Freshwater fishes and water status in México: A country-wide appraisal.

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México is the southernmost country in North America, and extends into Central America, south of the Isthmus of Tehuantepec. The northern half of México is located on the Temperate belt and is arid in character (Nearctic), while the rest is within the Tropical belt (Neotropical). Climate varies from extremely temperate desert in the north, to tropical humid in the south. México has more than 500 freshwater fish species, about 271 of them country endemics, and approximately 48 endemics from binational basins. There are still some 30–40 fish species not yet described. There are 563 fish species colonizing coastal flood plain species. In addition to the numbers of colonizing fishes, the burden of introduced exotics has also been growing. In 1904, only 4 species were recognized as exotics; by 1997 the number had increased to 94, and by 2008 to 115. The main fish collections in Mexico are at IPN, UNAM, and UANL and are the most representative, being national in scope, although concentrated in the tropics, central region, and general in coverage, respectively. The decline of the native fish fauna has been in focus in recent years, usually as trend-in-time comparisons, where the loss of native forms and increase of exotics and/or colonizer species is evident in many basins, mainly in Río Balsas, Río Grande, and Río Lerma-Santiago. As a result, the numbers of species reported at some degree of risk have been increasing also, from 17 in 1963 to 192 in 2005. The trends in colonizers, exotics, and species at risk among Mexican fishes are parallel. The Index of Biological Integrity (IBI), in either its geographical, or historical form (IBIh), has been applied to the Rio Grande/Río Bravo basin, USA and México. IBIh values go between 0–91 (average 31). Alien species are regarded as detrimental. Overall, the IBI trends have been similar in all regions, starting from 70–95% in upper reaches, decreasing to less than 0–35% in the lower reaches of West central basins, and then down to 15% or less near the Lower Rio Grande delta. Several alien species of plecos have been recognized in the rivers Balsas, Grijalva-Río Usumacinta complex, and, also, one in the Rio Grande. Mexican rivers are notoriously dewatered in the northern half of the country. Until 1962, the Rio Grande had an average runoff of 12,000+ millions of cubic meters/year; however by 2002 it was less than 2% of that value. The river went nearly dry along the Big Bend region and was dry for months in the delta region, both in 2002 and 2004. The Rio Grande is mostly dry north of the Río Conchos junction, its main Mexican tributary, and other tributaries provide now between 1% (Río San Juan) and 20% (Río Conchos) of pre-1960 runoff. A modified Index of Biological Integrity for Rio Grande resulted in grades from 70 to 95% of the baseline in upper reaches, less than 35% in lower reaches, to less than 15% near the coast. The Texan version of the IBI was not representative as it suppresses data on euryhaline fishes. The reports of total toxics were masked, since the sum should have included both organics and heavy metals exceeding USA regulations to the total count, but only one of the two was included.

Keywords: basins, monitoring, quality, runoff, integrity

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Introduction

The rising trend in freshwater fish species at risk, the global freshwater crises, the academic and social pressures for environmental conservation, and the relatively recent rise in understanding of biodiversity and the sustainability paradigm, have focussed interest on the global status of freshwater fishes, as basic bioindicators of the availability of freshwaters by quantity and quality. To gain such a global perspective requires a country-by-country summarization of the state of knowledge and understanding of freshwater fish and hydrological basins, as inclusively as possible. For these reasons, we have undertaken this task for México, as our contribution.

México is the southernmost country in North America, and extends into Central America south of the Isthmus of Tehuantepec. This continental area is located between N 14°32′45″ to 32°43′05″ and W 86° to 117°08′ coordinates, extending north and south from the Tropic of Cancer, which is approximately in the middle of the country. Its eastern limits are the Gulf of México and the Caribbean Sea, and in the Pacific Ocean along the west, including the entire Gulf of California (Alba and Reyes, 1998). It extends through two of the greatest biogeographical global realms, the Nearctic (North America south to the Mexican plateau) and the Neotropic (Mexican central coasts to South America) (De Buen, 1947).

Two large mountain ranges extend along its continental part in a north-south axis, the Sierra Madre Oriental (East) and the Sierra Madre Occidental (West), joining through the Volcano Axis (Eje Volcánico or Transversal), and continuing towards Central America with the Sierra Madre del Sur (Figure 1). These ranges produce a complex geography, e.g., topography, orography, hydrology, with high mountains, deep valleys, plateaus, and coastal plains, and large and small drainages. Some basins are highly fragmented, like the Rio Grande/Río Bravo in the North, or the central Lerma-Chapala basins (Tamayo and West, 1964) in central México (Figure 2).

The northern half of México is located on the temperate belt and is arid in character (Nearctic), while the rest is within the tropical belt (Neotropical) (De Buen, 1947). Climate varies from extremely temperate deserts in the north, to tropical humid forests in the south. Altitude spans from sea level to 5,600 masl. México coasts are in the hurricane belt, although storms tend to be more forceful on the eastern states. Vegetation varies according to the climate pattern, from rain forest to alpine meadow or desert shrubs, and even some sand dune country (Rzedowski, 1994).

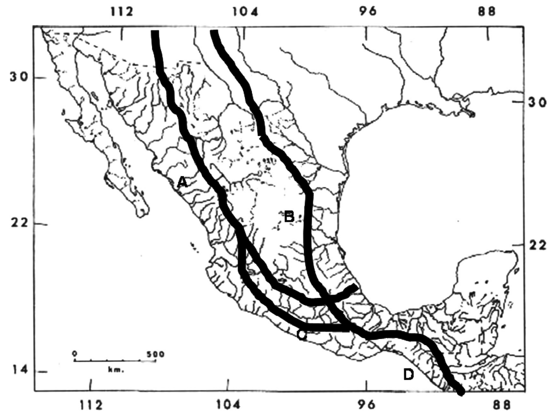

Figure 1. The main sierras, or mountain ranges, of México, schematic: A) Sierra Madre Occidental, B) Sierra Madre Oriental, C) Eje Volcánico Transversal, and D) Sierra Madre del Sur.

Fishes

México has more than 504 described and recognized native true freshwater species (Miller et al., 2006; Contreras-Balderas and Ramírez-Flores, 2000); more than 271 of them are country endemics, plus some 48 endemics from shared binational basins. Some 30–40 have yet to be described. Most of the new species are endemics that have been described within the last 30 years, as new methods and techniques, and more methodical surveys have been applied to such a rich fish fauna. New discoveries happen with each major expedition. As an example, a new family of catfishes was discovered in the last 5 years (Rodiles et al., 2005), and at least 8 new species have been discovered in cenotes and small drainages around the already well explored Yucatán Peninsula.

The biogeography of fishes in México has been the focus of several papers, beginning with overviews (De Buen, 1947; Miller, 1966). Some papers deal with country regions like the Central basins (Miller and Smith, 1986); Rio Grande/Río Bravo (Smith and Miller, 1986); the central Eastern basins (Contreras-Balderas et al., 1991). Biogeographical comments have been included as convenient components of revisionary works for genera such as *Chirostoma* (Barbour, 1973), *Algansea* (Barbour and Miller, 1978), the

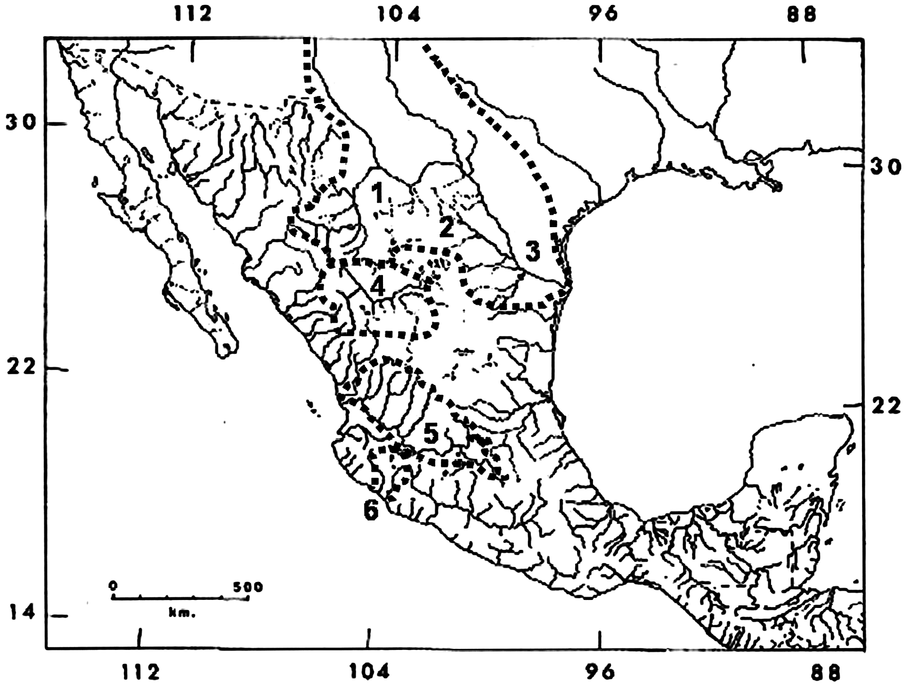

Figure 2. Mexican basins where the Index of Biological Integrity has been applied: in the Rio Grande/Río Bravo, historical version: Río Conchos (1), Río Salado (2), International section (3); Rio Nazas (4), the original IBI version applied in Río Lerma-Santiago (5), and West central rivers (6).

lepida clade of *Cyprinella* (Contreras-Balderas and Lozano, 1994), *Dionda* (Mayden et al., 1984), and more recently on the Goodeidae (Doadrio and Domínguez, 2003).

Recently a trend of coastal plain species, mostly warm water freshwater forms, and brackish or marine fishes, colonizing basins upstream has been recognized (Contreras-Balderas, 1976; Edwards and Contreras-Balderas, 1991; Castro-Aguirre, 1976; Castro-Aguirre et al., 1999; Contreras-Balderas, 1999). This colonization is impacting the native Mexican freshwater species, especially the endemics (Contreras, 1976; Contreras-Balderas and Lozano-Vilano, 1993; Contreras-Balderas et al., 2000). Countrywide, such invasions have increased from 349 species in 1976 (Castro-Aguirre, 1976), to 563 in 1997 (Castro-Aguirre et al., 1999). This invasion has been favoured locally by drought and overexploitation of freshwater bodies, especially when combined with agricultural and industrial salinization (Contreras-Balderas and Lozano-Vilano, 1994), and with the natural trend to upstream colonization exhibited by many species (Lagler et al., 1977). This colonization phenomenon urgently needs countrywide and international studies and actions to measure the extent and impacts, to monitor its development, to evaluate its importance, and to raise enough effort to change the trends.

In addition to the burden of colonizing fishes, the number of exotics has also been growing. In 1904, only four species were recognized as exotics (Meek, 1904), increasing to 7 in 1949 (Alvarez, 1950) and 1969 (Alvarez, 1970), 55 in 1983 (Contreras-Balderas and Escalante, 1984) and 94 in 1997 (Contreras-Balderas, 1999). Ongoing research by the senior author showed the number of exotics in México increasing to at least 113 in 2008.

The decline of the native fish fauna has been in focus in recent years, usually through time-series comparisons; where losses of native forms and increases of exotics and/or colonizer species are evident. In México, such losses have been reported for the Lower Colorado river (Miller, 1961), northern arid zones (Contreras-Balderas, 1969; 1973; 1976), north western rivers (Hendrickson, 1984), Rio Grande/Río Bravo (Edwards and Contreras-Balderas, 1991; Contreras-Balderas, 2000; Contreras-Balderas et al., 2002), Río Lerma (Díaz-Pardo et al., 1993), portions of the Río Balsas (Contreras-McBeath et al., 1998), west central

Table 1. Fishes at risk or extinct in México, 1963–2006 (modified from Contreras-Balderas and Ramírez-Flores, 1999).

Degree of Risk	1963	1969	1979	1984	1989	1994	1997	2005
Endangered	11	33	29	58	41	59	65	69
Threatened	?	?	12	35	26	60	78	87
Vulnerable/ Rare	?	?	19	26	54	?	36	42
Extinct	7	7	?	?	7	?	19	27
Total	18	40	>67	>126	132	>130	208	225

rivers (Lyons et al., 1998), and Lower California (Ruiz-Campos et al., 2002).

As a result of the combined situation summarized above, the number of species reported at some degree of risk have been increasing also, from 17 in 1963 (Miller, 1961), to as high as 169 in 2002 (Contreras-Balderas et al., 2003), increasing to 192 in 2004 (research in progress), according to academic listings. The official federal lists in México appeared in 1994 (Norma Oficial Mexicana [NOM] 054-ECOL-1994) with 136 freshwater fish species included, and the 2001 revision (NOM 054-SEMARNAT-2001) considered 169 freshwater species. The trend of fish species endangerment has been upward since 1963, approximately doubling 3 times between 1963 and 1984, and then increasing more slowly since.

The parallel increased trends in colonizers, exotics, and species at risk in Mexican fishes may be considered more clearly by examining Table 1, Fig. 3 (Contreras-Balderas and Ramírez, 1999). The statistical correlation is low; however, it constitutes strong circumstantial evidence that such exotics are

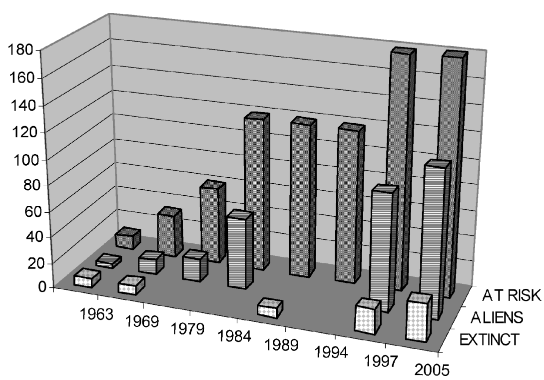

Figure 3. The numbers of species at risk, extinct or exotics (= invasives) in México, 1963 to 2005 (updated from Contreras-Balderas and Ramírez-Flores, 2000). Note the parallel trends for native species at risk and invasive species.

contributing to the demise of many fish species, by either competition, or predation and even by physical displacement through sheer numbers.

Successful documentation of Mexican fishes depends on the presence of sufficient professional biosystematic services. There are few centres of excellence for fish systematics in México. The national centres are the Instituto Politécnico Nacional (IPN, Colección de Peces Mexicanos), established in 1949. The next is at Universidad Nacional Autónoma de México (UNAM, Colección Nacional de Peces), founded in 1937. The Universidad Autónoma de Nuevo León, although started in 1958, was housed at the institution in 1965 (UANL, Colección de Peces), all recognized as having national coverage by the Sociedad Ictiológica Mexicana. These collections are the most representative, being country-wide in scope, although their coverage was mostly in the tropics, central region, and general, respectively. The UANL has a growing representation of fishes from other countries beyond North America. There are several other fish collections, rather regional or local in content, and often expanding. Until 1999, there were 11 registered fish collections, and an undetermined number of vertebrate or zoological collections with some fish holdings (Llorente-Bousquets et al., 1999). However, it should be noted that the biosystematics services are highly concentrated only in a few places and always have insufficient funding.

Freshwater fisheries

The Mexican fisheries regulator (Carta Nacional Pesquera, 2000) reported approximately 13,936 epicontinental water bodies, with a surface area of 1,116,051 hectares; including lakes, lagoons, reservoirs and diverse small aquatic ecosystems (Arredondo-Figueroa y Flores-Nava, 1992). Up until 1995, México had built 3000 dams, with capacities between less than one to 5 million cubic meters that became the site of 90% of freshwater harvests (De la Lanza-Espino and García-Calderón, 2002).

Freshwater fisheries in Mexico reached a maximum catch in 1996 (152,766 metric tons), with a maximum economic value in 2003 (1682.9 million pesos = 155,824.00 US$), and constituted 9.4% of catch and 9.8% of the value of all Mexican fisheries in 1994–2003. Interpretation of fisheries statistics is difficult since records refer to species groups, rather than single species. Catch per species-group is variable. All catfish were 6625 metric tons in 1992, 6715 metric tons in 1993, and then slowly declined to 3913 tons in 2003. Freshwater drum (*Aplodinotus grunniens*) reporting started in 1997, with maximum catches in 2001 (2,157 ton). Common carp harvest peaked in the late 90's (33171 ton). The silversides (charales: several species) catches were highest in the 80's and early 90's, going above 7000 tons, and reaching 9000 tons in 1990. Catches of black bass (*Micropterus salmoides*) have been erratic in the last 20 years. Catches of robalo (black bass plus snook), and trout (trouts/seatrouts/corvinas) have increased since 1999, although such official names are confusing, comprising both freshwater and marine species.

Official reports consider the most valuable freshwater species to be: catfishes, freshwater drum, common carp, charales, black bass, mojarras, and trout (Anuarios Estadísticos de Pesca, 2006). Fisheries in Lago de Pátzcuaro are based in eight endemic and five alien species (Gaspar-Dillanes et al., 2001), nine native species and four introduced in Lago de Chapala (Orbe-Mendoza et al., 2001), and seven native and three exotics in the reservoir Lic. Adolfo López Mateos "Infiernillo" (Jiménez-Badillo et al., 2001). Other important fisheries are known from Las Adjuntas (Tamaulipas) (Elizondo-Garza et al., 1995), Lago de Chapala (Jalisco) (Elizondo-Garza and Fernández-Méndez, 1995), and Lago de Pátzcuaro (Michoacán) (Orbe-Mendoza et al., 2002), comprising mainly food fish like blancos and charales, which are being replaced by alien species, *Cyprinus carpio*, *Micropterus salmoides* and *M. floridanus*, and tilapiines. Native species diminish through complex interactions with alien species, which are not yet fully understood. The main fishery resources country-wide are four species of tilapia, five of Asian carps and several species of mojarras (cichlids and centrarchids of the genus *Lepomis*) representing the highest catch volume (Elizondo-Garza and Rodríguez-Páez, 1993; Orbe-Mendoza et al., 1996, 1998, unpubl.).

Most of freshwater fisheries are covered by the concept of extensive aquaculture, which in fact does not mean any real cultural practices, but consists of stocking fry, mostly in reservoirs, and harvesting them later. In such systems, fish such as common carp (*Cyprinus carpio*) usually breed freely while others of the Chinese polyculture system do not breed. Tilapia fisheries went from the average crop of 18,953 tonnes at Infiernillo reservoir on Río Balsas in 1987 (Juárez-Palacios, 1989), reportedly the best in the world, and went down to 4,470 tonnes in 1998 (Juárez-Palacios, no year; Jiménez-Badillo and Nepita-Villanueva, 2004). In Infiernillo reservoir, formerly, 2–3 individuals were reported as comprising one fillet/pound in 1970, but the rate was down to 12–16 per fillet/pound by 1998. The decline is attributed to different causes unofficially. More recently it has been interpreted as resulting from overexploitation, combined with the accidental release of several plecos (loricariids) species since at least 1995 (Guzmán and Barragán, 1997). These plecos now constitute from 30 to 90% of the catch. These plecos are also damaging fishing gear (Contreras and three research groups, ongoing programs). Several species of plecos have been recognized in the Río Balsas, Río Grijalva-Río Usumacinta complex, and one in the Rio Grande.

Aquaculture

This activity has been based almost exclusively in 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*), as reported by federal biologists (Arredondo-Figueroa and Lozano-Gracia, 2003) often with support from FAO. Along the northern border with USA, Fish and Wildlife and several US state agencies have stocked true trouts, catfishes, black basses, sunfishes, sauger and walleye, temperate basses, and several esocids. Along the southern border, at least "tigre" cichlids are entering México from Guatemala (Contreras-Balderas, 1999). Those countries neighbouring México have never requested agreements to stock such alien species in binational waters of Mexican jurisdiction or shown any interest. Most of the harvest is in reservoirs and should be managed as fisheries, rather than as aquaculture, given that attention to the populations does not go much beyond stocking. In general, of the 94 reported alien fish in México (Contreras-Balderas, 1999), roughly two thirds derive from aquaculture related activities (food, forage, sports and ornamental). Aquaculture regulations are inappropriate, not enforced or non-existent.

Fish helminth parasites

The biogeography of helminth parasites of Mexican freshwater fishes in general tend to follow that of their hosts, except for the alien parasites, which succeed better in environments similar to those where they originated. Up to now

262 parasite forms are known from Mexican fish species, 18 of them endemic to the country, 55 to Central America, and 21 alien species have been added (Salgado-Maldonado, 2006). No information regarding whether a general survey of the parasites or diseases in Mexican fishes has been done is known.

Water quantity

The dewatering of Mexican rivers is notorious in the northern half of the country. Until 1962, the Rio Grande had a runoff of 12,000+ millions of cubic meters/year, and in 2002 it was less than 2% of the original. The river went nearly dry along the Big Bend region, and was dry for months in the delta region, both in 2002 and 2004. The Rio Grande is mostly dry upstream of the Río Conchos junction, its main Mexican tributary. Rio Grande tributaries provide now between 1% (Río San Juan) and 20% (Río Conchos) of the original runoff (Fig. 4; Table 2). The Rio Colorado (California, Arizona, Baja California, Sonora) is nearly dry most of the time, and does not reach the Sea of Cortéz. Up to 1994 there were more than 10,000 river km and 94 springs artificially dried up in Northern México, that have caused at least 6 extinctions in nature (Contreras-Balderas and Lozano Vilano, 1993). Phreatic water exploitation has been the main cause of such drying, and is held at an unsustainable level, above recharge capacities in nearly all aquifers, with abatement of water table ranging between 0.2 and 2 m/year (INEGI, 1982; 1994). River waters in southern Mexico are plentiful and show less overexploitation.

Water quality

Federal water authorities have developed an Index of Water Quality (ICA), based on physics and

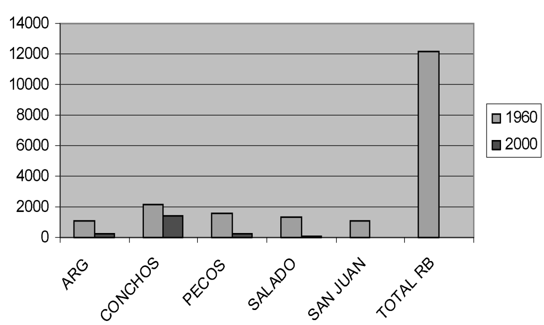

Figure 4. Water flows in the Rio Grande/Río Bravo (RB) basin and its main tributaries from 1923–1960 and 1990–2000, in thousands of cubic meters based on data of the International Boundary and Water Commission. ARG = Upper Rio Grande.

Table 2. Average runoff of the Rio Grande/Rio Bravo basin and main tributaries, averages in millions of cubic meters (Source: IBWC Hydrological Bulletins).

Reaches and Tributaries	1960	1990–2000	% of 1960
Upper Rio Grande, Colorado, New Mexico	1,080	217.6	20
Rio Conchos, Chihuahua, Mex.	2,196	75.1–2636.7*	2.9–120.04
Rio Pecos, New Mexico-Texas	1,593	238.6	22
Rio Salado, Mexico	1,293	70.2	5
Rio San Juan, Mexico	1,125	12	1
Rio Grande/Rio Bravo delta	12,135	1.2	0.1

*Rio Conchos is the most variable tributary of RG/RB, and in recent years (+2000) tends to be in the lowest level. The delta was dry between 2003 and 2004.

chemistry, with values from 100 for distilled water down to 0 for the worst pollution cases. Development of the ICA was around 1987, and its application has become standard practice. There was no public access to most of the data until recently. However, regional delegates have supplied some information since 2005. The water quality index developed by the Mexican federal government was reported as increasing from an average of 44.16 in 1989–90, and 45.09 in 1991 (INEGI, 1994). It is well known that all Mexican hydrometrical stations provide information showing poor water quality (INEGI, 1994).

The survey of Rio Grande waters which has been on-going since 1964 with continuous monitoring, has shown that the river is highly polluted, frequently exceeding USA and Mexican norms both in time and place (TNRCC, 1994, 1996; Kelly and Contreras-Balderas, 1994).

Integrity of aquatic ecosystems

The Index of Biological Integrity (IBI) is the preferred method for evaluation of the integrity and health of ecosystems. The original method, a geographical perspective (Karr, 1981) was adapted to evaluate the West central Mexican basins, resulting in grades between 35 and 80%, in the rivers Marabasco, Ayuquila, Duero and Purificación, state of Jalisco (Mercado-Silva et al., 2002). The Texan IBIs calculated in conjunction to the toxics study (TNRCC, 1994) disregarded brackish water species and gave high results masking the high rates of invasion by such euryhaline forms reported in other papers (Contreras-Balderas, 1976; Edwards and Contreras-Balderas, 1991; Contreras-Balderas et al., 2003). The Texas study also reported organics and heavy metals exceedences from norms, However, the total toxic exceedences was masked, when they failed to add both types, organics and heavy metals (Kelly and Contreras-Balderas, 1995), which resulted in lower inferred levels of toxicity and environmental damage.

The IBI was modified from the original of Karr (1981), to allow trend-in-time historical analysis (IBIh). The change is measured as percent change between the oldest recorded fish assemblage (=100%), against its actual composition (Contreras-Balderas et al., 2000, 2005). Alien species are tallied as negative components. This modified IBIh was applied to several basins. In regions of the Rio Grande, like the Tamaulipas/Texas section, reported integrity had an average of 31% (range 0–73) (Contreras-Balderas et al., 2000). The Río San Juan of Río Salado (state of Coahuila) averaged 32 (0–59) (Contreras-Balderas et al., 2001). The Presa (reservoir) Venustiano Carranza on Rio Salado (also Coahuila) had an average of 46.5 (Contreras-Balderas et al., 2002). The Rio Conchos (state of Chihuahua) averaged 48 (IBIh 0 to 95) (Contreras-Balderas et al., 2003). Another IBIh application was in the Lower Río Nazas (Contreras-Balderas et al., 2005). In summary, the IBIh grades were similar in all regions, from 70–80% in upper and middle reaches, to less than 35% in the lower reaches of West central basins, and down to 1.5% near the Lower Rio Grande delta.

Aquatic habitats in Mexico are commonly highly impacted by the combination of dewatering, channelization, damming and pollution (siltation, salinization). Ecosystems are also impacted by overexploitation and alien species introduced for food or sports by government, or incidentals by amateur and entrepreneur aquariophiles (Contreras-Balderas, 1999). The brackish water species that invade rivers were reported as 349 in 1976 (Castro Aguirre, 1976), and increased to 563 in 1999 (Castro-Aguire et al., 1999), accompanied by an increase in salinity and reduction of fresh water runoff (Contreras-Balderas and Lozano-Vilano, 1994). All phreatic aquifers known in 1981 were overexploited; with water level abatements ranging from 0.2 to 2 meters/year (SARH-PNH, 1981).

Discussion

The fish fauna of México is highly varied and well known, although still incompletely, considering recent findings. Its complexity and high endemism is the result of a complex orography and hydrography, plus wide climatic diversity. It is also under great pressure of impacts from unsustainable development, especially from alien species and colonizing and potentially harmful species. Losses are high, and result in a high number of its 504 species at risk, affecting 40% of the fish fauna, and as many as 29 extinctions, mostly in the last 50 years. The integrity of aquatic ecosystems is highly diminished, although existing countrywide coverage is insufficient, and the average from more than 50 localities studied is under 50%, which explains the high number of species at risk. The fisheries are complicated, giving strong regional variation in the numerous basins, and are based on alien species mostly. Officially, they are also masked under the name of aquaculture. Water quantity is constantly diminishing, due to overexploitation and pollution, converting rivers into sewage channels of very low quality; especially in desert areas, where more conservation is needed. The invasion of freshwaters by euryhaline species most likely is the consequence of increasing salinity and fresh water reduction from development; mainly agricultural, due to overuse of water (Contreras-Balderas and Lozano-Vilano, 1994).

Biosystematic services are scarce and concentrated in a few institutions. Species at risk, mostly endemics, amount to roughly 40% of the total freshwater fish fauna. There are heavy physical, chemical and biological impacts, often anthropogenic, such as overexploitation, dewatering, habitat disruption, and competition with alien species of diverse sources. Most alien fish species are stocked for food to fight poverty and malnutrition. Most fisheries depend on alien fishes. There is modest use of native fishes, often in artisanal fisheries. Water resources, both surface and subterranean, are often overexploited. Pollution levels are unsustainably high.

Conclusions and recommendations

To manage freshwater fishery resources we recommend the following actions:

1. Determine the actual and sustainable biological productivity at each water body with research projects focussed on native species;
2. Strictly enforce locally developed closed areas/seasons when fish are breeding;
3. Restrict exploitation using size limits for each species;
4. Continuous inspection to reduce the use of prohibited fishing gear, like seine nets;
5. Strict regulation of capture per unit effort using gill nets adjusted to population size and water body size and productivity;
6. Restock exclusively with native species to optimize or maintain productivity;
7. Evaluate anthropogenic impacts when pursuing the health and productivity of freshwater ecosystems;
8. Progressively reduce the stocking of alien species;
9. Encourage rational understanding and use of the native fish fauna, due to its high ecological, social and economic values, and
10. Last, but not least, develop new and sustainable ways to regulate water use, especially to stop dewatering of surface and subterraneous aquifers.

References

Alba, E. de, Reyes, M. E., 1998. Contexto Físico, En: CONABIO, La diversidad biológica de México: Estudio de país. Parte 1. (Biological Diversity of Mexico: study of the country. In Spanish). El País, 3–22.

Alvarez, J., 1950. Claves para la determinación de especies en los peces de las aguas continentales mexicanas. (Keys for determining species of fish in the continental Waters of Mexico. In Spanish.). Secretaría de Marina, México.

Alvarez, J., 1970. Peces Mexicanos (Claves) Insert: (Mexican Fishes. (Keys) In Spanish.). Serie Investigación Pesquera, Instituto Nacional de Investigaciones Biológico Pesqueras México.

Anuarios Estadísticos de Pesca, 2006. (Annual Statistics of Fisheries. In Spanish.). Secretaría de Pesca National Institute of Fisheries, Secretariat of Fisheries, México.

Arredondo-Figueroa, J. L., Flores-Nava, A., 1992. Característica limnológica de pequeños embalses epicontinentales, su uso y manejo en la acuacultura. (Limnological characteristics of epicontinental small reservoirs. In Spanish.). Hidrobiológica 3/4, 1–10.

Arredondeo-Figueroa, J. Lozano-Gracia, S. D., 2003. La acuicultura en México. (Aquiculture in Mexico In Spanish). Universidad Autónoma Metropolitana, México.

Barbour, C. D., 1973. The systematics and evolution of the genus *Chirostoma* Swainson (Pisces: Atherinidae). Tulane Stud. Zool. Bot., 18, 97–141.

Barbour, C. D., Miller, R. R, 1978. A revision of the Mexican cyprinid genus *Algansea*. Misc. Publ. Mus. Zool., Univ. Mich., 155, 1–72.

Carta Nacional Pesquera, 2000. *Diario Oficial de la Federación*. (*Offical Diary of the Mexican federation.* In Spanish), Mexico.

Castro-Aguirre, J. L., 1976. Catálogo sistemático de los peces marinos que penetran a las aguas continentales de México, con aspectos zoogeográficos y ecológicos. (Systematic catalogue of marine fishes that penetrate the continental waters of Mexico. In Spanish.). Depto. De Pesca México, Ser. Cient. 19, 298.

Castro-Aguirre, J. L., Espinosa-Pérez, H., Schmitter-Soto, J. J., 1999. Ictiofauna estuarino-lacunar y vicaria de México. (Lacustruine-esturaine and vicariante ichthyofauna of Mexico. In Spanish.). Textos Politécnicos, Series Biotecnologías.

Contreras-Balderas, S., 1969. Perspectivas de la Ictiofauna en las Zonas Aridas del Norte de México. (Perspectives of the ichthyofauna from arid zones in Northern Mexico. In Spanish.). Mem. Primer Simp. Internacional de Aumento de Produccion en Zonas Aridas ICASALS, Texas Tech. Publ. 3, 294–304.

Contreras-Balderas, S., 1973. Speciation aspects and man-made community composition changes in Chihuahuan desert fishes. Trans. Proc. 3, 1–658 (Published in 1978).

Contreras-Balderas, S., 1976. Impacto ambiental de obras hidráulicas. ([Environmental Impacts of Hydraulic Works. In Spanish.). Technical Report. Secretaría de Recursos Hidráulicos, Informe Técnico.

Contreras-Balderas, S., 1999. Annotated checklist of introduced invasive fishes in México, with examples of some recent introductions, pp. 33–54. In: R. Claudi and J. H. Leach (Eds.), *Nonindigenous freshwater organisms—vectors, biology, and impacts*, pp. 33–54. Lewis Publ., Stockport.

Contreras-Balderas, S., 2000. Alteraciones en Biodiversidad y Notas de Impacto Ambiental en Presas del Noreste de México: Revisado. (Alterations of Biodiversity and environmental impacts noted in reservoirs of Northeastern Mexico. In Spanish.). In: *De la Lanza Espino*:*Lagos y Presas de México* (*Lakes and Reservoirs in Mexico*), pp. 486–499. Centro de Ecología y Desarrollo, A.C.

Contreras-Balderas, S., Escalante, M. A., 1984. Distribution and known impacts of exotic fishes in México,. In: W. C. Courtenay Jr., J. R. Stauffer Jr., (Eds.), *Distribution, Biology, and Management of Exotic Fishes*, pp. 102–130. Johns Hopkins University Press, Baltimore.

Contreras-Balderas, S., Lozano-Vilano, M. L., 1993. Water, Endangered Fishes, and Development Perspectives in Arid Lands of México. Conserv. Biol., 8(2), 379–387.

Contreras-Balderas, S., Lozano-Vilano, M. L., 1994. *Cyprinella alvarezdelvillari* sp. nv. from Río Nazas, New Cyprinid Fish from México. COPEIA, 1994(4), 897–906.

Contreras-McBeath, T., Mejía-Mójica, H., Carrillo-Wilson, R., 1998. Negative impact on the aquatic ecosystems of the state of Morelos, México, from introduced aquarium and other comercial fish. Aquar. Sci. Conserv., 2, 67–78.

Contreras-Balderas, S., Ramírez-Flores, M., 1999. Acuacultura, Ictiodiversidad, Transfaunación Acuática y Peces en Riesgo en México. (Aquaculture, Ichthyodiversity, Aquatic transfaunation, and Fishes at risk in Mexico. In Spanish.). Mem.IV Reunión Nal. Redes Investigación en Acuacultura 1, 97–102.

Contreras-Balderas, S., Ramírez-Flores, M., 2000. Biodiversidad en las aguas continentales de México. (Biodiversity in continental Waters of Mexico. In Spanish.). Estado de salud de la acuacultura. Instituto Nacional de la Pesca, Dirección General de Investigación en Acuacultura (México) 1(4), 1–13.

Contreras-Balderas, S., Lozano-Vilano, M. L., García-Ramírez, M. E., 2000. Ecology chapters. In: J. Schmandt, *Water and Sustainable development in the Lower Rio Grande/Río Bravo*. Texas and México Houston Advanced Research Center.

Contreras-Balderas, S., Lozano-Vilano, M. L., García-Ramírez, M. E., 2001. Indice Biológico de Integridad del Río Sabinas, Coahuila, México. (Index of Biological Integrity of the Sabinas River, Coahuila, Mexico. In Spanish). Reporte Técnico, Gobierno de Coahuila, Mexico.

Contreras-Balderas, S., Lozano-Vilano, M. L., García-Ramírez, M. E., 2002. Indice Biológico de Integridad de la Presa Venustiano Carranza, Coahuila, México. (Index of Biological Integrity of the Venustiano Carranza Reservoir, Coahuila, Mexico. In Spanish.). Reporte Técnico, Gobierno de Coahuila, Mexico.

Contreras-Balderas, S., Edwards, R. J.,Lozano-Vilano, M. L. García-Ramírez, M. E., 2002. Fish Biodiversity Changes in the Lower Rio Grande/Río Bravo 1953–1996. (Cambios en la Biodiversidad de Peces en el Bajo Rio Grande/Río Bravo). Reviews in Fish Biology and Fisheries, 12(2–3), 219–240. (Edición Especial Bilingüe [Special bilingual edition]).

Contreras-Balderas, S., Lozano-Vilano, M. L., García-Ramírez, M. E., 2003. Indice Biológico de Integridad del Rio Conchos, Chihuahua, México. (Index of Biological Integrity of the Conchos River, Chihuahua, Mexico. In Spanish.). Reporte Técnico, World Wildlife Fund, Mexico.

Contreras-Balderas, S., Almada-Villela, P., Lozano-Vilano, M. L., García-Ramírez, M. E., 2003. Freshwater fish species at risk or extinct in México. Reviews in Fish Biology and Fisheries, 12(2–3), 241–251.

Contreras-Balderas, S., Lozano-Vilano, M. L., García-Ramírez, M. E., 2005. Historical changes in the Index of Biological Integrity for the Lower Río Nazas, Durango, México. In J. N. Rinne, R. M. Hughes, B. Calamusso (Eds.), *Historical Changes in Large river assemblages of the Americas*. Amer. Fish. Soc. Symp., 45.

De Buen, F., 1947. Ictiogeografía Continental Mexicana (I, II y III). (Mexican Continental Ichthyogeography. In Spanish.). Revista de la Sociedad Mexicana de Historia Natural., 7(1–4), 87–138.

De la Lanza-Espino, G., García-Calderón, J. L., 2002. *Lagos y Presas de México*. (*Lakes and Reservoirs of Mexico*, In Spanish.). AGT Editor, S. A., México.

Díaz-Pardo, E., Godínez Rodríguez, M. A., López-López, E., Soto Galera, E. 1993. Ecología de los peces del Río Lerma, México. (Ecology of fishes of the Lerma River, Mexico. In Spanish.). Anales, Escuela Nacional de Ciencias Biológicas, Instituto Politécnico Nacional [Annals, National School of Biological Sciences, National Polytechnical Institute 39, 103–127.

Doadrio, I., Domínguez, O., 2003. Phylogenetic relationships within the family Goodeidae based on cytochrome b sequence data. Molecular Phylogenetics and Evolution, 31(2), 416–430.

Edwards, R. J., Contreras-Balderas, S., 1991. Historical changes in the ichthyofauna of the Lower Rio Grande (Rio Bravo del Norte), Texas and México. Southwest. Nat., 36(2), 201–212.

Elizondo-Garza, R., Fernández-Méndez, J. J., 1995. Caracterización Biológico Pesquera del Lago de Chapala, Jalisco-Michoacán, México, con un análisis de las capturas de charal *Chirostoma chapalae* (Jordan y Snyder, 1900), en redes mangueadoras y atarrayas [Fisheries biology. Characterization of Chapala lake, Jalisco-Michoacán, Mexico. In Spanish.). Publicaciones Biológicas, Facultad de Ciencias Biológicas/ Universidad Autónoma de Nuevo León, México, 8(1–2), 62–96.

Elizondo-Garza, R. Rodríguez-Páez, A. E., 1993. Análisis sobre capturas comerciales y su relación con los artes de pesca en el Lago de Chapala (Jalisco-Michoacán). (Analysis of commercial catch and their relation with fishing gear in Lake Chapala (Jalisco-Michoacan) In Spanish.). Ciencia Pesquera, Instituto Nacional de Pesca, Secretaría de Pesca México, 9, 33–48.

Elizondo-Garza, R., Martínez-Zavala, M. A., Roque-Villada, I., Fernández-Méndez, J. J., 1995. Caracterización biológica de la Presa Vicente Guerrero (Las Adjuntas), Tamps., México, con un análisis de las capturas de tilapia, Oreochromis aureus (Steindachner, 1864), y lobina negra, Micropterus salmoides (Lacépède, 1802). (Biological characterization of Vicente Guerrero Reservoir (Las Adjuntas), Tamps., with an análisis of tilapia (Oreochromis aureus (Steindachner, 1864), and black bass, Micropterus salmoides match. In Spanish.). Publicaciones Biológicas, Facultad de Ciencias Biológicas/ Universidad Autónoma de Nuevo León, México, 8(1–2), 25–61.

Gaspar-Dillanes, M. T., Rojas-Carrillo, P., Fernández-Méndez, J. I., Toledo Díaz-Rubín, M. P., 2001. Pesquerías de Aguas Continentales: Lago de Pátzcuaro (Fisheries in continental Waters: Lake Patzcuaro. In Spanish), pp. 793–820. *En:* C. A. Díaz de León, M. A. Cisneros (Eds.), *Sustentabilidad y pesca responsable en México: Evaluación y manejo [Sustainability and responsable fishing in Mexico: Evaluation and management] 1999–2000*. Instituto Nacional de la Pesca, Secretaría de Medio Ambiente, Recursos Naturales y Pesca, México.

Guzmán, A. F., Barragán, J., 1997. Presencia de bagre sudamericano (Osteichthyes: Loricariidae) en el Río Mezcala, Guerrero, México. (Presence of a Southamerican catfish (Osteichthyes: Loricariidae. In Spanish). Vertebrata Mexicana, 3, 1–4.

Hendrickson, D. A., 1984. Distribution records of native and exotic fishes in Pacific drainages of Northern México. J. Ariz.-Nev. Acad, Sci., 1983, 18, 33–38.

IBWC, 1923–2003. Water Bull. 1–72. Internacional Boundary and Water Commission, USA/Mexico.

Instituto Nacional de Pesca [National Institute of Fisheries], 1994. Presa Adolfo López Mateos, "Infiernillo" [Adolfo Lopez Mateos Reservoir, "Little Hell". (In Spanish.). www.semarnat.gob.mx

INEGI (Instituto Nacional de Estadística, Geografía e Informática) (National Institute of Statistics, Geography, and Informatics. In Spanish.), 1982. Estadísticas del Medio Ambiente, México.

INEGI (Instituto Nacional de Estadística, Geografía e Informática) (National Institute of Statistics, Geography, and Informatics. In Spanish.), 1994. Estadísticas del Medio Ambiente, Mexico.

Jiménez-Badillo, M.L., Nepita-Villanueva, M. R., 2004. Espectro trófico de la Tilapia *Oreochromis aureus* (Perciformes: Cichlidae) en la Presa Infiernillo, Michoacán-Guerrero, México [Trophic position of tilapia *Oreochromis aureus* (Perciformes: Cichlidae)]. Revista de Biología Tropical, 48(2–3), 487–494.

Jiménez-Badillo, M.L., Ramírez-Camarena, C., Osuna-Paredes, C., 2001. Pesquerías de Aguas Continentales: Presa el Infiernillo (Fisheries in continental Waters: Little Hell Reservoir. In Spanish.), 851–874. In: C. A. Díaz de León, M. A. Cisneros (Eds.). Sustentabilidad y pesca responsable en México: Evaluación y manejo *[Sustainability and responsable fishing in Mexico: Evaluation and management]* 1999–2000. Instituto Nacional de la Pesca, Secretaría de Medio Ambiente, Recursos Naturales y Pesca, México.

Juárez-Palacios, R., 1989. Presa Adolfo López Mateos El Infiernillo: caracterización, informe preliminary (Adolfo López Mateois Reservoir the Little Hell: characterization, preliminary report. In Spanish.). Informes, Secretaría de Pesca, México.

Karr, J., 1981. Assessment of biotic integrity using fish communities. Fisheries, 6(6), 21–27.

Kelly, M., Contreras-Balderas, S., 1995. The TNRCC, Binacional study regarding the presence of toxic substances in the Rio Grande/Rio Bravo and its tributaries along the boundary portion between the United Status and Mexico. Texas Natural Resources Conservation Commission. User's manual. Texas Center for Policy Studies and Bioconservación, A.C., Austin and Monterrey.

Lagler, J. F., Bardach, J. E., Miller, R. R. Passino, D. R. M., 1977. *Ichthyology, 2nd. Ed*. J. Wiley, NY.

Llorente-Bousquets, J., Koleff-Osorio, P., Benítez-Díaz, H., Lara-Morales, L., 1999. Síntesis del Estado de las Colecciones Biológicas Mexicanas, CONABIO. (Synthesis of the status of Mexican biological collections. CONABIO. In Spanish).

Lyons, J., González-Hernández, G. Soto-Galera, E., Guzmán-Arroyo, M., 1998. Decline of freshwater fishes and fisheries in selected drainages of West-central México. Fisheries, 23(4), 10–18.

Martínez-Ramírez, E., Doadrio-Villarejo, I., de Sotoa-Fernández, A., 2004. Peces Continentales (Continental fishes). In: A. J. García-Mendoza, M. De J. Ordóñez, M. Briones-Salas (Eds.), *Biodiversidad de Oaxaca (Biodiversity of Oaxaca. In Spanish.),* pp. 357–373. Instituto de Biología, Universidad Nacional Autónoma de México.

Mayden, R. L., Matson, R. H., Hillis, D. M., 1984. Speciation in the North American genus *Dionda*. In: R. L. Mayden (Ed.), *Systematics, Historical Ecology, and North American Freshwater Fishes*, pp. 710–746. Stanford University Press, Stanford.

Meek, S. E., 1904. The freshwater fishes of México north of the Isthmus of Tehuantepec. Field Col. Mus. Publ. 93, Zool. Ser.

Mercado-Silva, N., Lyons, J. D. Salgado-Maldonado, G. Medina-Nava, M., 2002. Validation of a fish based index of biological integrity for streams and rivers of central México. Reviews in Fish Biology and Fisheries, 12(2), 179–191.

Miller, R. R., 1961. Man and the changing fish fauna of the American Soutwest. Pap. Mich. Acad. Sci. Arts and Letters, 46(1960), 365–404.

Miller, R. R., Smith, M., 1986. Origin and geography of the fishes of central Mexico. In: C. H. Hocutt, E. O. Wiley (Eds.), *The zoogeography of North American freshwater fishes*, p. 487. J. Wiley, NY.

Miller, R. R., Minckley, W. L., Norris, S. M., 2005. *Freshwater fishes of Mexico*. Chicago University Press, IL.

NOM-059-ECOL, 1994. Norma Oficial Mexicana 059 Ecol(ogy), De las especies mexicanas en peligro, amenazadas o de protección especial. Diario Oficial de la Federación (Offical Diary of the Mexican federation. In Spanish).

NOM-059-SEMARNAT, 2001. Norma Oficial Mexicana 059 Ecol de las especies mexicanas: en peligro, amenazadas o de protección especial. Diario Oficial de la Federación Mexicana. (Ecology Of Mexican species: endangered, threatened, or of special protection. In Spanish.). Offical Diary of the Mexican federation.

Orbe-Mendoza, A., Acevedo-García, J., Lyons, J., 2002. Lake Patzcuaro fishery management plan. Reviews in Fish Biology and Fisheries, 12(2–3), 207–217.

Orbe-Mendoza, A., Guzmán-Arroyo, M., Flores-Herrera, R., 1996. Embalses del Estado de Michoacán, México (Reservoirs of the State of Michoacan. In Spanish.). In: Fuentes-Castellanos, D.F., García-Real, S. Peñalosa (Eds.), *Pesquerías relevantes de México, XXX Aniversario de la pesca*, *1st Ed.* pp. 673–695. (Relevant fisheries in Mexico, XXX Anniversary of fishing), Instituto Nacional de Pesca-Secretaría del Medio Ambiente Recxursos Naturales y Pesca.

Orbe-Mendoza, A., Hernández-Montaño, D., Acevedo-García, J., 2001. Pesquerías de Aguas Continentales: Lago de Chapala [Fishewries in Continental Waters], 821–836. *In*: C. A. Díaz de León, M. A. Cisneros (Eds.), *Sustentabilidad y pesca responsable en México: Evaluación y manejo* Sustainability and responsable fishing in Mexico. In Spanish.) 1999–2000. Instituto Nacional de la Pesca, Secretaría de Medio Ambiente, Recursos Naturales y Pesca.

Orbe-Mendoza, A., Romero, A. C., Acevedo, J., 1999. Producción y rendimiento pesquero en la presa Lic. Adolfo López Mateos (El Infiernillo) Michoacán-Guerrero, México. (Production and fishing yield in the Lic. Adolfo Lopez Mateos reservoir (Little Hell) Michoiacan-Guerrero, Mexico. In Spanish.). Hidrobiologica, 9(1), 1–8.

Rodiles-Hernández, R., Hendrickson, D. A., Lundberg, G. J., Humphries, J. M., 2005. *Lacantunia enigmatica* (Teleostei, Siluriformes) a new and phylogenetically puzzling fish from Mesoamerica. Zootaxa 1000, 1–24.

Ruiz-Campos, G., Castro-Aguirre, J. L., Contreras-Balderas, S., Lozano-Vilano, M. L., González-Acosta, A. F., Sánchez-Acosta, S., 2003. An annotated distributional checklist of the freshwater fish from Baja California Sur, México. Reviews in Fish Biology and Fisheries, 12(2–3), 143–155.

Rzedowski, J., 1978. *Vegetación de México*. (*Vegetation of Mexico*. In Spanish.) Ed. Limusa, México.

Salgado-Maldonado, G., 2006. Checklist of Heliminth parasites of freshwater fishes from Mexico. Zootaxa, 1324, 1–357.

SARH-PNH, 1981. (Secretaria de Agricultura y Recursos Hidraulicos—Plan Nacional Hidraulico.) (Secretariat of Agriculture and Hydraulic Resources—National Hydraulic Plan. In Spanish.). In: Mexico, Informe de la situación general en materia de equilibrio ecologico y proteccion al ambiente [Mexico, Report on General Situation in Ecological Equilibrium and Enviromental Protection] 1991–1992, Secretaria de Desarrollo Social [Secretariat of Social Development], Mexico, 1993.

Smith, M., Miller, R. R., 1986. The evolution of the Rio Grande basin as inferred from its fish fauna. pp. 457–485. In: C. H. Hocutt and E. O. Wiley (Eds.), *The zoogeography of North American freshwater fishes*. J. Wiley, NY.

Tamayo, J. L., 1963. Geografía General de México (General Geography of Mexico. In Spanish). Instituto de Estudios Económicos, Universidad Nacional Autónoma de México. 4 volumes and atlas.

Tamayo, J. L., West, G., 1963. The hydrography of Middle America. In. R. Wauchope, R. C. West (Eds.), *Handbook of Middle American Indians, Vol.I*, pp. 84–121.

TNRCC, 1994. Binacional study regarding the presence of toxic substances in the Rio Grande/Rio Bravo and its tributaries along the boundary portion between the United Status and Mexico. Texas Natural Resources Conservation Commission, TX.