shows the results of stakeholder analysis, mentioning their stake/mandate, their positive or negative impact and their potential role in the project, finally the priority with which they should be considered.

Grouping stakeholders by priority demonstrates that the most important ones are those related to the governmental sector, which are those towards the present proposal is directed. These are followed by local communities, which in Mexico own 80% of common resources, and who would be the direct beneficiaries of conservation action; academics whose contributions have been and will be crucial for generating information and evaluating conservation success; the owners of aquatic parks, because of the fact that six species could be preserved by establishing conservation actions in these sites; NGOs that would be important in fund raising and in capacity building as well as in raising awareness; and finally the ornamental fish industry that could be an important allie, but who could be negatively impacted through this proposal, because a ban would be put on the introduction of alien species where there are species in imminent risk of extinction.

Table 6.4 *Stakeholders grouped by priority.*

Stakeholder	Stake/mandate	Impact	Potential role in project	Priority
Government sector	Primary program beneficiaries, and main decision makers for biodiversity conservation	1+	Crucial partner for implementation, development of rules and law enforcement	1
Local communities	Natural resource owners (including agriculture sector)	1+	Participate in conservation initiatives and alternative development projects	1
Academics	Research, communication and training	1+	Technical advisers and site/species specific project development	1
Water park owners	Use of water for recreational purposes	1+	Financial support, conservation of species and raising awareness	1
NOGs (including FFSG)	Develop conservation projects and raise awareness	1+	Financial support, technical assistance, and lobbying	1

Stakeholder	Stake/mandate	Impact	Potential role in project	Priority
Aquaculturists	Intensive and extensive fish production	1-	Financial support, ban introduction of invasives and raising awareness	1
Local fishermen	Subsistence and commercial fisheries	1+	Participate in conservation initiatives	2
Ramsar	Conservation of wetlands	1+	Financial support, technical assistance, and lobbying	2
Water industry	Sustainable use of water resources	?	Financial support	2
Aquarium Hobbyists	Ex situ management and raising awareness	1+	Financial support, technical assistance, and communication	2
Tourists	Recreational activities	1+	Financial support and lobbying	3
Aquarium dealers	Incorporating new species into the hobby	?	Financial support, technical assistance, and lobbying	3

In second priority are local fishermen that can be divided in two groups, subsistence fishermen and commercial fisherman, but both could be important due to the political power they have; the Ramsar convention that is also viewed as an important stakeholder that could endorse the proposal and provide international funding; the water industry that includes private companies and regional water operators that must participate in conservation strategies, by means of financing initiatives, or by setting aside water for environmental flows; finally aquarium hobbyists who could provide resources, participate in *ex situ* strategies, and raise awareness.

In third priority are placed tourists that visit sites where endangered species inhabit, that by paying fees would finance conservation and education programs. Aquarium dealers could be important by incorporating Mexican freshwater fish species into the trade and could participate by financing initiatives and raising awareness.

6.5.7 The conceptual model

With the information produced in the previous sections a conceptual model was developed using *Miradi*™ 3.3.2 software (Figure 6.7), where scope, vision, and conservation goal are incorporated. In the same manner conservation objects or critical sites containing species in imminent risk of extinction described in sections 6.5.3.1, 6.5.3.2 and 6.5.3.3 are shown in the green box. Affecting these are the main direct threats identified: recreational activities, water management/use, water pollution and invasive species (Red boxes). Contributing factors for each direct threat are shown in the orange boxes, while in yellow general actions proposed to minimize these contributing factors are listed.

Due to the fact that this study aims mainly to stimulate Mexican Federal, State and Municipal authorities towards freshwater fish conservation action related to species in imminent risk of extinction, no actions for specific sites or species are given, rather than this, general actions directed towards minimizing contributing factors and threats are described, in consequence, following Salaksky *et al*. (2008), local and specific conservation planning processes will need to be developed for each particular site. This could be done applying the complete project cycle described by the Open Standards (CMP 2007).

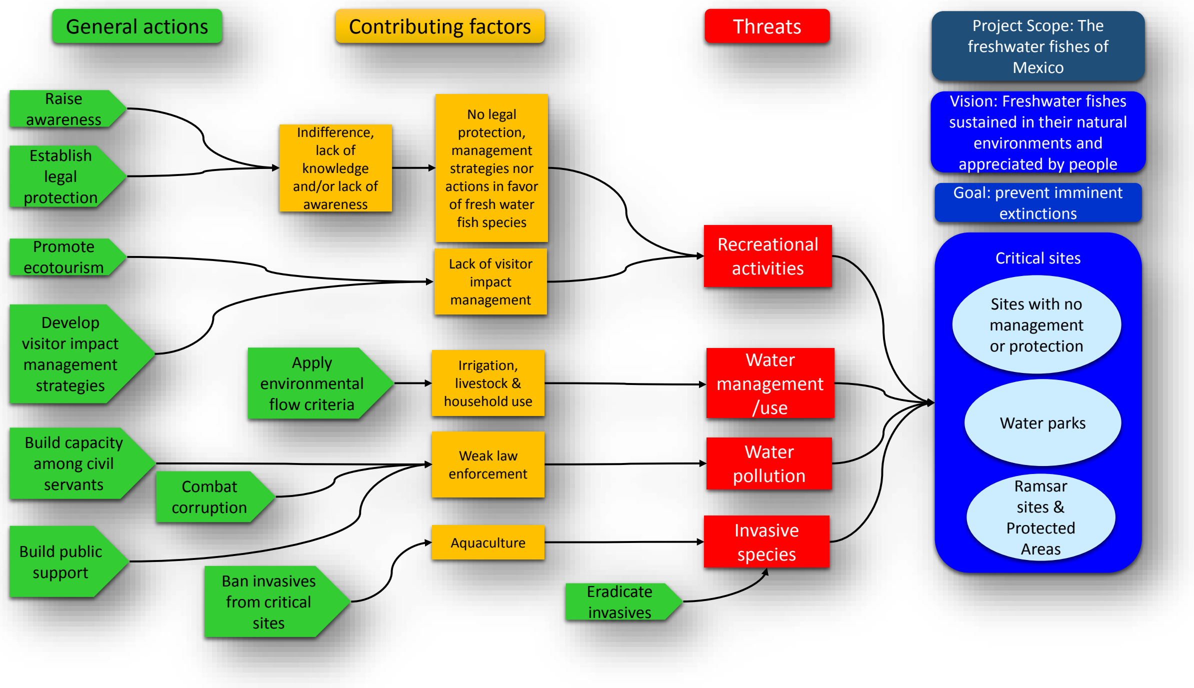


Figure 6.7 *Conceptual model for the conservation of the freshwater fish species of Mexico in imminent risk of extinction.*

6.5.7.1 Direct threats

As a result of the conceptual model four main threats were identified for the sites where species in imminent risk of extinction are distributed: (1) recreational activities, (2) water management/use, (3) water pollution and (4) invasive species, these are described below.

Recreational activities are described by Salafsky *et al.* (2008) as human intrusions and disturbance caused by people spending time in nature or traveling in vehicles outside of established transport corridors, for recreational reasons that alter, destroy and disturb habitats and species associated with nonconsumptive uses of biological resources. This threat is more likely to be more intense in areas with no management nor protection, relatively less intense in water parks and low in protected areas where access is controlled, but this is not the general rule, because only in protected areas like Cuatro Cienegas access is controlled, and water parks like “Balneario Ojo de Dolores” in Chihuahua, the only site where *Cyprinodon macrolepis* exists, where there are no limits on the number of tourists that can access the site, in spite of its conservation significance (Figure 6.8). And there are no signs nor warnings on any specific rules as to what can be done in the water body.

Figure 6.8 *“Balneario Ojo de Dolores” in Chihuahua, only site for Cyprinodon macrolepis, a day with no visitors, and a busy day.*

A similar situation occurs in practically all springs, whether they are aquatic parks or not, this same situation happens in crater lakes of Puebla, where not even the local authorities know of the existence of threatened species. The impacts of visitors to these sites are clear, these include modification of the littoral and benthic zones, the deposition of waste and in some occasions the extraction of specimens for recreation.

Water management/use, is considered by Salafsky *et al.* (2008) under the category of natural system modifications that encompasses threats from actions that convert or degrade habitat in service of “managing” natural or semi-natural systems, often to improve human welfare. Main human activities associated with this threat are surface water diversion, groundwater pumping, and channelization for irrigation. Apart from water parks, where water is normally extracted downstream from where recreational activities take place, this threat is common to all sites, but causes acute problems in the arid lands of Northern Mexico. So this threat is considered as critical in Cuatro Cienegas Ramsar and Protected Area (Figure 6.9), which is considered as a global freshwater *hotspot* and where three species in imminent risk of extinction were identified (*Cyprinella xanthicara, Etheostoma lugoi* and *Xiphophorus gordoni*) , “El Toboso” spring in Durango, only site for *Characodon audax*, lake “Magdalena” in Jalisco, that has been drained to a critical situation even though it is the only known site for *Allotoca maculata*, among others. This is a very important threat that should be addressed because it has been identified as the main cause for the extinction or extirpation of 19 freshwater fish species in Mexico (Chapter 4 section 4.5.2).

Figure 6.9 *Ramsar site and Protected Area Cuatro Ciénegas in the Northern State of Coahuila.*

Water pollution, is considered by Salafsky *et al.* (2008) as threats from introduction of exotic and/or excess materials or energy from point and nonpoint sources, in this case a whole array of types can be identified in these sites such as water-borne sewage and nonpoint runoff from housing, urban, and industrial areas, as well as pollutants from agricultural, silivicultural, and aquaculture systems areas, all of which include nutrients, toxic chemicals and/or sediments. This threat is not present in springs (including water parks) but is evident in streams, rivers and some lakes, mostly in Central Mexico, where there is a higher concentration of industrial activities and human populations such as the Lerma-Chapala system, so it has impact in sites of the State of Mexico like “Los Reyes stream”, which has the remaining site for *Algansea barbata*, in the stream near “Los Reyes & Condempas Wetland” of the State of Michoacán, where *Allotoca regalis* and *Allotoca meeki* can be found, and it is very important in lake “Chapala”, in Jalisco (Figure 6.10), that receives all the pollution from the “río Lerma”, a place where four species where identified from the analysis

(*Tetrapleurodon spadicea, Chirostoma contrerasi, Yuriria chapalae* & *Algansea popoche*).

Figure 6.10 *Tributary of lake "Chapala", where pollution by detergents coming from the city of Guadalajara can be seen.*

Invasive species are considered by Salafsky *et al.* (2008) as those non-native and native plants, animals, pathogens/microbes, or genetic materials that have or are predicted to have harmful effects on biodiversity following their introduction, spread and/or increase in abundance. In our analysis only freshwater fish invasives where considered, and these are found in almost all sites. In "Balneario el Rincón de Tehuchitlán" in the State of Jalisco, that is the last site for *Ameca splendens* and *Zoogoneticus tequila*, in spite of its conservation significance *Tilapia* sp. have been introduced with no apparent reason, due to the fact that it is a water park. One of the most outstanding cases is that of lake "Chichancanab" in the States of Yucatan and Quintana Roo, that has a flock composed of six endemic species of Cyprinodonts (*Cyprinodon beltrani*, *C. simus*, *C. maya*, *C. labiousus*, *C. esconditus* & *C. verecundus*) that is threatened mainly by the introduction of *Tilapia* sp. (Strecker 2006) (Figure 6.11).

Figure 6.11 *Tilapia sp. are considered as some of the worst invasive species.*

6.5.7.2 Result chains and conservation actions

Due to the complexity of the conceptual model, in order to facilitate it analysis, it was disaggregated into result chains related to each of the identified threats, their contributing factors, and the proposed general actions to solve them. For didactic purposes, general strategies are described for the threats that they are most associated with in the conceptual model (Figure 6.6), but these can be associated with more than one threat and many times they are complementary. Each result chain is described below:

Recreational activities

In figure 6.12 the result chain associated with the threat caused by recreational activities is described. Even though in the diagram these are presented as related mainly with critical sites with no management or protection and with aquatic parks, this is also true in many protected areas where visitor control is not strict. But the fact is that in sites with no management or protection and in water parks, recreational activities are the main contributing factors that threaten freshwater biodiversity and specifically fishes.

Contributing factors that produce this situation are the lack of legal protection and management strategies related to the conservation of freshwater fish species. These in turn are associated to three subjacent contributing factors which are: (1) lack of knowledge and/or awareness, that occurs when there is scientific knowledge related to the presence on a threatened species, but Government Agencies and the general public are not aware of this situation, so nothing is done, and (2) indifference, that occurs when in spite of knowing that there are threatened species, nothing is done to protect them.

Another contributing factor that is related mainly to water parks is the lack of visitor impact management strategies, as was exemplified with "Balneario Ojo de Dolores" in Chihuahua, only site for *Cyprinodon macrolepis* (Figure 6.11). For obvious reasons it is lacking in sites with no management or protection.

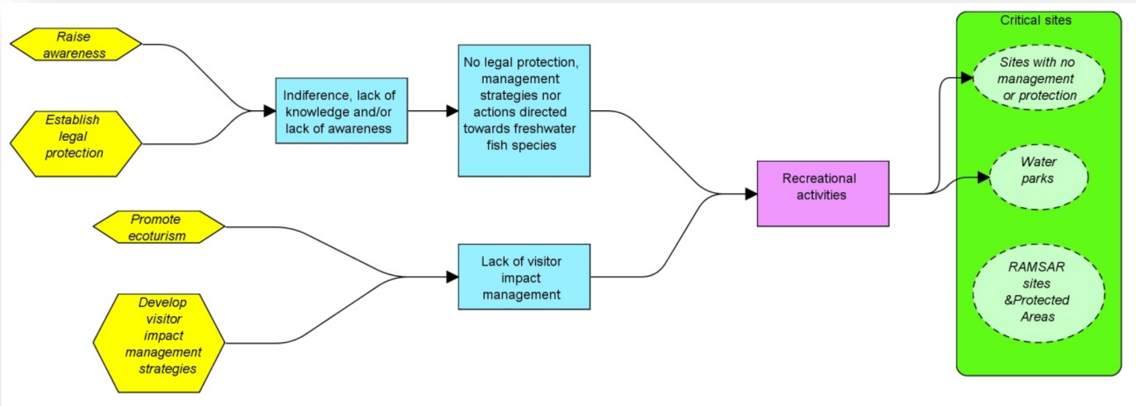


Figure 6.12 *Result chain associated with the threat posed by recreational activities.*

General action 1 Raise awareness: The first general action identified is related to raising awareness; this represents maybe the most important tool to promote sustainable development and species conservation (SEMARNAT 2006). Lack of awareness is probably the most important aspect related to freshwater fishes in Mexico, and in many parts of the world (Miller 2005, Verıssimo *et al*. 2011). A recent study that did a cost-benefit analysis on this issue (Sánchez 2010), demonstrated that the best way to raise awareness with respect to freshwater fish conservation is by taking advantage of information technologies and social media, thus by creating a Web page outlining the situation of freshwater fish species, as well as the proposed strategies, but be the best way to get public attention and in consequence the response of environmental authorities and local conservation organizations. Such a site would also serve as a means to keep the general public informed on the progress of conservation initiatives.

General action 2 Establish legal protection: The designation of protected areas, mainly in the terrestrial environment, has been the cornerstone of conservation efforts (Pimm et al. 2001, Mora & Sale 2011), and recently the use of large, undisturbed portions of habitat for conservation has become prominent in the marine environment (Suski & Cooke 2007), but freshwater protected areas have fallen far behind as conservation strategies, maybe because few models of good protected area design exist, and because traditional notions of protected areas translate imperfectly to the freshwater realm (Abell *et al.* 2007). In this respect, the basic conservation strategy for these sites must be to provide them with some type of legal protection, so it is urgent to develop the technical studies required by the Mexican law (LGEEPA 1997), and in consequence define their pertinence and characteristics, such as category, level (Federal, State, Municipal), area and conservation strategies. This last point is crucial, because as was mentioned in section 6.5.5.3, among the 12 protected areas that have species in imminent risk of extinction, only three "Humedales Maria Eugenia", "El Texcal" and "Cuatro Cienegas" have in their management plans specific actions directed towards the conservation of freshwater fish species (INE 1999, CEAMA 2010, SMAVeHN 2011). Even though it represents no formal legal status, another important strategy that could be implemented, is to consider these sites as areas of cero extinction, which is an important global strategy that promotes conservation action and raises awareness (Butchart *et al*. 2012).

General action 3 Promote ecotourism: Globally (Radulescu 2011) and in Mexico (Wilson 2008) tourism is amongst the most dynamic economic sectors and is credited with a high potential for the start-up and sustainable development at local level (Brandon 1996). In this respect, even though the environmental problems associated with the promotion of touristic activities in natural areas, it is recognized as an important activity that can generate income for local communities (Brandon 1996, Báez 2003, Buclkey 2012) and with good management can be a tool for promoting conservation. With this in mind, for all identified sites even those in established protected areas, a strategy to strengthen ecoturism should be put in place, but in such a way that it considers freshwater fish species, because most of the time these are ignored (Contreras-MacBeath & Urbina 2001). This action would not only promote conservation, but it would also raise awareness.

General action 4 Develop visitor impact management strategies: As described in the previous section, even though ecoturism represents an important conservation strategy, there are numerous potential impacts that must be considered (Gössling 1999). In this respect, in every site, even those already protected, it will be crucial to develop strategies to minimize visitor impacts. Traditionally this was done using the model of carrying capacity (Otero & Rivas 1995), but in open areas, where there is no controlled access it is difficult to achieve, so an alternative model has been developed, known as Limits of Acceptable Change (LAC), in which the amount of change to be allowed is defined explicitly by means of quantitative standards, the appropriate management actions needed to prevent further change are identified, and procedures for monitoring and evaluating management performance are established (Stankey et al. 1985). This is the proposed model to be implemented.

Water management/use

In figure 6.13 the result chain related to water management/use is presented. As was described in section 7.5.7.1 this threat affects all the critical sites identified, but is less intense in water parks, even though in those established in arid lands still are in risk of disappearing due to water over extraction (see section 1.5.2). The main contributing factor identified is water extraction for irrigation, cattle raising, household and industrial use. This is considered the most important conflict between humans and wildlife in Mexico (Vargas *et al*. 2010, Guzmán 2011).

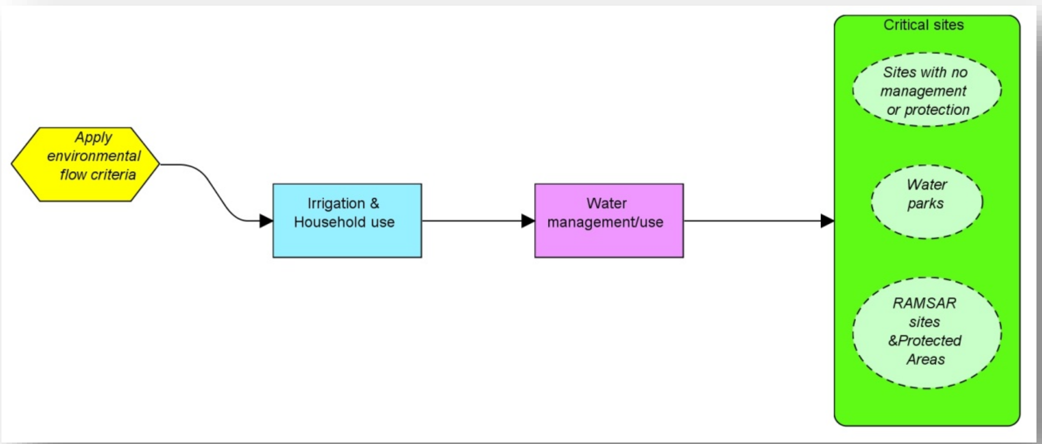


Figure 6.13 *Result chain related to water management/use.*

General action 5 Apply environmental flow criteria: Due to the magnitude of this problem, as well as the interests involved, it seems difficult to resolve, but Mexico has recently passed a law related to environmental flows, that has been developed to prevent water extraction in such a way that it could threaten the survival of freshwater species (Alonso-EguíaLis *et al*. 2007), so more effort must be directed towards establishing these criteria at local levels, and should be imposed in critical sites. Never the less, the ideal situation would be to establish integrated water basin management strategies that would allow sustainable aquifer recharge and water use for multiple purposes (Dourojeanni *et al*. 2002, GWP 2009, Mittermeier *et al*. 2010).

Water pollution

In figure 6.14 the result chain associated with water pollution is presented. By looking at the diagram it is evident that this threat mainly affects sites with no management or protection and some protected areas, but is not present in water parks, due to the touristic activity in those places. Due to the fact that Mexico has relatively good legislation related to water quality control, and that there are significant resources available for water treatment, the main contributing factor identified is weak law enforcement. In consequence three actions are proposed to solve this situation: 1) build capacity among civil servants, 2) combat corruption and 3) build public support. These are described below.

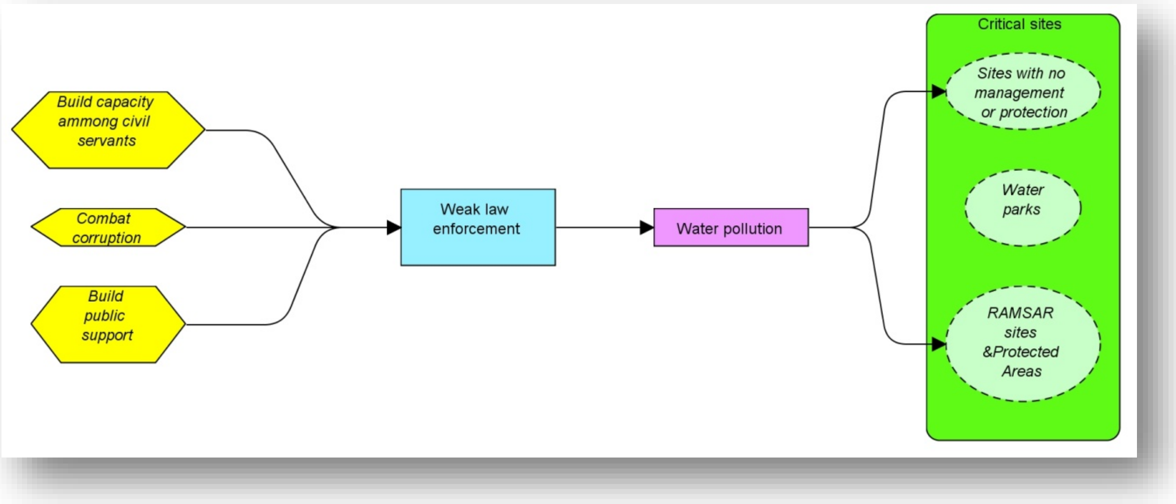


Figure 6.14 *Result chain related to water pollution.*

General action 6 Build capacity among civil servants: In some cases one of the main drivers of weak law enforcement is related to the lack of capacity of local water authorities to apply environmental laws related to water quality (Cotler 2004) so many times omissions are made. Building capacity among these local authorities would not only reduce considerably this threat, but would allow them to have more resources for water treatment, thus preserving critical sites.

General action 7 Combat corruption: A possible driver, which is not widespread, but that without a doubt is present in some sites, is the one related to corrupt local water authorities that act as accomplices of those who pollute the water. This is a difficult driver to solve, but a strategy related to combating corruption must be put in place.

General action 8 Build public support: None of the above strategies will work if society is not involved in strategy development, decision making, and implementation, so one of the main actions must be building public support. In order to achieve this participatory planning should be implemented, this has been proven to be effective in numerous water management projects (Lanna 2004, Vargas *et al*. 2010). Another way of gaining public support is by means of community based social Marketing (Fine 1981), a strategy that has been effective in many environmental projects (McKenzie-Mohr 2000, Armstrong-Schellenberg 2001).

Invasive species

In figure 6.15 the result chain related to invasive species is presented. It was found that these affect all critical sites. In this case aquaculture is considered the most important contributing factor, as a consequence of extensive fisheries management that is promoted by governmental agencies, and that is done by introducing exotics in every aquatic system as is the case of lakes Chapala and Patzcuaro (SEMARNAT-IMTA 2009), or in some cases by means of specimens that escape from fish farms, as has been the case of many ornamental species present in the Balsas river Basin (Contreras-MacBeath *et al.* 1995).

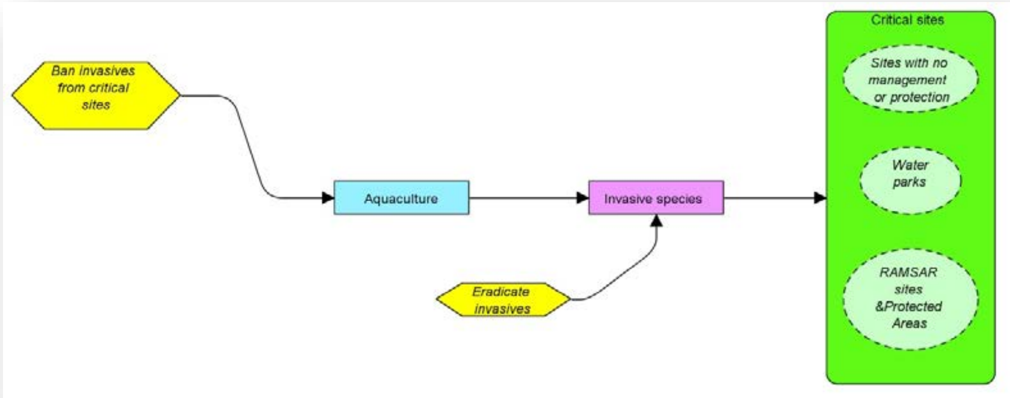


Figure 6.15 *Result chain associated with invasive species.*

General action 9 Ban invasives from critical sites: To establish as a rule to ban invasive species from critical sites is a straight forward action that must be imposed by the Mexican Environmental authority. By doing this propagule pressure is reduced (Ricciardi & Kipp 2008, Lockwood *et al.* 2009). This action could be easily implemented in small sites such as springs and creeks (many water parks), but would be very difficult in large places like Chapala and Patzcuaro, where due to traditional governmental thinking, a well established fishery based on Tilapia *spp*. is now in place, something that is currently threatening six endemic species (table 6.3).

General action 10 Eradicate invasives: The eradication of invasive species has proven to be one of the most effective conservation strategies (Hoffman *et al.* 2010). In this respect, in small sites this strategy can be easily implemented, but even in larger areas campaigns should be put in place to eradicate as many invasives as possible. This will eventually reduce the impact on endangered species.

7.5.8 Implementation

Even though implementing concrete conservation actions for the protection of specific species is beyond the scope of the present study, an example of how the ten conservation actions here identified can be applied is given based on work carried out in recent years with *Notropis boucardi*, and that have managed to protect this species by means of an important conservation effort that involves academic institutions, international agencies, federal, state and local government agencies, the general public, but most importantly by the community that owns the land where the species is distributed, with the participation of water users.

6.6 Conclusions

Due to the fact that this study aims to stimulate Mexican authorities towards freshwater fish conservation action, a decision was made to frame it as a subcomponent of the Mexican Biodiversity Strategy, but centered on the protection and restoration components, and more specifically with the ones related to *in si*tu conservation and species rescue.

Lack of institutional attention towards freshwater fish conservation found in Chapter 6, the magnitude of the problem identified in chapter 5, and the limited economic resources available for species conservation, led to a decision to focus on the worst problem identified, which is the high proportion of extinct freshwater fish species.

The strategic planning process produced the following:

Scope: *to protect the 616 Freshwater Fishes of Mexico.*

Vision: *Mexican freshwater fishes sustained in their natural environments and appreciated by people.*

Goal: *to prevent any further extinction of endemic Mexican freshwater fish species.*

Prioritization towards species in imminent risk of extinction produced a list of 45 species within nine families identified as those with the highest extinction risk. This is a relatively high number, due to the fact that it represents 7.3% of the freshwater fish species registered for Mexico.

These 45 species are distributed in 30 different sites along Mexico, 12 sites are considered as having no management or formal protection, six which are water parks, and 12 which have some type of protection, including four sites that have more than one category of protection, such as the “Parque Estatal El Texcal”, which is a State protected area as well as a Ramsar site.

By means of *Miradi*™ 3.3.2 software a conceptual model for the conservation of these critical sites was developed using, where scope, vision, and conservation goal are incorporated. As a result of this conceptual model four main threats were identified for the sites where species in imminent risk of extinction are distributed: (1)

recreational activities, (2) water management/use, (3) water pollution and (4) invasive species. Based on these main threats general actions were described:

1. Raise awareness
2. Establish legal protection
3. Build public support
4. Promote ecotourism
5. Build capacity among civil servants
6. Combat corruption
7. Develop visitor impact management strategies
8. Apply environmental flow criteria
9. Ban invasives from critical sites
10. Eradicate invasives

Seven of the actions described above have effectively contributed towards the conservation of *N. boucardi*, and following this case study, a general conclusion can be made in the sense that applying the general actions described here, if designed and applied in a participatory manner, could also contribute to the conservation of other threatened species in the critical sites identified.

Chapter 7: Case study *Notropis boucardi*

7.1 Introduction

In order to demonstrate how the general actions described above can be turned into an action plan and implemented, a case study with the Morelos Minnow (*Notropis boucardi*) is presented. The information used is the result of several years of work by the author with this species, and by contributions made by several coworkers and students (Contreras-MacBeath 2005, Urbina *et al.* 2006, Contreras-MacBeath & Rivas 2007, Osorio 2008, Rivas 2008, Contreras-MacBeath *et al*. 2010, Preciado 2012, González 2012). These have led to the protection of *N. boucardi*, with the involvement of local communities, governmental authorities and international agencies. Even though actions are now in place for the whole distribution area of this species, special emphasis is placed on actions done in Hueyapan Ramsar site which represents 50% of its area of occupancy. This site also resulted as a priority one from the imminent risk of extinction analyses presented in section 6.5.5.

7.2 Species description

Figure 7.1 *Notropis boucardi (photo by Topiltzin Contreras)*

Body elongated (max. TL=12 cm); subterminal mouth, inferior jaw shorter than the superior; dorsal fin with 10–11 rays, one of which is small and not ramified; 36–38 scales on a longitudinal series, and from 16 to 19 predorsal scales. The species has 7 scales from the lateral line to the base of the dorsal fin, and from 4 to 5 between the pelvic fins. During the greatest part of the year it is silver in color, with a darker tone on the dorsal part of the body, and has a black stripe that runs from the eye to the caudal fin. During reproduction bright red coloration is evident in its ventral region (Figure 7.1).

7.3 Distribution

Traditionally thought to be distributed throughout the Balsas river basin (Espinosa *et al.* 1993). But mitochondrial Cytochrome *b* analysis (Schönhuth & Doadrio 2003), showed that the species is restricted to a small system of streams located to the west of Cuernavaca, Capital of Morelos State, as well as in an endoreic spring (Laguna de Hueyapan) of the neighboring municipality of Jiutepec, within a state protected area called “El Texcal”. Those sites are in a one mile radius from the type locality (Günther 1868).

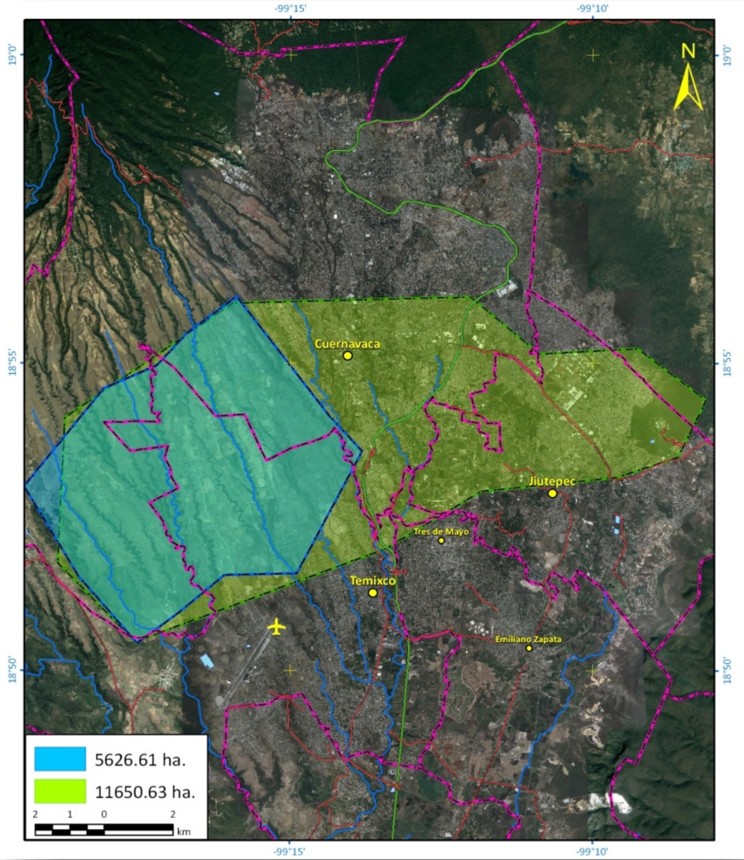


Figure 7.2 Historical (green) and current (blue) distribution of *Notropis boucardi.*

A distribution study (Preciado 2012) demonstrated that the historical distribution of *N. boucardi* covered 11,650.63 hectares and now only 5,626.61 hectares, which means that in a period of about 50 years, the species has 51.7% of its original distribution (Figure 7.2). The same study showed that the Area of Occupancy of this species is 4.6 hectares, and that one hectare of these corresponds to the Hueyapan Ramsar site. But more recently, a phylogeographic study on the same populations, based on mitochondrial Cytochrome *b* analysis (Joel 2014), demonstrated that there are two species of minnows in the area, *Notropis boucardi* and *N. moralesi*, and that the first one is only distributed in two streams, and the Hueyapan Ramsar site, a result that further builds on level of threat to the species and the need to protect it in its distributional area.

7.4 Threats

Three main threats to *N. boucardi* have been identified, water pollution, water management/use and invasive species. In the first case as the consequence of the growth of the city of Cuernavaca in the last 50 years, and the lack of appropriate wastewater treatment, most of the streams within the urban area of the city are polluted in such a manner that it is not possible for *N. boucardi* to survive. In this respect in an environmental evaluation study Martínez (1996) found high levels of pollutants that could not sustain fish.

Specifically for the State Park “El Texcal” which is also a Ramsar site, Gonzalez (2012) described how the basin that feeds into Hueyapan has been invaded by uncontrolled urban development, and how there is overdrafting of the aquifer, two situation that puts the area at risk. Following its original declaration as a protected area in 1992 with an extension of 407 ha, by 2010 el “El Texcal” had lost 149 ha (37% in 18 years) of its surface to squatters. In 2010 there was a new decree by the State Government reducing the protected area to the remaining 258 ha. In spite of this, when the new State Government took office in 2012, there were another 70 ha invaded by squatters, and had put the whole area at risk.

With respect to invasive species, through the surveys carried out by Preciado (2012) in the current distribution area of *N. boucardi*, it was evident that when the invasive fishes *Onchorynchus meeki* (rainbow trout), *Xiphophorus helleri* (swordfish) or *Heterandria bimaculata* were present, *N. boucardi* was not, except in Hueyapan Ramsar site, where even though rainbow trout were present, some specimens of *N. boucardi* survived hidden among dense aquatic vegetation.

7.5 Conservation action

The conservation strategy that has been implemented for the protection of *N. boucardi* in Hueyapan Ramsar site includes eight (*raise awareness, build public support, establish legal protection, enforce the law, promote ecotourism, develop visitor impact management strategies, ban invasives from critical sites and eradicate invasives)* of the 10 general actions in section 6.5.7.2, these are described below:

7.5.1 Raise awareness

Raising awareness in order to gain public and institutional support for the conservation of less charismatic and least known species such as N. boucardi is a difficult task, so an intense outreach and communication program was developed for this species.

In order to gain support for the conservation of *N. boucardi* from Federal, State and local authorities, as well as from the general public is was necessary to develop a communication strategy that included the publication of information related to this species in journals, books, magazines, and Web Pages (Contreras-MacBeath 2005, Urbina *et al.* 2006, Contreras-MacBeath & Rivas 2007, Osorio 2008, Contreras-MacBeath *et al*. 2010), as well as by articles in newspapers, radio and TV interviews, presentations in meetings and conferences, and by presentations in public and community meetings. Because of this effort, *N. boucardi* is now recognized as a focal species in the State of Morelos, due to the fact that it represents the only endemic vertebrate of the State.

Figure 7.3 *Notropis boucardi* emissions sticker on a vehicle.

State governmental support has been such, that in 2013 an image of *N. boucardi* was used as a symbol of the sticker of the vehicle pollution verification program in the State of Morelos (Figure 7.3).

7.5.2 Build public support

Due to the magnitude and complexity of the problems, as well as the possible political impacts of the actions that needed to be implemented in relation to the conservation of *N. boucardi*, described in the following sections, in order to gain public support, the communication strategy implemented used different media, including large format signs describing the importance of *N. boucardi* as an indicator species for water quality were displayed in different public spaces of the city (Figure 7.4).

Figure 7.4 Large format *Notropis boucardi* image and information on a public space.

In order to reach a wider audience, with funding from the Mohamed Sayed Species Conservation Fund, a case study of *N. boucardi* was included in the documentary "the conservationists" that tracks six conservation projects from different parts of the world. This documentary was included in the "*Cinema Planeta*" Film Festival 2014, where 15 screenings in local theaters were presented to 3,700 people, mainly students (Figure 7.5). More recently, the documentary was transmitted in the local TV station, reaching a larger audience (Figure 7.6)

Figure 7.5 Presentation of "T*he Conservationists*" documentary for students.

Figure 7.6 E-card for the documentary of *N. boucardi.*

Special attention has been placed on a strategy directed towards the construction of agreements among different stakeholders related to Hueyapan Ramsar site (González 2012) (Figure 7.7), because of the conservation action to take place in that specific site.

As a result of this strategy there is now widespread public support regarding the conservation of *N. boucardi*, which in turn has driven local and federal environmental authorities to put in place, in their work plans, strategies for the conservation of this species.

Figure 7.7 Workshop in the community of Tejalpa for the management of Hueyapan Ramsar site, which represents 50% of the area of occupancy of *N. boucardi.*

7.5.3 Establish legal protection

The public support described in the previous section, has made it easy to establish legal protection in the distribution areas of *N. boucardi*, in the first case, by declaring as conservation areas the streams where this species lives in the Municipality of Cuernavaca, in the territorial management plan (PO-Morelos 2009). This designation has recently prevented the establishment of a Municipal landfill, and the construction of a mayor highway, both of which could have had severe impact on *N. boucardi*. Currently the local University is developing a management plan for this region that considers *N. boucardi* as a focal species.

Figure 7.8 *Localization of Hueyapan Ramsar site within state protected area "el Texcal".*

On the other hand, as a result of a study related to the conservation significance of Hueyapan wetland (Rivas 2008), this site (yellow circle Figure 7.8) which represents 50% of the Area of Occupancy of *N. boucardi*, has been declared as a Ramsar site (Ramsar 2011), with one of its main justifications, the protection of this species.

Following this declaration, a conservation strategy for this site, as well as for *N. boucardi*, has been developed with the local community of Tejalpa, who are the legal owners of the land.

7.5.4 Enforce the law

As described in section 7.4, in the Ramsar site "El Texcal", the most serious threat was loss of forest habitat in the basin due to human invasions by squatters. In this respect, in order to preserve the area, having as one of the main justification in doing so the conservation of *N. boucardi*, from 2013 the State Government of Morelos developed a strategy directed towards recuperating the invaded area. The strategy consisted in producing a detail diagnostic of the magnitude of the problem, the actors involved, as well as the political consequences of taking action.

Seventy hectares were found to be affected (Figure 7.9), which represented 24% of the total surface of the protected area (green line in Figure 7.9). Within this perimeter 400 constructions were identified, mainly rustic houses, 80 of these were consolidated regarding construction materials (red dots) while the rest were huts without people (yellow dots).

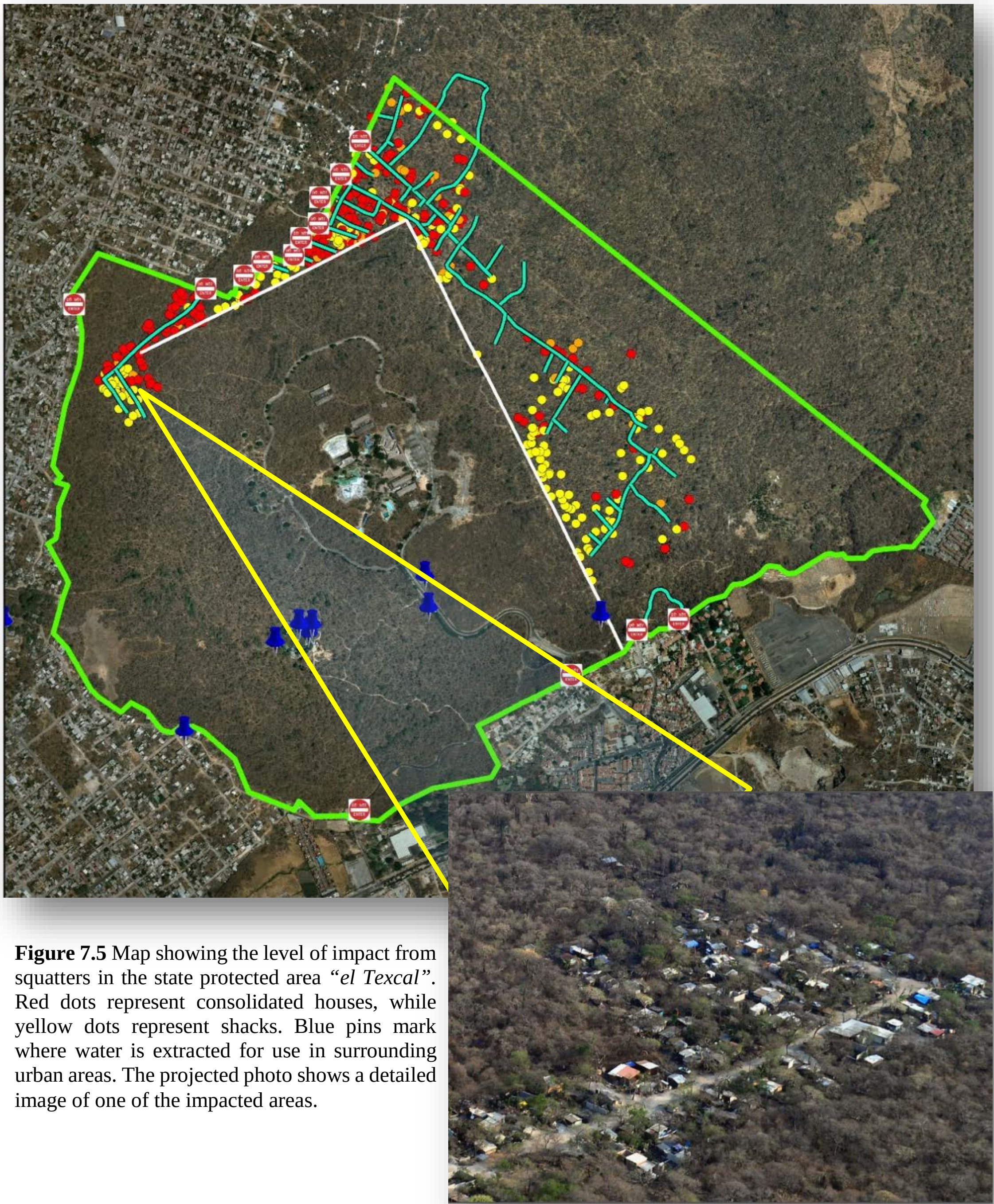


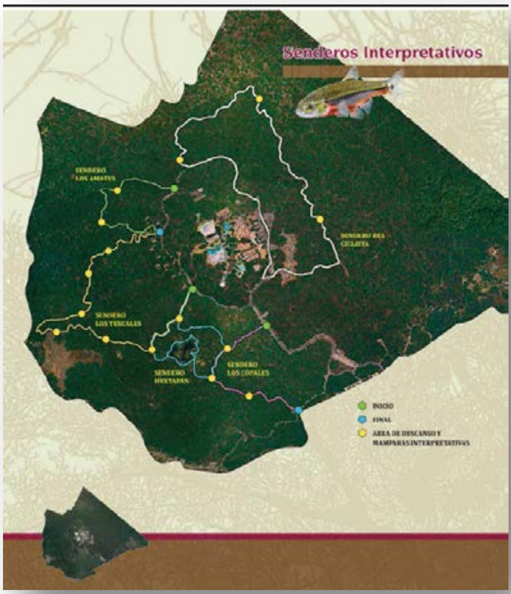
Figure 7.5 Map showing the level of impact from squatters in the state protected area *"el Texcal"*. Red dots represent consolidated houses, while yellow dots represent shacks. Blue pins mark where water is extracted for use in surrounding urban areas. The projected photo shows a detailed image of one of the impacted areas.

With this information an intervention strategy involving the Municipal, State and Federal Government was established to take squatters out of the protected area, but having the support of the community of Tejalpa, which are the legal owners of the land (Figure 7.6).

This consisted in 15 interventions with the aid of 350 policemen and 90 people from the community, who were legally habilitated to take people out of their land and bring down constructions. As a result of these actions the 70 ha invaded were recuperated, with no major problems. Even though this type of actions are normally not done by governments due to alleged high political costs, as a result of the outreach program and community strategy described in the previous sections, there was a generalized support from different sectors of society, and there is now even pressure to have these interventions in other protected areas with similar problems. This is something unprecedented in Mexico.

Figure 7.6 Photographs showing part of the activities carried out by the local government and the community of Tejalpa in order to recuperate invaded areas by squatters.

7.5.5 Promote ecotourism and develop visitor impact management strategies



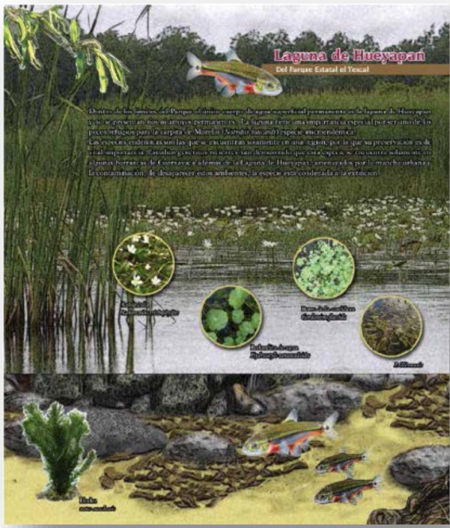


Figure 7.6 *Map of the visitor trails and a sign showing the main species of the wetland, including N. boucardi*

Promoting ecotourism and developing visitor impact management strategies, are two very important activities for the conservation of *N. boucardi*, specifically within the State Protected Area “El Texcal”, because of the potential that this activity has in generating income for the local community, and consequently strengthening conservation efforts.

“El Texcal” is localized in the Municipality of Jiutepec, which has one of the highest urban densities in Mexico, so the protected area is constantly subject to threats from illegal urban development. Since its establishment 16 years ago, “El Texcal” has lost 37% of its original area because of the uncontrolled growth of the city. Seeking to preserve the remaining 258 hectares that belong to the community of Tejalpa, the local government, with the aid of the Biological Research Center at the University of Morelos are developing a conservation strategy that involves several ecotourism projects for the community, such as the reopening of an abandoned water park (infrastructure shown in figure 7.6), the remodeling of 14 eco-cabins that are rented by visitors, the establishment of an Environmental Management Unit for the propagation of white tailed deer, and black iguanas, as well as the construction of several visitor trails, one of which goes into the wetland (Figure 7.6).

7.5.6 Ban and eradicate invasives

Traditionally in Hueyapan wetland rainbow trout (*Onchorhynchus mykiis*) had been introduced for fisheries purposes, even though it is a very small area (less than one hectare), and that no formal fishing activity took place, but people from the community had always the idea that having a stock of trout was somehow good. This situation had led to the displacement of *N. boucardi* to a small and shallow area of the wetland where trouts did not have access. After a process of participatory planning with the local community, they decided to ban trout from the wetland. Following this decision, a strategy for the eradication of trout was put in place.

In the same manner, a plan for the eradication of invasive aquatic plants (*Egeria densa* and *Typha* sp.) was put in operation. These two species were introduced into the wetland in the 90s, and as can be seen in figure 7.7, where aerial photos from 2004 and 2010 are compared, they have been gaining terrain over the aquatic habitat, and reducing the capacity of fishes to exist.

Figure 7.7 *Aerial photos of Hueyapan Ramsar site in 2004 and 2010, where the invasion of aquatic plants is evident (photo Topiltzin Contreras).*

In order to stop the growth of these two species, a restoration program with the community of Tejalpa was established; it included the participation of local water authorities that extract water from the wetland for household use. As part of this strategy the parties involved have participated in several eradication events (Figure 7.8).

The actions implemented so far have made it possible to recover 60% of the original water body (González 2012), and more actiones are planned to keep these aquatic invasives under control.

7.6 Conclusions

Figure 7.8 *Eradication of aquatic plants by the local community in Hueyapan Ramsar site (photo Topiltzin Contreras).*

All of the actions described above have effectively contributed towards the conservation of *N. boucardi*, and following this case study, a general conclusion can be made in the sense that applying the general actions described here, if designed and applied in a participatory manner, could also contribute to the conservation of other threatened species in the critical sites identified.

Chapter 8: General Conclusions

8.1 General conclusions

In general terms it can be said that the present study has contributed to the knowledge of Mexican freshwater fish species, their conservation status and threats, and that the basis for the implementation of specific conservation actions for species with imminent risk of extinction is delineated. But it is clear that much work is still needed in order to change the precarious situation of freshwater fishes and their habitats.

As a result of the work done in Chapter 3, a list of 616 fish species grouped in 61 families for Mexican freshwaters was obtained. Considering that globally there are approximately 12,000 described freshwater fish species (Nelson 2006), according to this study, Mexico holds about 5.1% of the global freshwater fish diversity. This is a large figure, taking into account that the Mexican territory represents only 1.3% of the world's land area. Lévêque *et al*. (2008) lists 74 families and 1411 species of freshwater fishes for North America, which means that, according to our numbers, Mexico has within its territory about 82% of the families and 43% of the species known for this subcontinent.

Out of the 616 species listed here, 266 are Mexican endemics (43.1%), grouped in 19 families. The six most diverse families represent 86.3 % of the total, with 229 endemic species. In this case, Poeciliidae is again the most diverse family, with 58 endemics, followed by Cyprinidae, Goodeidae, Atherinopsidae, Cyprinidontidae and Cichlidae, with 45, 44, 34, 26 and 24 species, respectively.

The Goodeidae family is worth highlighting, due to the fact that out of the close to 50 known species, 43 are Mexican endemics and all representatives of the Goodeinae subfamily, which is endemic to Central Mexico (Domínguez-Domínguez *et al.* 2006).

This chapter presents and up to date list of fishes inhabiting Mexican freshwaters, but even though Mexico's ichthyofauna is quite well know, there are still from 30-50 species to be described (Contreras *et al*. 2008, Miller *et al.* 2009) and giving the fact that several groups such as Cichlids and Poecilids need revisions, as well as new information provided by the use of modern molecular techniques in biodiversity assessments (Hulsey *et al*. 2004, Concheiro *et al*. 2007) we feel that at least 10% of

Mexican freshwater species are yet to be described, so the real number could be close to 700 species.

The study of richness and endemism presented in Chapter 4 has been crucial for identifying hotspots and for identifying priorities for conservation efforts. Mapping these centers by means of geographical information systems based on museum data have made it possible to confirm several previously identified centres of freshwater fish richness (Southeastern Mexico, the Mesa Central, the Bravo-Conchos river system and the Panuco and Tuxpan-Nautla rivers). Seven areas with high CWEI endemism values were also identified, but the valley of Cuatrociénegas is recognized as a true centre. An alarming result is the identification of a “Ghost” centre of endemism (Llanos El Salado) in Southwestern Nuevo León, where the six endemic Cyprinodont species that where present in this center are all extinct or extinct in nature. 49 single site endemics where found to be very much distributed all over Mexico, but it is noteworthy to mention Chichancanab lagoon in the border between Yucatan and Quintana Roo, where a flock composed of 6 endemic Cyprinodonts is present. Three hotspots of richness+endemism in Mexico were also identified, the most important of which is the Mesa Central where many impacts of human activities have had a detrimental effect on fish populations.

After assessing the 616 species of Mexican freshwater fishes using IUCN Red list criteria (Chapter 5), 219 species in 25 families are classified as threatened, 47 are critically endangered, 83 are endangered, and 89 are vulnerable. These proportions are very similar to those found for European freshwater fishes (Kottelat & Freyhof 2007).

With a total of 160 threatened species, five families compromise 73% of the total, these are Cyprinidae with 55 threatened species, Goodeidae with 38, Poeciliidae with 23, Atherinopsidae with 22 and Cyprinidontidae with 21.

There are 26 lost freshwater fish species for Mexico, 15 extinct species, five extinct in the wild and six that are now regionally extinct. Globally extinct fishes, both extinct and extinct in the wild represent 3% of the total with 20 species, 15 of which are Mexican endemics. If we consider that there are 67 documented freshwater fish global extinctions (IUCN 2011.1), Mexican extinctions represent 30% of the global total. This high number, as well as the tendencies found towards things getting worse clearly demonstrates that there is a severe extinction crisis in Mexico related to fresh water fishes.

Most of these extinctions (19) were caused by excessive water extraction in arid areas that resulted in drying up of the aquatic habitat. One of the most severe examples of this is that of *Chirostoma bartoni*, a species that went from Vulnerable to Extinct as a consequence of the disappearance of its only known site, the crater lake “La Alberca” West of Valle de Santiago, Guanajuato that dried out (Jelks *et al.* 2008). Five extinctions are recognized to be produced by pollution and two by invasive species.

Data shows that based on the classification proposed by Salafsky *et al.* (2008) direct threats or the proximate human activities or processes that have caused and are causing the destruction, degradation, and/or impairment of freshwater fish species in Mexico are: dams and other natural system modifications related to water management/use, pollution, invasive species, aquaculture, and overfishing. Even though it is well known that stressors act in synergy to impact freshwater species (Strayer 2010).

The assessment of the Mexican legal and institutional framework related to freshwater fish species conservation, as well as the effectiveness of ongoing biodiversity conservation strategies carried out in Chapter 5 demonstrated that there is a robust framework and a commitment by the Mexican government towards biodiversity protection and the transition towards sustainable development, something that is backed by the federal budget which had a 350% increase in the period between 2001 and 2011. Currently £ 2,511,714,168 are spent on environmental programs, which represents 0.9% of GDP, a figure that is equal to the 0.9% spent by Italy, and higher to the 0.8% spent by France or the 0.6% spent by Belgium (INEGI 2013).

Conservation efforts by the Mexican government have been effective in protecting many terrestrial species and habitats in Mexico (Dirzo *et al.* 2009, Figueroa *et al*. 2011, Halffter 2011), but unfortunately, *ex-post* analysis and data from Chapter 5 demonstrates that this has not been the case of freshwater fish species.

Designation of protected areas has been the cornerstone of Mexican conservation initiatives and there are now 25.3 million hectares protected (11.8% of the nation’s territory), but these have been designed and designated with a terrestrial focus, a situation considered by many authors as having little impact on the conservation of freshwater species (Saunders *et al*. 2002, Abell *et al*. 2007, Suski & Cooke 2007, Lawrence *et al*. 2011, Williams et *al*. 2011), and even though many freshwater fish species are distributed in freshwater habitats within protected areas, there are almost no conservation actions directed towards them (Contreras-MacBeath1997, Contreras-MacBeath 2005, Pino-Del-Carpio *et al*. 2010).

The Program for the Conservation of Species at Risk currently has 49 priority species, most of which are terrestrial. All fish species considered are from the springs of Cuatro Ciénegas. In December of 2011 a workshop was held in Mexico City to produce a new list, and for the first time a group of ichthyologists were invited. The result from this workshop was a list of 119 freshwater fish species that should be introduced, but the Mexican environmental authority, wrongly interpreting Article 1° of the General Wildlife Law, did not include them, with the argument that these should be managed by other government ministries.

Much of this can be attributed to two fundamental situations: (1) the first one is related to the fact that fishes are still considered as resources, and not as wildlife, (2) The second situation is related to the way that the "*green, blue and gray policy Agendas*" applied by SEMARNAT, sectorizes attention to environmental issues in such a way that it generates confusion and judicial inefficiencies, promotes rivalry among governmental agencies (Cañas *et al.* 2009), and creates gaps like the one that leaves freshwater fishes greatly unattended.

As described in Chapter 6, due to the fact that this study aims to stimulate Mexican authorities towards freshwater fish conservation action, a decision was made to frame it as a subcomponent of the Mexican Biodiversity Strategy, but centered on the protection and restoration components, and more specifically with the ones related to *in si*tu conservation and species rescue.

Lack of institutional attention towards freshwater fish conservation found in Chapter 5, the magnitude of the problem identified in chapter 4, and the limited economic resources available for species conservation, led to a decision to focus on the worst problem identified, which is the high proportion of extinct freshwater fish species.

Even though some progress in Mexican institutions and policies is evident, due to the fact that all the answers to the questions put forward in the institutional gap analysis were negative with respect to freshwater fish species, fourteen recommendations are given in order tomove towards an institutional arrangement that better promotes the conservation of these species.

1. Due to the lack of clarity in financial information, is seems necessary to produce precise data on environmental spending, but specifically on species conservation. This will make it possible to contrast biodiversity conservation spending, against money spent on those policies that negatively impact freshwater fishes, and their environments.
2. Based on the result from the previous section, a periodization program that would promote “smart” spending and better results should be carried out, and contradicting monetary spending policies should be aligned in favor of the conservation of threatened species.
3. It is fundamental to reduce or eliminate perverse incentives that work against biodiversity conservation.
4. It is necessary to strengthen Federal and State and Municipal environmental institutions, specialy those related to biodiversity conservation.
5. Strenghthen and promote the integration of decision structures that coordinate efforts among different levels of government, and among ministries.
6. It is fundamental to promote the production and implementation of State Biodiversity strategies, and that these put special emphasis on the conservation of species at the local level, including freshwater fish species.
7. Consolidate information systems related to the management and conservation of biodiversity, so it can be posible to evaluate its impacts.
8. Review conservation policies so special attention can be put on species in imminent risk of extinction, with special focus on freshwater fishes.
9. Change article 1° of the National Wildelife Law in a way that freshwater fishes are included.
10. Change the way in which freshwater fisheries are managed.
11. Even though the general goals and targets are clear, specific target need to be put in place to focus on priority species such as freshwater fishes.
12. As in other cases (Marine environments, invasive species, amons others) a strategy to focus on freshwater species should be implemented.
13. Develop a communication strategy aimed at making freshwater fishes relevant to public oficials and to the general public.
14. Develop a conservation evidence based strategy associated to freshwater fishes and their ecosystems.

Thus even though the strategic planning process was developed for all Mexican freshwater species, strategy development was targeted towards species with imminent risk of extinction. Strategic planning produced the following:

Scope: *to protect the 616 Freshwater Fishes of Mexico.*

Vision: *Mexican freshwater fishes sustained in their natural environments and appreciated by people.*

Goal: *to prevent any further extinction of endemic Mexican freshwater fish species.*

Prioritization towards species in imminent risk of extinction produced a list of 45 species within nine families identified as those with the highest extinction risk. This is a relatively high number, due to the fact that it represents 7.3% of the freshwater fish species registered for Mexico.

These 45 species are distributed in 30 different sites along Mexico, 12 sites are considered as having no management or formal protection, six which are water parks, and 12 which have some type of protection, including four sites that have more than one category of protection, such as the "Parque Estatal El Texcal", which is a State protected area as well as a Ramsar site.

By means of *Miradi*™ 3.3.2 software a conceptual model for the conservation of these critical sites was developed using, where scope, vision, and conservation goal are incorporated. As a result of this conceptual model four main threats were identified for the sites where species in imminent risk of extinction are distributed: (1) recreational activities, (2) water management/use, (3) water pollution and (4) invasive species. Based on these main threats general actions were described: (1) Raise awareness, (2) establish legal protection (3) build public support, (4) promote ecotourism, (5) build capacity among civil servants, (6) combat corruption, (7) develop visitor impact management strategies, (8) apply environmental flow criteria, (9) ban invasives from critical sites, and (10) eradicate invasives.

Seven of the actions described above have effectively contributed towards the conservation of *N. boucardi*, and following this case study, a general conclusion can be made in the sense that applying the general actions described here, if designed and applied in a participatory manner, could also contribute to the conservation of other threatened species in the critical sites identified.

8.2 Research needs

There is evidence to suggest that conservation practitioners fail to incorporate contemporary scientific evidence into decision making for natural-resource management (Pullin *et al*. 2004). One of the perceived barriers limiting the implementation and adoption of evidence-based conservation is the notion that scientific research activities are not focused on issues of relevance to decision makers and natural-resource policy. A recent global exercise has been undertaken to identify 100 questions of relevance to policy makers (Sutherland 2009) that, if answered, would improve decision making and conservation actions. Following this analysis Cooke *et al*. (2010) evaluate the 100 questions by relating them to themes and questions of relevance to aquatic and fisheries professionals, and they also evaluate if there is a need to carry out a similar exercise, but with a freshwater perspective.

Following this, based on the results of this research, in this section a brief analysis on which are the future research needs to further freshwater species conservation, and more specifically to freshwater fish conservation in Mexico.

In general terms research needs to be developed in two directions if we are to promote effective conservation actions: the first one has to do with generating more information related to freshwater species, their status and threats, as well as more knowledge on their life histories and ecology; and the second one has to do with policies and management, and how to attain the best conservation results. These are described in the following sections.

8.2.1 Information on data deficient species (DD)

The Red List, in conjunction with the comprehensive data compiled to support it and in spite of several important limitations, has become an increasingly powerful tool for conservation planning, management, monitoring and decision making (Rodrigues *et al*. 2006), but one of its most neglected results related to species assessments has to do with Data Deficient species (DD), or those lacking adequate information to make a direct, or indirect, assessment of the risk of extinction of a species based on its distribution and/or population status.

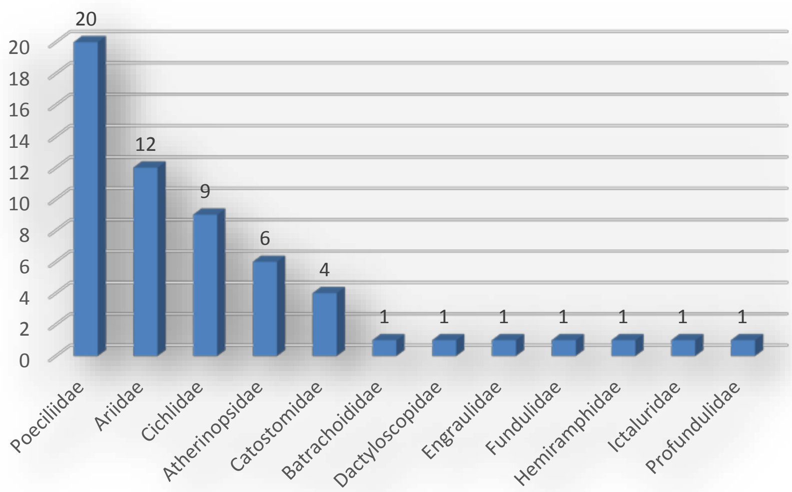


Figure 8.1 *Number of data defficient (DD) species by family*

One of the identified research priorities has to do with furthering the knowledge on these 58 species, to a point which we can at least have enough information for their conservation assessment. This implies knowing more about: (1) their actual and historic distribution; (2) basic life history data; (3) aspects of their ecology; and (4) their main theats.

8.2.2 Production of species conservation action plans

Avoiding species extinction can be seen as the fundamental goal of biodiversity conservation, because while all of humanity's other impacts on the Earth can be repaired, species extinction is irreversible (Brooks 2010). Several authors have put forward the idea that there is a gap between conservation planning and action, and that there needs much more action in order to achieve conservation results (Salafsky *et al*. 2002, Knight *et al*. 2006, Knight *et al*. 2006a, and Knight *et al*. 2007). In this respect, species conservation planning is more directly related to conservation action, and probably the most important efforts have been related to the implementation of the United States *Endangered Species Act* 1973 (ESA) (Czech & Krausman 2001, Goble *et al.* 2006). IUCN has a Species Conservation Planning Task Force dedicated to developing best planning methodologies, and promoting plan development (IUCN/SSC 2008). Over several years, the Task force has developed Plans for many species and groups of species. In the case of Mexico conservation strategies have been developed for some charismatic species such as the Mexican grey wolf, bighorn sheep, black bear, golden eagle, American pronghorn, vaquita popoise, and red macaw

(SEMARNAP 1999a, 1999b, 2000d, 2000e, 2000f, WWF 2001, Carreon *et al*. 2001), or groups of species such as crocodiles, marine turtles, Pinnipeds, Psitacids and Cycads (SEMARNAP 1999, 2000, 2000a, 2000b, 2000c) by means of structuring conservation and management plans. But none have been developed for any freshwater fish species.

As a result of the present study 45 species distributed in 30 different sites were identified as being in imminent risk of extinction (section 6.5.5), these species are in urgent need of the production of a species conservation action plan (PACE *in Spanish*) that would be included in the Mexican "*Program for the Conservation of Species at Risk*" managed by CONANP. In order to do so a recommendation is made to use the Strategic Planning for Species Conservation Handbook produce by IUCN/SSC species conservation planning task force (IUCN/SSC 2008), this would require (1) to conduct a thorough Status Review; (2) to develop, through broad consultation with stakeholders, a Vision and Goals for the conservation of each species or species group; (3) setting Objectives to help achieve the Vision and Goals; and (4) to address those Objectives through geographically and thematically specific Actions.

8.2.3 Developing models for freshwater protected areas

The designation of protected areas, mainly in the terrestrial environment, has been the cornerstone of conservation efforts, and recently the use of large, undisturbed portions of habitat for conservation has become prominent in the marine environment (Suski and Cooke 2007), but freshwater protected areas have fallen far behind as conservation strategies, maybe because few models of good protected area design exist, and because traditional notions of protected areas translate imperfectly to the freshwater realm (Abell *et al*. 2007). In this respect Saunders et al. (2002) stated that the relative absence of research into the design and management of freshwater protected areas, has been a serious obstacle to the achievement of conservation goals.

Nel *et al*. (2009) in their analyses of the progress and challenges in freshwater conservation planning identify key research priorities that 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.

8.2.4 Sustainable fisheries management

In spite of the contribution of freshwater fisheries to human wellbeing (as described in section 1.2.1) these are jeopardized by lack of research-based understanding of the impacts 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).

Currently most of freshwater fisheries in Mexico are covered by the concept of extensive aquaculture, which in fact does not mean any real aquaculture practices, but consists of stocking fry and harvesting them later, mostly of exotic fishes, that include, but are not restricted to, Chinese carps (common, Israel, Amur, black, silver, bream), tilapias (several species), brook and rainbow trouts, black basses, bluegill (*Lepomis macrochirus*), and channel catfish (*Ictalurus punctatus*) (Arredondo-Figueroa and Lozano-Gracia 2003). This makes interpretation of fisheries statistics is difficult since records refer to species groups, rather than single species and most of the available information relates to introduced species (Contreras-Balderas *et al*. 2008).

This situation is the consequence of the official interpretation that freshwater fisheries of native species are not productive, which is not true, as demonstrated by the results from several studies that have evaluated traditional freshwater fisheries from different Mexican basins (Lara 1997, Fonseca 2002, Inda-Díaz *et al.* 2009, Mercado-Silva *et al*. 2011). Another evidence of the importance of Mexican traditional freshwater fisheries, relies on the fact that historically, the different prehispanic cultures of Mexico were distinguished by capturing and consuming a wide variety of freshwater fishes and other aquatic organisms such as crayfish and Axolotls, a situation that has persisted into this millennium, due to the fact that in rural Mexico many freshwater species such as Poecilids, Characids and Catfishes of different sizes are captured (Contreras-MacBeath 1996).

The negative impacts of this view of Mexican freshwater fisheries are many, including the promotion of the introduction of exotic species (Contreras-Balderas *et al*. 2008, Contreras-MacBeath *et al*. 2014), thus enhancing the negative impacts that these bring to freshwater ecosystems and their species, which have been described in section 4.6.3.4, as well as the decline of some of the most important freshwater fisheries, such as those of Lakes Chapala and Patzcuaro (see section 4.6.3.1), a situation that has profound impacts on the wellbeing on local communities.

In order to revert this situation, a paradigm shift with respect to freshwater fisheries has to come about, in order to move to a sustainable system that protects native species. This would need to consider the ecosystem approach to fisheries proposed by Beard *et al.* (2011). Due to the conditions of riverine fisheries in Mexico, that include vast coastal lagoons, it would be important to work across aquatic boundaries between freshwater, brackish and marine environments for enhanced sustainable management, as proposed by Cooke *et al.* (2014).

This new paradigm would have to be directly related to the fisheries treaty signed by several governments, including Mexico, during the Rio Earth Summit in 1992. The treaty has several principles that need to be adopted: (1) to recognize the importance of traditional fisheries for domestic consumption, and 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, and by using integrated management principles, and taking into account human activities that contribute to the degradation of freshwater ecosystems.

By recognizing these principles and this new freshwater fisheries paradigm, many research needs must be met and supported. These are summarized in the work of Beard *et al.* (2011): (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 (Millennium Development Goals); (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 behavior, societal norms and environmental quality.

8.2.5 Conservation evidence

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). In their review, Sutherland *et al.* (2004) found that much conservation practice is based upon anecdote and myth rather than upon the systematic appraisal of the evidence, including experience of others who have tackled the same problem, and suggest that this is a major problem for conservationists and requires a rethinking of the manner in which conservation operates. This is particularly true for freshwater conservation, where there is a lack of evidence-based studies on how best to support the effective implementation (Nel *et al*. 2009). Regarding freshwater fishes, Cooke (2010) mentions that there is no question that evidence-based approaches to conservation are essential for addressing the many threats that face aquatic ecosystems and reverse the imperilment trends among ichthyofauna.

Sutherland *et al.* (2013) propose that there are a few elements of inquiry, taken from experimental design principles, which are missing from the majority of conservation projects that we suggest could transform effectiveness, evaluation and monitoring standards in the conservation field. These are: (1) Identify a question that could change practice if solved (for example is it better to treat a particular invasive plant species in April or July or does placing signs asking visitors to stay on the path reduce or increase the probability of them doing so). This question should be something practitioners are specifically interested in, yet there is insufficient existing research; (2) either compare two treatments (for example treating the invasive plant in different months) or compare one treatment with a control that is equivalent but without the treatment (e.g. comparing a path with signs and a similar path without signs). An alternative is to compare outcomes before and after the treatment; (3) replicate, and if possible randomize replicates. Without replication and randomization the observed difference could be due to another reason. For example, the invasive plants in the patch treated in July could by chance have been trampled by deer; (4) quantify the results of the test (these measurements can be simple, such as comparing the average height of a sample of the invasive plants between treatments or counting the proportion of visitors each day who leave the path along a given section; and (5) Disseminate the results (the sharing of information between practitioners is capable of making a considerable difference to global practice by encouraging implementation of successful interventions and avoiding the repeated use of ineffective treatments.

Taking this into account, it is important to develop systematic revisions related conservation evidence related to freshwater species conservation. This has been recognized by IUCNs Freshwater Species Conservation Sub Committee (FCSC 2012), that has stablished as one of its main goals, to develop conservation evidence analysis in the following areas: (1) damns an biodiversity; (2) invasive species; and (3) freshwater protected areas. Information should also be produced on (4) sustainable freshwater fisheries; and (5) successful threatened species recuperation programs.

8.3 Where do we go from here?

The problem of lack of attention towards the conservation of freshwater fishes is not exclusive of Mexico, and even though there are some interesting results in general terms there is a lack of public support for their conservation, as they are seen as resources, rather than as an important component of aquatic ecosystems (Contreras-MacBeath 2005, Helfman 2007, Reid *et al*. 2013). Much work needs to be done in the area of building public support towards freshwater fish conservation, and here the FFSG, as well as zoos and public aquaria will play an important role in changing people's perceptions related to freshwater fishes.

Even though as a result of the present study there is better idea of the status of Mexican freshwater fishes, their conservation priorities, and of the actions that have to be taken in order to prevent further extinctions, the important issue is how to implement this strategy.

An ideal scenario would be to change the current sectorisation of the Mexican environmental policies (green, gray and blue agendas) that leaves freshwater fishes in a sort of attention "limbo" with no conservation benefits. Unfortunately the new Mexican federal government, that has recently taken office, maintains the same structure so this gives little hope on more or different action (DOF 2013).

But even though structural changes at the federal level can be very difficult, changes could be made in the law, such as modifying Article 1° of the National Wildlife Law in such a way that it covers freshwater fishes, and thus promoting action.

In order to achieve the implementation of the current strategy, specifically regarding species in imminent risk of extinction, even though under the current conditions little can be expected from the federal government, there is a niche of opportunity in State and Local governments. In fact, current successful fish conservation examples in Mexico are at this scale, *Cyprinodon julimes* from the "Balneario El Pandeño de los Pando" in the Chihuahuan desert (De la Maza *et al.* 2010), *Profundulus hildebrandi* in the State Protected Area "Humedales Maria Eugenia" (SMAVeHN 2011) and *Notropis boucardi* in the highlands of the Rio Balsas (Contreras-MacBeath & Rivas 2007). In this respect, the 45 species in imminent risk of extinction identified are distributed in 12 (Chihuahua, Durango, Jalisco, Michoacán, Puebla, México, Nuevo León, Tabasco, Chiapas, Coahuila, Morelos y Quinatana Roo) of the 32 States of Mexico, so a strategy can be promoted to get these states to include the conservation of these species in their local environmental plans. This could be done through the National Association of State Environmental Authorities (ANAAE) that has regular meetings in order to promote local environmental policies. The presentation of the results of this study within ANAAE, could promote local conservation action, but in a coordinated manner.

Another possible strategy could be to involve research institutions that in Mexico have a long tradition in generating and promoting conservation and development in almost every part of the country (Dirzo *et al*. 2009). This has been the case of *Notropis boucardi*, where the Biological Research Centre at the Autonomous University of the State of Morelos, has led research and conservation strategies.

The involvement of NGOs is another strategy that can make a difference. This has been the case of *Cyprinodon julimes* where with the participation of PRONATURA Noreste A.C. and local communities a strategy for declaring the spring where the species inhabits as a Ramsar site.

Ecoturism is one of the most economically and environmentally sustainable activities, and it has been proposed as a means to promote biodiversity protection (Crosby & Moreda 1996, Gossling 1999, Honey & Rome 2001), in this respect, in the case of water parks incentives should be generated in order to promote conservation actions by owners. With a good communication strategy, these can also become important spaces for raising awareness on the issue of freshwater fish conservation.

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APPENDIX A.

List of fish species found in Mexican freshwaters

ORDER
Family
Species

PETROMYZONTIFORMES
Petromyzontidae
Tetrapleurodon geminis Álvarez, 1964
Tetrapleurodon spadicea (Bean, 1887)
Entospheneus tridentatus (Gairdner, 1836)
CARCHARHINIFORMES
Carcharhinidae
Carcharhinus leucas (Müller & Henle, 1839)
PRISTIFORMES
Pristidae
Pristis pristis (Linnaeus, 1758)
MYLIOBATIFORMES
Urolophidae
Urobatis jamaicensis (Cuvier, 1816)
Dasyatidae
Dasyatis sabina (Lesueur, 1824)
Himantura schmardae (Werner, 1904)
ACIPENSERIFORMES
Acipenseridae
Acipenser oxyrinchus Mitchill, 1815
LEPISOSTEIFORMES
Lepisosteidae
Atractosteus spatula (Lacepède, 1803)
Atractosteus tropicus Gill, 1863
Lepisosteus oculatus Winchell, 1864
Lepisosteus osseus (Linnaeus, 1758)
ELOPIFORMES
Elopidae
Elops affinis Regan, 1909
Elops saurus Linnaeus, 1766
Elops smithi McBride, Rocha, Ruiz-Carus & Bowen 2010
Megalopidae
Megalops atlanticus Valenciennes, 1847
ALBULIFORMES
Albulidae
Albula esuncula (Garman, 1899)
Albula pacifica (Beebe, 1942)
Albula vulpes (Linnaeus, 1758)
ANGUILLIFORMES
Anguillidae
Anguilla rostrata (Lesueur, 1817)

Muraenidae

Gymnothorax dovii (Günther, 1870)
Gymnothorax ocellatus Agassiz, 1831

Ophichthidae

Myrophis punctatus Lütken, 1852
Myrophis vafer Jordan & Gilbert, 1883
Ophichthus gomesii (Castelnau, 1855)

CLUPEIFORMES

Clupeidae

Brevoortia gunteri Hildebrand, 1948
Brevoortia patronus Goode, 1878
Dorosoma anale Meek, 1904
Dorosoma cepedianum (Lesueur, 1818)
Dorosoma petenense (Günther, 1867)
Dorosoma smithi Hubbs & Miller, 1941
Harengula jaguana Poey, 1865
Harengula thrissina (Jordan & Gilbert, 1882)
Lile gracilis Castro-Aguirre & Vivero, 1990
Lile stolifera (Jordan & Gilbert, 1882)

Engraulidae

Anchoa analis (Miller, 1945)
Anchoa belizensis (Thomerson & Greenfield, 1975)
Anchoa mitchilli (Valenciennes, 1848)
Anchoa mundeola (Gilbert & Pierson, 1898)
Anchoa parva (Meek & Hildebrand, 1923)
Anchoa walkeri Baldwin & Chang, 1970
Anchovia macrolepidota (Kner, 1863)

CYPRINIFORMES

Cyprinidae

Agosia chrysogaster Girard, 1856
Algansea amecae Pérez-Rodríguez, Pérez-Ponce de León, Domínguez-Domínguez & Doadrio, 2009
Algansea aphanea Barbour & Miller, 1978
Algansea avia Barbour & Miller, 1978
Algansea barbata Álvarez & Cortés, 1964
Algansea lacustris Steindachner, 1895
Algansea monticola Barbour & Contreras-Balderas, 1968
Algansea popoche (Jordan & Snyder, 1899)
Algansea tincella (Valenciennes, 1844)
Campostoma anomalum (Rafinesque, 1820)
Campostoma ornatum Girard, 1856
Codoma ornata (Girard, 1856)
Cyprinella alvarezdelvillari Contreras-Balderas & Lozano-Vilano, 1994
Cyprinella bocagrande (Chernoff & Miller, 1982)
Cyprinella formosa (Girard, 1856)
Cyprinella garmani (Jordan, 1885)
Cyprinella lutrensis (Baird & Girard, 1853)
Cyprinella panarcys (Hubbs & Miller, 1978)

Cyprinella proserpina (Girard, 1856)
Cyprinella rutila (Girard, 1856)
Cyprinella venusta Girard, 1856
Cyprinella xanthicara (Minckley & Lytle, 1969)
Dionda argentosa Girard, 1856
Dionda diaboli Hubbs & Brown, 1957
Dionda episcopa Girard, 1856
Dionda melanops Girard, 1856
Evarra bustamantei Navarro, 1955
Evarra eigenmanni Woolman, 1894
Evarra tlahuacensis Meek, 1902
Gila brevicauda Norris, Fischer & Minckley, 2003
Gila conspersa Garman, 1881
Gila ditaenia Miller, 1945
Gila elegans Baird & Girard, 1853
Gila eremica DeMarais, 1991
Gila intermedia (Girard, 1856)
Gila minacae Meek, 1902
Gila modesta (Garman, 1881)
Gila nigrescens (Girard, 1856)
Gila pulchra (Girard, 1856)
Gila purpurea (Girard, 1856)
Gila robusta Baird & Girard, 1853
Hybognathus amarus (Girard, 1856)
Macrhybopsis aestivalis (Girard, 1856)
Notropis aguirrepequenoi Contreras-Balderas & Rivera-Teillery, 1973
Notropis amabilis (Girard, 1856)
Notropis amecae Chernoff & Miller, 1986
Notropis aulidion Chernoff & Miller, 1986
Notropis boucardi (Günther, 1868)
Notropis braytoni Jordan & Evermann, 1896
Notropis buchanani Meek, 1896
Notropis calabazas Lyons & Mercado-Silva, 2004
Notropis calientis Jordan & Snyder, 1899
Notropis chihuahua Woolman, 1892
Notropis cumingii (Günther, 1868)
Notropis grandis Domínguez-Domínguez, Pérez-Rodríguez, Escalera-Velázquez & Doadrio, 2009
Notropis imeldae Cortés, 1968
Notropis jemezanus (Cope, 1875)
Notropis marhabatiensis Domínguez-Domínguez, Pérez-Rodríguez, Escalera-Velázquez & Doadrio, 2009
Notropis moralesi de Buen, 1955
Notropis nazas Meek, 1904
Notropis orca Woolman, 1894
Notropis sallaei (Günther, 1868)
Notropis saladonis Hubbs & Hubbs, 1958
Notropis simus (Cope, 1875)
Notropis stramineus (Cope, 1865)

Notropis tropicus Hubbs & Miller, 1975
Pimephales promelas Rafinesque, 1820
Pimephales vigilax (Baird & Girard, 1853)
Ptychocheilus lucius Girard, 1856
Rhinichthys cataractae (Valenciennes, 1842)
Rhinichthys cobitis (Girard, 1856)
Rhinichthys osculus (Girard, 1856)
Stypodon signifer Garman, 1881
Tampichthys catostomops (Hubbs & Miller, 1977)
Tampichthys dichromus (Hubbs & Miller, 1977)
Tampichthys erimyzonops (Hubbs & Miller, 1974)
Tampichthys ipni (Álvarez & Navarro, 1953)
Tampichthys mandibularis (Contreras-Balderas & Verduzco-Martínez, 1977)
Tampichthys rasconis (Jordan & Snyder, 1899)
Yuriria alta (Jordan, 1880)
Yuriria amatlana Domínguez-Domínguez, Pompa-Domínguez & Doadrio, 2007
Yuriria chapalae (Jordan & Snyder, 1899)

Catostomidae

Carpiodes carpio (Rafinesque, 1820)
Catostomus bernardini Girard, 1856
Catostomus cahita Siebert & Minckley, 1986
Catostomus clarkii Baird & Girard, 1854
Catostomus insignis Baird & Girard, 1854
Catostomus leopoldi Siebert & Minckley, 1986
Catostomus nebuliferus Garman, 1881
Catostomus plebeius Baird & Girard, 1854
Catostomus wigginsi Herre & Brock, 1936
Cycleptus elongatus (Lesueur, 1817)
Ictiobus bubalus (Rafinesque, 1818)
Ictiobus labiosus (Meek, 1904)
Ictiobus meridionalis (Günther, 1868)
Ictiobus niger (Rafinesque, 1819)
Moxostoma albidum (Girard, 1856)
Moxostoma austrinum Bean, 1880
Moxostoma congestum (Baird & Girard, 1854)
Moxostoma mascotae Regan, 1907
Xyrauchen texanus (Abbott, 1860)

CHARACIFORMES

Characidae

Astyanax aeneus (Günther, 1860)
Astyanax altior Hubbs, 1936
Astyanax mexicanus (de Filippi, 1853)
Bramocharax caballeroi Contreras-Balderas & Rivera-Teillery, 1985
Brycon guatemalensis Regan, 1908
Hyphessobrycon compressus (Meek, 1904)
Roeboides bouchellei Fowler, 1923

SILURIFORMES

Ariidae

Bagre marinus (Mitchill, 1815)
Bagre panamensis (Gill, 1863)
Bagre pinnimaculatus (Steindachner, 1877)
Cathorops aguadulce (Meek, 1904)
Cathorops belizensis Marceniuk & Betancur-R., 2008
Cathorops fuerthii (Steindachner, 1877)
Cathorops kailolae Marceniuk & Betancur-R., 2008
Cathorops spixii (Agassiz, 1829)
Cathorops liropus (Bristol, 1897)
Cathorops raredonae Marceniuk, Betancur-R. & Acero P., 2009
Notarius kessleri (Steindachner, 1877)
Notarius planiceps (Steindachner, 1877)
Notarius troschelii (Gill, 1863)
Occidentarius platypogon (Günther, 1864)
Potamarius nelsoni (Evermann & Goldsborough, 1902)
Potamarius usumacintae Betancur-R. & Willink, 2007
Sciades assimilis (Günther, 1864)
Sciades dowii (Gill, 1863).
Sciades felis (Linnaeus, 1766)
Sciades guatemalensis (Günther, 1864)
Sciades seemanni (Günther, 1864)

Heptapteridae

Rhamdia guatemalensis (Günther, 1864)
Rhamdia laluchensis Weber, Allegrucci & Sbordoni, 2003
Rhamdia laticauda (Kner, 1858)
Rhamdia macuspanensis Weber & Wilkens, 1998
Rhamdia parryi Eigenmann & Eigenmann, 1888
Rhamdia reddelli Miller, 1984
Rhamdia zongolicensis Wilkens, 1993

Lacantuniidae

Lacantunia enigmatica Rodiles-Hernández, Hendrickson & Lundberg, 2005

Ictaluridae

Ameiurus melas (Rafinesque, 1820)
Ictalurus australis (Meek, 1904)
Ictalurus balsanus (Jordan & Snyder, 1899)
Ictalurus dugesii (Bean, 1880)
Ictalurus furcatus (Lesueur, 1840)
Ictalurus lupus (Girard, 1858)
Ictalurus meridionalis (Günther, 1864)
Ictalurus mexicanus (Meek, 1904)
Ictalurus ochoterenai (de Buen, 1946)
Ictalurus pricei (Rutter, 1896)
Ictalurus punctatus (Rafinesque, 1818)
Prietella lundbergi Walsh & Gilbert, 1995
Prietella phreatophila Carranza, 1954
Pylodictis olivaris (Rafinesque, 1818)

GYMNOTIFORMES

Gymnotidae

Gymnotus maculosus Albert & Miller, 1995

SALMONIFORMES

Salmonidae

Oncorhynchus chrysogaster (Needham & Gard, 1964)
Oncorhynchus mykiss (Walbaum, 1792)

OPHIDIIFORMES

Bythitidae

Typhliasina pearsei (Hubbs, 1938)

BATRACHOIDIFORMES

Batrachoididae

Batrachoides goldmani Evermann & Goldsborough, 1902
Opsanus beta (Goode & Bean, 1880)

MUGILIFORMES

Mugilidae

Agonostomus monticola (Bancroft, 1834)
Chaenomugil proboscideus (Günther, 1861)
Joturus pichardi Poey, 1860
Mugil cephalus Linnaeus, 1758
Mugil curema Valenciennes, 1836
Mugil liza Valenciennes, 1836

ATHERINIFORMES

Atherinopsidae

Atherinella alvarezi (Díaz-Pardo, 1972)
Atherinella ammophila Chernoff & Miller, 1984
Atherinella balsana (Meek, 1902)
Atherinella callida Chernoff, 1986
Atherinella crystallina (Jordan & Culver, 1895)
Atherinella elegans Chernoff, 1986
Atherinella guatemalensis (Günther, 1864)
Atherinella lisa (Meek, 1904)
Atherinella marvelae (Chernoff & Miller, 1982)
Atherinella pellosemeion Chernoff, 1986
Atherinella sallei (Regan, 1903)
Atherinella schultzi (Álvarez & Carranza, 1952)
Chirostoma aculeatum Barbour, 1973
Chirostoma arge (Jordan & Snyder, 1899)
Chirostoma attenuatum Meek, 1902
Chirostoma bartoni Jordan & Evermann, 1896
Chirostoma chapalae Jordan & Snyder, 1899
Chirostoma charari (de Buen, 1945)
Chirostoma consocium Jordan & Hubbs, 1919
Chirostoma contrerasi Barbour, 2002
Chirostoma estor Jordan, 1880
Chirostoma grandocule (Steindachner, 1894)
Chirostoma humboldtianum (Valenciennes, 1835)
Chirostoma jordani Woolman, 1894
Chirostoma labarcae Meek, 1902

Chirostoma lucius Boulenger, 1900
Chirostoma melanoccus Álvarez, 1963
Chirostoma mezquital Meek, 1904
Chirostoma patzcuaro Meek, 1902
Chirostoma promelas Jordan & Snyder, 1899
Chirostoma riojai Solórzano & López, 1966
Chirostoma sphyraena Boulenger, 1900
Membras vagrans (Goode & Bean, 1879)
Menidia beryllina (Cope, 1867)
Menidia peninsulae (Goode & Bean, 1879)
Poblana alchichica de Buen, 1945
Poblana ferdebueni Solórzano & López, 1965
Poblana letholepis Álvarez, 1950
Poblana squamata Álvarez, 1950

Atherinidae

Atherinomorus stipes (Müller & Troschel, 1848)

BELONIFORMES

Belonidae

Strongylura exilis (Girard, 1854)
Strongylura hubbsi Collette, 1974
Strongylura marina (Walbaum, 1792)
Strongylura notata (Poey, 1860)
Strongylura timucu (Walbaum, 1792)

Hemiramphidae

Chriodorus atherinoides Goode & Bean, 1882
Hyporhamphus gilli Meek & Hildebrand, 1923
Hyporhamphus mexicanus Álvarez, 1959
Hyporhamphus naos Banford & Collette, 2001
Hyporhamphus roberti (Valenciennes, 1847)
Hyporhamphus rosae (Jordan & Gilbert, 1880)

CYPRINODONTIFORMES

Rivulidae

Kryptolebias marmoratus (Poey, 1880)
Millerichthys robustus (Miller & Hubbs, 1974)
Rivulus tenuis (Meek, 1904)

Profundulidae

Profundulus candalarius Hubbs, 1924
Profundulus hildebrandi Miller, 1950
Profundulus labialis (Günther, 1866)
Profundulus oaxacae (Meek, 1902)
Profundulus punctatus (Günther, 1866)

Goodeidae

Allodontichthys hubbsi Miller & Uyeno, 1980
Allodontichthys polylepis Rauchenberger, 1988
Allodontichthys tamazulae Turner, 1946
Allodontichthys zonistius (Hubbs, 1932)
Alloophorus robustus (Bean, 1892)
Allotoca catarinae (de Buen, 1942)
Allotoca diazi (Meek, 1902)

Allotoca dugesii (Bean, 1887)
Allotoca goslinei Smith & Miller, 1987
Allotoca maculata Smith & Miller, 1980
Allotoca meeki (Álvarez, 1959)
Allotoca regalis (Álvarez, 1959)
Allotoca zacapuensis Meyer, Radda & Domínguez, 2001
Ameca splendens Miller & Fitzsimons, 1971
Ataeniobius toweri (Meek, 1904)
Chapalichthys encaustus (Jordan & Snyder, 1899)
Chapalichthys pardalis Álvarez, 1963
Chapalichthys peraticus Álvarez, 1963
Characodon audax Smith & Miller, 1986
Characodon garmani Jordan & Evermann, 1898
Characodon lateralis Günther, 1866
Girardinichthys ireneae Radda & Meyer, 2003
Girardinichthys multiradiatus (Meek, 1904)
Girardinichthys viviparus (Bustamante, 1837)
Goodea atripinnis Jordan, 1880
Goodea gracilis Hubbs & Turner, 1939
Goodea luitpoldii (Steindachner, 1894)
Hubbsina turneri de Buen, 1940
Ilyodon cortesae Paulo-Maya & Trujillo-Jiménez, 2000
Ilyodon furcidens (Jordan & Gilbert, 1882)
Ilyodon lennoni Meyer & Förster, 1983
Ilyodon whitei (Meek, 1904)
Skiffia bilineata (Bean, 1887)
Skiffia francesae Kingston, 1978
Skiffia lermae Meek, 1902
Skiffia multipunctata (Pellegrin, 1901)
Xenoophorus captivus (Hubbs, 1924)
Xenotaenia resolanae Turner, 1946
Xenotoca eiseni (Rutter, 1896)
Xenotoca melanosoma Fitzsimons, 1972
Xenotoca variata (Bean, 1887)
Zoogoneticus purhepechus Domínguez-Domínguez, Pérez-Rodríguez & Doadrio, 2008
Zoogoneticus quitzeoensis (Bean, 1898)
Zoogoneticus tequila Webb & Miller, 1998

Fundulidae

Fundulus grandis Baird & Girard, 1853
Fundulus grandissimus Hubbs, 1936
Fundulus lima Vaillant, 1894
Fundulus parvipinnis Girard, 1854
Fundulus persimilis Miller, 1955
Fundulus philpisteri García-Ramírez, Contreras-Balderas & Lozano-Vilano, 2007
Fundulus similis (Baird & Girard, 1853)
Lucania interioris Hubbs & Miller, 1965
Lucania parva (Baird & Girard, 1855)

Cyprinodontidae

Cualac tessellatus Miller, 1956
Cyprinodon albivelis Minckley & Miller, 2002
Cyprinodon alvarezi Miller, 1976
Cyprinodon artifrons Hubbs, 1936
Cyprinodon atrorus Miller, 1968
Cyprinodon beltrani Álvarez, 1949
Cyprinodon bifasciatus Miller, 1968
Cyprinodon bobmilleri Lozano-Vilano & Contreras-Balderas, 1999
Cyprinodon ceciliae Lozano-Vilano & Contreras-Balderas, 1993
Cyprinodon eremus Miller & Fuiman, 1987
Cyprinodon esconditus Strecker, 2002
Cyprinodon eximius Girard, 1859
Cyprinodon fontinalis Smith & Miller, 1980
Cyprinodon inmemoriam Lozano-Vilano & Contreras-Balderas, 1993
Cyprinodon julimes de la Maza-Benignos & Vela-Valladares 2009
Cyprinodon labiosus Humphries & Miller, 1981
Cyprinodon latifasciatus Garman, 1881
Cyprinodon longidorsalis Lozano-Vilano & Contreras-Balderas, 1993
Cyprinodon macrolepis Miller, 1976
Cyprinodon macularius Baird & Girard, 1853
Cyprinodon maya Humphries & Miller, 1981
Cyprinodon meeki Miller, 1976
Cyprinodon nazas Miller, 1976
Cyprinodon pachycephalus Minckley & Minckley, 1986
Cyprinodon pisteri Miller & Minckley, 2002
Cyprinodon salvadori Lozano-Vilano, 2002
Cyprinodon simus Humphries & Miller, 1981
Cyprinodon suavium Strecker, 2005
Cyprinodon variegatus Lacepède, 1803
Cyprinodon verecundus Humphries, 1984
Cyprinodon veronicae Lozano-Vilano & Contreras-Balderas, 1993
Floridichthys polyommus Hubbs, 1936
Jordanella pulchra (Hubbs, 1936)
Megupsilon aporus Miller & Walters, 1972

Anablepidae

Anableps dowi Gill, 1861

Poeciliidae

Belonesox belizanus Kner, 1860
Brachyrhaphis hartwegi Rosen & Bailey, 1963
Carlhubbsia kidderi (Hubbs, 1936)
Gambusia affinis (Baird & Girard, 1853)
Gambusia alvarezi Hubbs & Springer, 1957
Gambusia atrora Rosen & Bailey, 1963
Gambusia aurata Miller & Minckley, 1970
Gambusia eurystoma Miller, 1975
Gambusia hurtadoi Hubbs & Springer, 1957
Gambusia krumholzi Minckley, 1963
Gambusia longispinis Minckley, 1962

Gambusia luma Rosen & Bailey, 1963
Gambusia marshi Minckley & Craddock, 1962
Gambusia panuco Hubbs, 1926
Gambusia regani Hubbs, 1926
Gambusia senilis Girard, 1859
Gambusia sexradiata Hubbs, 1936
Gambusia speciosa Girard, 1859
Gambusia vittata Hubbs, 1926
Gambusia yucatana Regan, 1914
Heterandria bimaculata (Heckel, 1848)
Heterandria jonesii (Günther, 1874)
Heterandria tuxtlaensis McEachran & Dewitt, 2008
Heterophallus echeagarayi (Álvarez, 1952)
Heterophallus milleri Radda, 1987
Heterophallus rachovii Regan, 1914
Phallichthys fairweatheri Rosen & Bailey, 1959
Poecilia butleri Jordan, 1889
Poecilia catemaconis Miller, 1975
Poecilia chica Miller, 1975
Poecilia formosa (Girard, 1859)
Poecilia latipinna (Lesueur, 1821)
Poecilia latipunctata Meek, 1904
Poecilia maylandi Meyer, 1983
Poecilia mexicana Steindachner, 1863
Poecilia orri Fowler, 1943
Poecilia petenensis (Günther, 1866)
Poecilia sphenops Valenciennes, 1846
Poecilia sulphuraria (Álvarez, 1948)
Poecilia velifera (Regan, 1914)
Poeciliopsis baenschi Meyer, Radda, Riehl & Feichtinger, 1986
Poeciliopsis balsas Hubbs, 1926
Poeciliopsis catemaco Miller, 1975
Poeciliopsis fasciata (Meek, 1904)
Poeciliopsis gracilis (Heckel, 1848)
Poeciliopsis hnilickai Meyer & Vogel, 1981
Poeciliopsis infans (Woolman, 1894)
Poeciliopsis latidens (Garman, 1895)
Poeciliopsis lucida Miller, 1960
Poeciliopsis lutzi (Meek, 1902)
Poeciliopsis monacha Miller, 1960
Poeciliopsis occidentalis (Baird & Girard, 1853)
Poeciliopsis pleurospilus (Günther, 1866)
Poeciliopsis presidionis (Jordan & Culver, 1895)
Poeciliopsis prolifica Miller, 1960
Poeciliopsis scarlli Meyer, Riehl, Dawes & Dibble, 1985
Poeciliopsis sonoriensis (Girard, 1859)
Poeciliopsis turneri Miller, 1975
Poeciliopsis turrubarensis (Meek, 1912)
Poeciliopsis viriosa Miller, 1960

Priapella bonita (Meek, 1904)
Priapella chamulae Schartl, Meyer & Wilde, 2006
Priapella compressa Álvarez, 1948
Priapella intermedia Álvarez & Carranza, 1952
Priapella olmecae Meyer & Espinosa-Pérez, 1990
Xenodexia ctenolepis Hubbs, 1950
Xiphophorus alvarezi Rosen, 1960
Xiphophorus andersi Meyer & Schartl, 1980
Xiphophorus birchmanni Lechner & Radda, 1987
Xiphophorus clemenciae Álvarez, 1959
Xiphophorus continens Rauchenberger, Kallman & Morizot, 1990
Xiphophorus cortezi Rosen, 1960
Xiphophorus couchianus (Girard, 1859)
Xiphophorus evelynae Rosen, 1960
Xiphophorus gordoni Miller & Minckley, 1963
Xiphophorus hellerii Heckel, 1848
Xiphophorus kallmani Meyer & Schartl, 2003
Xiphophorus maculatus (Günther, 1866)
Xiphophorus malinche Rauchenberger, Kallman & Morizot, 1990
Xiphophorus meyeri Schartl & Schröder, 1988
Xiphophorus milleri Rosen, 1960
Xiphophorus montezumae Jordan & Snyder, 1899
Xiphophorus multilineatus Rauchenberger, Kallman & Morizot, 1990
Xiphophorus nezahualcoyotl Rauchenberger, Kallman & Morizot, 1990
Xiphophorus nigrensis Rosen, 1960
Xiphophorus pygmaeus Hubbs & Gordon, 1943
Xiphophorus variatus (Meek, 1904)
Xiphophorus xiphidium (Gordon, 1932)

GASTEROSTEIFORMES

Gasterosteidae

Gasterosteus aculeatus Linnaeus, 1758

Syngnathidae

Microphis brachyurus (Bleeker, 1853)
Pseudophallus mindii (Meek & Hidebrand, 1923)
Pseudophallus starksii (Jordan & Culver, 1895)
Syngnathus scovelli (Evermann & Kendall, 1896)

SYNBRANCHIFORMES

Synbranchidae

Ophisternon aenigmaticum Rosen & Greenwood, 1976
Ophisternon infernale (Hubbs, 1938)
Synbranchus marmoratus Bloch, 1795

SCORPAENIFORMES

Cottidae

Leptocottus armatus Girard, 1854

PERCIFORMES

Centropomidae

Centropomus armatus Gill, 1863
Centropomus ensiferus Poey, 1860

Centropomus medius Günther, 1864
Centropomus mexicanus Bocourt, 1868
Centropomus nigrescens Günther, 1864
Centropomus parallelus Poey, 1860
Centropomus pectinatus Poey, 1860
Centropomus poeyi Chávez, 1961
Centropomus robalito Jordan & Gilbert, 1882
Centropomus undecimalis (Bloch, 1792)
Centropomus unionensis Bocourt,1868
Centropomus viridis Lockington,1877

Centrarchidae

Lepomis macrochirus Rafinesque, 1819
Lepomis megalotis (Rafinesque, 1820)
Micropterus salmoides (Lacepède, 1802)

Percidae

Etheostoma australe Jordan, 1889
Etheostoma grahami (Girard, 1859)
Etheostoma lugoi Norris & Minckley, 1997
Etheostoma pottsii (Girard, 1859)
Etheostoma segrex Norris & Minckley, 1997
Percina macrolepida Stevenson, 1971

Carangidae

Caranx hippos (Linnaeus, 1766)
Caranx latus Agassiz, 1831
Caranx sexfasciatus Quoy & Gaimard, 1825
Oligoplites altus (Günther, 1868)
Oligoplites saurus (Bloch & Schneider, 1801)

Lutjanidae

Lutjanus apodus (Walbaum, 1792)
Lutjanus argentiventris (Peters, 1869)
Lutjanus colorado Jordan & Gilbert, 1882
Lutjanus griseus (Linnaeus, 1758)
Lutjanus novemfasciatus Gill, 1862

Gerreidae

Diapterus auratus Ranzani, 1842
Diapterus brevirostris (Sauvage, 1879)
Diapterus rhombeus (Cuvier, 1829)
Eucinostomus argenteus Baird & Girard, 1855
Eucinostomus currani Zahuranec, 1980
Eucinostomus dowii (Gill, 1863)
Eucinostomus entomelas Zahuranec, 1980
Eucinostomus gracilis (Gill, 1862)
Eucinostomus gula (Quoy & Gaimard, 1824)
Eucinostomus harengulus Goode & Bean, 1879
Eucinostomus lefroyi (Goode, 1874)
Eucinostomus melanopterus (Bleeker, 1863)
Eugerres awlae Schultz, 1949
Eugerres axillaris (Günther, 1864)
Eugerres brevimanus (Günther, 1864)

Eugerres lineatus (Humboldt, 1821)
Eugerres mexicanus (Steindachner, 1863)
Eugerres plumieri (Cuvier, 1830)
Gerres cinereus (Walbaum, 1792)

Haemulidae

Haemulopsis leuciscus (Günther, 1864)
Pomadasys bayanus Jordan & Evermann, 1898
Pomadasys branickii (Steindachner, 1879)
Pomadasys crocro (Cuvier, 1830)
Pomadasys macracanthus (Günther, 1864)

Sparidae

Archosargus probatocephalus (Walbaum, 1792)
Lagodon rhomboides (Linnaeus, 1766)

Sciaenidae

Aplodinotus grunniens Rafinesque, 1819
Bairdiella chrysoura (Lacepède, 1802)
Bairdiella ronchus (Cuvier, 1830)
Cynoscion nebulosus (Cuvier, 1830)
Leiostomus xanthurus Lacepède, 1802
Micropogonias undulatus (Linnaeus, 1766)
Pogonias cromis (Linnaeus, 1766)
Sciaenops ocellatus (Linnaeus, 1766)
Stellifer lanceolatus (Holbrook, 1855)
Totoaba macdonaldi (Gilbert, 1890)

Cichlidae

Amphilophus macracanthus (Günther, 1847)
Amphilophus nourissati (Allgayer, 1989)
Amphilophus robertsoni (Regan, 1905)
Cichlasoma beani (Jordan, 1889)
Cichlasoma geddesi (Regan, 1905)
Cichlasoma grammodes Taylor & Miller, 1980
Cichlasoma istlanum (Jordan & Snyder, 1899)
Cichlasoma nebuliferum (Günther, 1860)
Cichlasoma salvini (Günther, 1862)
Cichlasoma trimaculatum (Günther, 1867)
Cichlasoma urophthalmus (Günther, 1862)
Cryptoheros chetumalensis Schmitter-Soto, 2007
Herichthys bartoni (Bean, 1892)
Herichthys carpintis (Jordan & Snyder, 1899)
Herichthys cyanoguttatus Baird & Girard, 1854
Herichthys deppii (Heckel, 1840)
Herichthys labridens (Pellegrin, 1903)
Herichthys minckleyi (Kornfield & Taylor, 1983)
Herichthys pantostictus (Taylor & Miller, 1983)
Herichthys steindachneri (Jordan & Snyder, 1899)
Herichthys tamasopoensis Artigas- Azas, 1993
Parachromis friedrichsthalii (Heckel, 1840)
Paraneetroplus argentea (Allgayer, 1991)
Paraneetroplus bifasciata (Steindachner, 1864)

Paraneetroplus breidohri (Werner & Stawikowski, 1987)
Paraneetroplus bulleri Regan, 1905
Paraneetroplus fenestrata (Günther, 1860)
Paraneetroplus gibbiceps (Steindachner, 1864)
Paraneetroplus guttulata (Günther, 1864)
Paraneetroplus hartwegi (Taylor & Miller, 1980)
Paraneetroplus intermedia (Günther, 1862)
Paraneetroplus nebuliferus (Günther, 1860)
Paraneetroplus regani (Miller, 1974)
Paraneetroplus synspila (Hubbs, 1935)
Paraneetroplus zonata (Meek, 1905)
Petenia splendida Günther, 1862
Rocio gemmata Contreras-Balderas & Schmitter-Soto, 2007
Rocio ocotal Schmitter-Soto, 2007
Rocio octofasciata (Regan, 1903)
Theraps coeruleus Stawikowski & Werner, 1987
Theraps heterospilus (Hubbs, 1936)
Theraps intermedius (Günther, 1862)
Theraps irregularis Günther, 1862
Theraps lentiginosus (Steindachner, 1864)
Theraps nourissati Allgayer 1989
Theraps pearsei (Hubbs, 1936)
Theraps rheophilus (Seegers & Staeck, 1985)
Theraps ufermanni (Allgayer, 2002)
Thorichthys affinis (Günther, 1862)
Thorichthys callolepis (Regan, 1904)
Thorichthys ellioti Meek, 1904
Thorichthys hellerii (Steindachner, 1864)
Thorichthys meeki Brind, 1918
Thorichthys pasionis (Rivas, 1962)
Thorichthys socolofi (Miller & Taylor, 1984)

Dactyloscopidae

Dactyloscopus amnis Miller & Briggs, 1962

Blenniidae

Lupinoblennius nicholsi (Tavolga, 1954)

Gobiesocidae

Gobiesox fluviatilis Briggs & Miller, 1960
Gobiesox juniperoserrai Espinosa Pérez & Castro-Aguirre, 1996
Gobiesox mexicanus Briggs & Miller, 1960

Eleotridae

Dormitator latifrons (Richardson, 1844)
Dormitator maculatus (Bloch, 1792)
Eleotris amblyopsis (Cope, 1871)
Eleotris perniger (Cope, 1871)
Eleotris picta Kner, 1863
Gobiomorus dormitor Lacepède, 1800
Gobiomorus maculatus (Günther, 1859)
Gobiomorus polylepis Ginsburg, 1953
Guavina guavina (Valenciennes, 1837)

Gobiidae

Awaous banana (Valenciennes, 1837)
Bathygobius curacao (Metzelaar, 1919)
Bathygobius soporator (Valenciennes, 1837)
Ctenogobius claytonii (Meek, 1902)
Ctenogobius boleosoma (Jordan & Gilbert, 1882)
Evorthodus lyricus (Girard, 1858)
Evorthodus minutus Meek & Hildebrand, 1928
Gillichthys mirabilis Cooper, 1864
Gobioides broussonnetii Lacepède, 1800
Gobionellus microdon (Gilbert, 1892)
Gobionellus oceanicus (Pallas, 1770)
Gobiosoma bosc (Lacepède, 1800)
Gobiosoma yucatanum Dawson, 1971
Lophogobius cyprinoides (Pallas, 1770)
Microgobius miraflorensis Gilbert & Starks, 1904
Microgobius tabogensis Meek & Hildebrand, 1928
Sicydium gymnogaster Ogilvie-Grant, 1884
Sicydium multipunctatum Regan, 1906

PLEURONECTIFORMES

Paralichthyidae

Citharichthys abbotti Dawson, 1969
Citharichthys gilberti Jenkins & Evermann, 1889
Citharichthys spilopterus Günther, 1862
Citharichthys uhleri Jordan, 1889

Achiridae

Achirus lineatus (Linnaeus, 1758)
Achirus mazatlanus (Steindachner, 1869)
Trinectes fonsecensis (Günther, 1862)
Trinectes maculatus (Bloch & Schneider, 1801)
Trinectes paulistanus (de Miranda-Ribeiro, 1915)

Cynoglossidae

Symphurus plagiusa (Linnaeus, 1766)

TETRAODONTIFORMES

Tetraodontidae

Sphoeroides annulatus (Jenyns, 1842)
Sphoeroides nephelus (Goode & Bean, 1882)
Sphoeroides parvus Shipp & Yerger, 1969
Sphoeroides testudineus (Linnaeus, 1758)

APPENDIX B.

Freshwater biodiversity surveys provided by CONABIO

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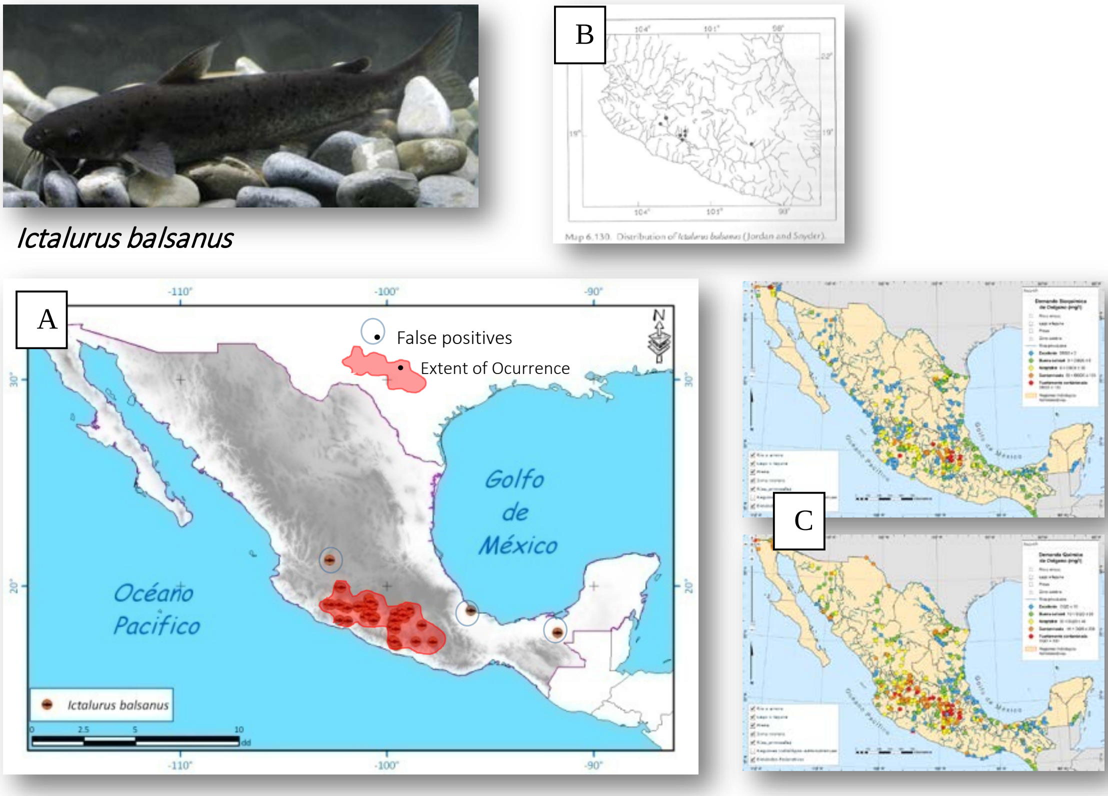
APPENDIX C.

Examples of the assessment process.

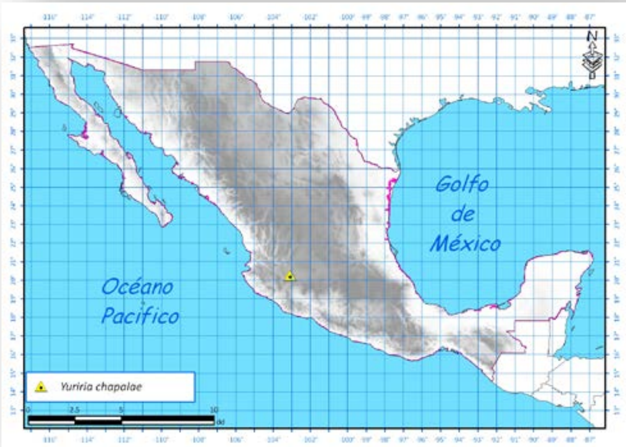


1. The point data of *Ictalurus balsanus* are represented on a map (A).
2. False positives are eliminated by reviewing literature of known distribution, in this case Miller 2005 (B).
3. An extent of occurrence map is drawn based on IUCN 2008.
4. Known threats are considered based on official data (C), such as pollution maps (CONAGUA 2010), as well as published information for the species (Contreras-MacBeath *et al*. 1998, Contreras-MacBeath *et al*. 2013).
5. A category is given, in this case vulnerable, because even though it is a widely distributed species, its distribution has been fragmented due to pollution, it is overfished, and many invasives have been introduced in its habitat, including its sister species (*Ictalurus punctatus*) that may be hybridizing.

Xirauchen texanus

1. Was only known from the lower Colorado River, near the delta.
2. Miller *et al*. 2009 mention its extirpation from Mexico due to predation mainly by introduced channel catfish *Ictalurus punctatus*.
3. Assessed as Regionally Extinct

Yuriria chapale



1. An endemic fish of Lake Chapala.
2. Lake Chapala is stocked with exotic fish every year for fisheries purposes.
3. The lake is also highly polluted receiving water from the Lerma basin.
4. Assessed as Endangered

Zoogoneticus quitzoensis

1. Even though it is widely distributed in the Rio Lerma basin, due to high levels of pollution and water extraction it is severely threatened (Domínguez-Domínguez *et al*. 2008, Pedraza 2011).
2. Assessed as Endangered

APPENDIX D.

Aichi Targets

Strategic Goal A: Address the underlying causes of biodiversity loss by mainstreaming biodiversity across government and society

Target 1
By 2020, at the latest, people are aware of the values of biodiversity and the steps they can take to conserve and use it sustainably.

Target 2
By 2020, at the latest, biodiversity values have been integrated into national and local development and poverty reduction strategies and planning processes and are being incorporated into national accounting, as appropriate, and reporting systems.

Target 3
By 2020, at the latest, incentives, including subsidies, harmful to biodiversity are eliminated, phased out or reformed in order to minimize or avoid negative impacts, and positive incentives for the conservation and sustainable use of biodiversity are developed and applied, consistent and in harmony with the Convention and other relevant international obligations, taking into account national socio economic conditions.

Target 4
By 2020, at the latest, Governments, business and stakeholders at all levels have taken steps to achieve or have implemented plans for sustainable production and consumption and have kept the impacts of use of natural resources well within safe ecological limits.

Strategic Goal B: Reduce the direct pressures on biodiversity and promote sustainable use

Target 5
By 2020, the rate of loss of all natural habitats, including forests, is at least halved and where feasible brought close to zero, and degradation and fragmentation is significantly reduced.

Target 6
By 2020 all fish and invertebrate stocks and aquatic plants are managed and harvested sustainably, legally and applying ecosystem based approaches, so that overfishing is avoided, recovery plans and measures are in place for all depleted species, fisheries have no significant adverse impacts on threatened species and vulnerable ecosystems and the impacts of fisheries on stocks, species and ecosystems are within safe ecological limits.

Target 7
By 2020 areas under agriculture, aquaculture and forestry are managed sustainably, ensuring conservation of biodiversity.

Target 8
By 2020, pollution, including from excess nutrients, has been brought to levels that are not detrimental to ecosystem function and biodiversity.

Target 9
By 2020, invasive alien species and pathways are identified and prioritized, priority species are controlled or eradicated, and measures are in place to manage pathways to prevent their introduction and establishment.

Target 10
By 2015, the multiple anthropogenic pressures on coral reefs, and other vulnerable ecosystems impacted by climate change or ocean acidification are minimized, so as to maintain their integrity and functioning.

Strategic Goal C: To improve the status of biodiversity by safeguarding ecosystems, species and genetic diversity

Target 11
By 2020, at least 17 per cent of terrestrial and inland water, and 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscapes and seascapes.

Target 12
By 2020 the extinction of known threatened species has been prevented and their conservation status, particularly of those most in decline, has been improved and sustained.

Target 13
By 2020, the genetic diversity of cultivated plants and farmed and domesticated animals and of wild relatives, including other socio-economically as well as culturally valuable species, is maintained, and strategies have been developed and implemented for minimizing genetic erosion and safeguarding their genetic diversity.

Strategic Goal D: Enhance the benefits to all from biodiversity and ecosystem services

Target 14
By 2020, ecosystems that provide essential services, including services related to water, and contribute to health, livelihoods and well-being, are restored and safeguarded, taking into account the needs of women, indigenous and local communities, and the poor and vulnerable.

Target 15
By 2020, ecosystem resilience and the contribution of biodiversity to carbon stocks has been enhanced, through conservation and restoration, including restoration of at least 15 per cent of degraded ecosystems, thereby contributing to climate change mitigation and adaptation and to combating desertification.

Target 16
By 2015, the Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization is in force and operational, consistent with national legislation.

Strategic Goal E: Enhance implementation through participatory planning, knowledge management and capacity building

Target 17
By 2015 each Party has developed, adopted as a policy instrument, and has commenced implementing an effective, participatory and updated national biodiversity strategy and action plan.

Target 18
By 2020, the traditional knowledge, innovations and practices of indigenous and local communities relevant for the conservation and sustainable use of biodiversity, and their customary use of biological resources, are respected, subject to national legislation and relevant international obligations, and fully integrated and reflected in the implementation of the Convention with the full and effective participation of indigenous and local communities, at all relevant levels.

Target 19
By 2020, knowledge, the science base and technologies relating to biodiversity, its values, functioning, status and trends, and the consequences of its loss, are improved, widely shared and transferred, and applied.

Target 20
By 2020, at the latest, the mobilization of financial resources for effectively implementing the Strategic Plan for Biodiversity 2011-2020 from all sources, and in accordance with the consolidated and agreed process in the Strategy for Resource Mobilization, should increase substantially from the current levels. This target will be subject to changes contingent to resource needs assessments to be developed and reported by Parties.