Water, Endangered Fishes, and Development Perspectives in Arid Lands of Mexico

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Abstract. *Nearly half of Mexico is arid or semiarid, with scarce waters. At least 92 springs and 2500 km of river have dried in this area. Surface waters have diminished, and phreatic waters are sinking deeper, provoking intrusion of saline waters and salinization of agricultural wells in Sonora, reversing phreatic circulation in the Comarca Lagunera, allowing arrival of arsenic to agricultural waters, and threatening metropolitan Torreón. There are nearly 200 species of freshwater fishes in this region, 120 under some threat, 15 extinct through human impact. As of 1985, an average of 68% of species was eradicated in local fish faunas. Finally, salinization of the lower Rio Bravo del Norte has replaced 32 native fish of fresh or slightly brackish water with 54 mainly marine or highly salt-tolerant species; the salinization threatens all uses of water. Some marine fishes invade up to 400 km upstream. Pollution is strong, and fish kills have been reported. These low-quality and scarce waters comprise future resources for cities such as Monterrey, which, along with its border twin cities, is expected to double its human population by 2010. Redesign of regional development is urgently needed, in keeping with the real availability of water. All water use should be equal to or less than lower recharge averages; norms of integral basin management should rely on criteria of high-use efficiency, recuperation, recycling, and reutilization. Also necessary are reduced pollution and increased treatment of residual waters. Innovative environmental vision is especially essential in light of expectations for development through the North American Free Trade Agreement, the Border Integral Environmental Plan, industrial expansion, and the modernization*

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Aguas, peces en peligro, y perspectivas de desarrollo en las tierras áridas de México

Resumen: *Casi la mitad de México es árido o semiárido, con escasas aguas. Al menos, 92 manantiales y 2500 Km de ríos se han secado. Las aguas superficiales han disminuído y las aguas freáticas se encuentran a mayor profundidad, provocando la intrusión de aguas salinas y la salinización de pozos agrícolas en Sonora, revirtiendo la circulación de la capa freática en la Comarca Lagunera, provocando la llegada de arsénico a aguas agrícolas y amenazando el área metropolitana del Torreón. Existen apróximadamente 200 especies de peces de agua dulce en esta región, 120 están amenazadas y 15 extintas por impacto humano. En 1985 un promedio de 68 especies fueron erradicadas de las faunas de peces locales. Finalmente, la salinización del bajo Río Bravo del Norte ha causado un cambio de 32 especies nativas dulceacuícolas o salobres, a 54 especies principalmente marinas o de una alta tolerancia a la salinidad, poniendo en peligro todo uso del agua. Algunas especies marinas penetran hasta 400 Km aguas arriba. La contaminación es grave y ha sido reportada la mortandad de peces, sin embargo, estas aguas escasas y de baja calidad constituyen los recursos futuros de ciudades como Monterrey y las ciudades gemelas fronterizas, cuyas poblaciones se duplicarán para el año 2010. Urge replantear el desarrollo regional y medirlo en función de la disponibilidad real de agua. Todos los usos deben ser iguales o menores a la capacidad de recarga promedio, las normas de manejo integral de la cuenca deben basarse en un criterio de alta eficiencia de uso, recuperación y reciclaje. También, es necesario reducir la polución e incrementar el tratamiento residual de las aguas. En necesaria una visión ambiental innovativa, epecialmente debido a las expectativas de desarrollo a través del tratado de libre co-*

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and internationalization of the northern Mexican border belt. These all conflict with the high priority recently decreed for species conservation by the Mexican Act, creating the National Committee on Knowledge and Use of Biodiversity.

mercio con Norte América, el Acuerdo de Protección Integral Ambiental Fronteriza, la expansión industrial, la modernización e internacionalización de la franja fronteriza norte. También debe considerarse la alta prioridad decretada recientemente por el Gobierno Mexicano para la Conservación de especies, creando la Comisión Nacional para el Conocimiento y Uso de la Biodiversidad.

Introduction

Arid and semiarid zones comprise from 40% to 60% of land in México, depending on the criteria applied. In this paper we (1) discuss consequences of economic development on diversity of endangered and threatened fishes, and problems of water availability, in the Mexican states of Baja California, Sonora, Chihuahua, Coahuila, Nuevo León, Tamaulipas, Durango, Zacatecas and San Luis Potosí (Figure 1); and (2) provide an overview of some ongoing environmental impacts that diminish biodiversity through abuse or misuse of water and display a lack of a broad environmental understanding. These points are particularly relevant to the North American Free Trade Agreement and the Border Environmental Plan, which do not take adequate account of biodiversity considerations (NAFTA 1992; SEDUE/EPA 1992).

This paper is not an exhaustive scientific review but rather a position paper summarizing personal research findings and other facts important for the future of the Méxican-U.S. border states.

In 1988, México promulgated legislation that made environmental impact evaluation a policy for all public or private works, mentioning, without defining or listing, endangered species and the legally recognized need of conservation. Until recently, there was no specific legal responsibility toward the knowledge, understanding, use, or protection of biodiversity as such. On March 16, 1992, the Mexican federal government promulgated the Decreto para el Uso y Conocimiento de la Biodiversidad, an act that assigned such responsibilities to all citizens and created the Comisión Nacional for said objectives. This act completes the legal background creating a program to protect Mexican flora and fauna, but it will be necessary to improve public understanding of

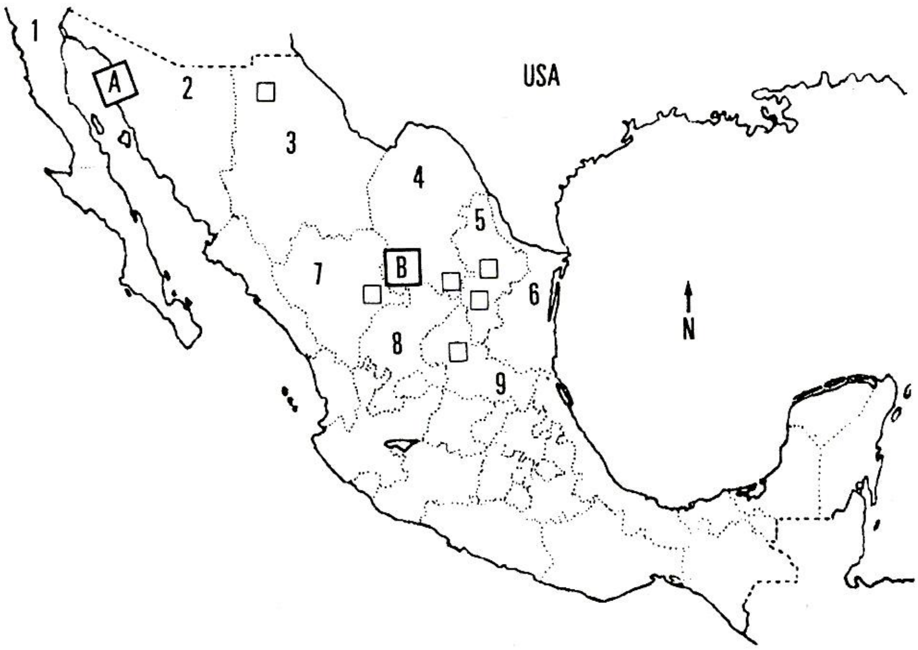

Figure 1. Northern Mexican States: (1) Baja California, (2) Sonora, (3) Chihuahua, (4) Coahuila, (5) Nuevo León, (6) Tamaulipas, (7) Durango, (8) Zacatecas, (9) San Luis Potosí. Large squares: (A) Sonora Coastal Plain, (B) Comarca Lagunera. Small squares; regions of drying springs referred to in text.

the survival of fishes, both as part of biodiversity and as indicators and sufferers of environmental degradation under global and regional views.

Water in Northern Mexico

Loss of Water Quantity

An early symptom of regional water deficiency is the drying of springs. Preliminary counts of dry springs in Northern México include the following: Nuevo León, 20 springs; Coahuila, more than 15 springs in the Saltillo Valley (a reference from the colonial period tells of 665 springs in this valley alone), and more than 10 springs each in the bolsones (playa lakes) of Viesca and Parras; Durango, 20 springs; Chihuahua, 5 springs; and San Luis Potosi, 12 springs (Fig. 1) (Contreras & Almada 1991). No data are available for Zacatecas or Sonora. The situation in Texas is not very different (Brune 1975, 1981). The data are from inspected localities only, and exploration is far from complete. Losses of springs have accelerated during the last 20 years, but only approximate dates of their dissappearance are known.

Another symptom of water deficiency is the lowering of riverine discharges, as in the following rivers: in Chihuahua, the lower Río del Carmen and Middle Rio Grande above Presidio; in Durango/Coahuila, Río Nazas and Bolson Mayrán, Río Aguanaval and Bolsón Viesca; in Coahuila, Río de Nadadores; in Coahuila/Nuevo León, Saltillo and Río Salinas; in Nuevo León, Río Sabinas and Río Santa Catarina; in San Luis Potosi, Río Ahualulco-Venado-Moctezuma region. These rivers have all become dry, intermittent, or occasional within the past two decades (Fig. 2) (Contreras & Lozano 1993).

Another indicator of water loss is lowering of the water table, which in Monterrey, Nuevo León, now lies at 200 m beneath the surface; in Comarca Lagunera, Coahuila, at 80 m, and in Sandia el Grande, Nuevo León, between 2 and 10 m, the last being close to the average for northern México. These are some of the same areas that contain dry springs. Some governmental offices still deny this collective information on loss of water resources.

In 1975, Plan Nacional Hidráulico (PNH 1975) issued a map of northern México with aquifer recharge, extraction, demand, and planned expansion sites. Using such data, 21.1% of sites were considered underexploited, 26.3% were overexploited, 52.6% had unknown recharge rates, and the average overexploitation was 66.2%; the map included data on immediate demand and planned expansion that already represented an 80% increase in water use (PNH 1975; Contreras 1975). We submit that no planning for further development or determination of rates of exploitation can be done without knowledge of water use and recharge rates.

Figure 2. Rivers of Northern México that are becoming dry or intermittent: (1) Lower Río Carmen, (2) Middle Río Grande above Presidio, Texas (3) Lower Río Nazas and Laguna Mayrán, (4) Middle and Lower Río Aguanaval and Laguna Viesca, (5) Rio de Nadadores, (6) Rio Sabinas, (7) Valle de Saltillo and Río Salinas, (8) Río Santa Catarina, and (9) Río Ahualulco-Venado-Moctezuma region.

In contrast, a few years later, the Instituto Nacional de Estadística, Geografía e Informática's geographical syntheses (INEGI: Nuevo León 1981; Zacatecas 1981; Coahuila 1983; Tamaulipas 1983; Baja California 1984) showed that in the early 1980s, with most aquifers having unknown recharges, 14,445 out of 20,249 (72%) water wells were regarded as underexploited (Table 1), in spite of the overall decline of the aquifers and obvious rise in regional development and groundwater use. Public explanation is thus required for the criteria defining over- or underexploitation. How can it be defined in the

Table 1. Wells considered to be underexploited, overexploited, in equilibrium, or dry in northern Mexico.

	Total	*Under Exploited*	*Over Exploited*	*In Equilibrium*	*Dry*
Baja California	3,472	147	2,825	482	—
Coahuila	4,525	2,689	1,836	—	—
Nuevo Leon	11,149	10,623	—	526	—
Tamaulipas	986	986	—	—	9
Zacatecas	117	?	?	?	9
Totals	20,249	14,445	4,661	1,008	18

Source: INEGLI (1981; 1983).

absence of recharge data? We define overexploitation as water extraction above the lowest average recharge level, which causes a lowering of the water table and drying of springs. Rational exploitation would then be defined as regulating the maximum average extraction to below the minimal average recharge as a safe and permissible average (maximum sustainable) use. The Mexican federal government has received outdated information and urgently needs to reconsider actual water availability.

Degradation of Water Quality

There was an apparently accidental spill of sulphuric acid on the Río Salinas of Nuevo León in 1990 (Fig. 3), resulting in a fish kill that was roughly estimated as somewhat less than 2000 fish *per* linear meter of river (average width 20 m), or 96 dead fish per square meter. The upper 2 km of river were explored, with an estimated 4,000,000 fish killed. Visible impact of the spill extended 20 km more downstream. There were no estimates for the intermediate area, and hence total impact can only be estimated (S. Contreras-B, personal observation). Incidents of this type may be expected more frequently as the region becomes more densely populated and industrialized.

The lower Río Bravo del Norte (Rio Grande) and lower Río San Juan, into the latter of which the Río Salinas flows, comprise some of the best irrigation districts along the Méxican-U.S. border. Yet, as an indication of broad ecological change, marine and brackish-water fishes are invading this area. In the 1850s, only six marine species were recorded (Edwards & Contreras 1991); in 1953 they were seven; by 1976 their numbers had risen to 18 (Contreras et al. 1976) and by 1989 to 54 (Edwards & Contreras 1991). This penetration has extended up to 400 km upstream from the ocean (Contreras et al. 1976). One species, tidewater silversides (*Menidia beryllina*), had by 1978 reached within 20 km northeast of Monterrey, Nuevo León, at Laguna Montfort (Figure 3). This invasion was stopped by pollution from Monterrey municipal and industrial sewage. In contrast, some freshwater species have retreated from the lower 400 km of the river (Contreras 1975; Contreras et al. 1976). From a qualitative viewpoint, invasion of marine/brackish fishes and retreat of freshwater species indicate that salinization is increasing rapidly, represents a threat to agriculture, will corrode industrial machinery, and will involve costly water treatment.

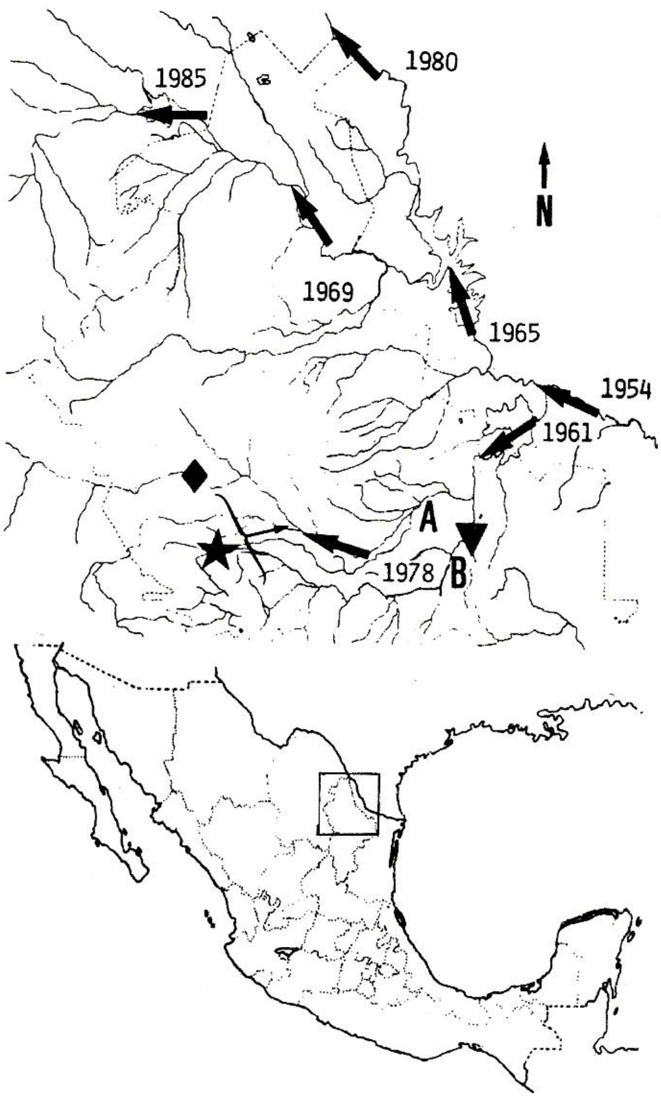

Figure 3. Map of Neuvo León, México. Arrows indicate progressive invasion of the Río Grande basin by the tidewater silversides, Menidia beryllina, *since 1954, in years shown. Bracket indicates area of residual water collectors and outflow planned to Río Pesquería (A) to bypass the future reservoir Presa El Cuchillo (inverted triangle) being built on Río San Juan (B) to provide tap water for Monterrey (star). The site of a major fish kill is marked with a diamond.*

The Comarca Lagunera (Torreon Region), Coahuila

The Comarca Lagunera and 30,000 of its human inhabitants are suffering from a complex problem. Maeda (1990; 1992) reported numerous mild to severe cases of arsenic poisoning in resident farmers north and east of Torreón, resulting in lesions, pustules, finger losses, and even some deaths. There are several possible explanations for this arsenic poisoning, and the most plausible is as follows: Flores (1990) reported that overexploitation of ground water lowered the water table enough to cause a reversal of its flow; formerly flowing southwest to northeast and away from Torreón, groundwater now flows northeast to southwest toward the city. On its return, water flows through arsenic minerals, resulting in the local arsenicism. Questioned about the timing of the arrival of such poisoned waters to the metropolitan Torreón tap-water sources, Flores suggested 10 years if overexploitation rates continue. This overexploitation was first indicated by drying of springs and rivers in the area (Contreras & Maeda 1985).

The Coastal Plain of Sonora

The coastal plain of Sonora has been and is an agricultural emporium. Overexploitation has lowered the water table, however, resulting in replacement of fresh by brackish water. This brackish water may come from marine intrusion or from replacement by salinized agricultural runoff; studies are needed to identify the source of salt. Salinization has reached up to 100 km inland, as in Caborca. Newspapers have reported that some salinized water wells have been used for culturing shrimp and may become part of local governmental plans. Large-scale change from irrigated agriculture to shrimp culture does not seem to us environmentally or economically advantageous.

Monterrey Tap Water: "Plan 4"

Widely publicized through newspapers and local hearings, "Plan 4" is a program that relies on the flow of Río San Juan to provide future tap water for metropolitan Monterrey, Nuevo León. This river, a tributary of Rio Bravo, is the largest stream in Nuevo León, draining most of the middle portion of the state. It has a large and nearly dry headwater in Coahuila, and a small run in Tamaulipas near its discharge to Río Bravo (Fig. 3). Its basin area is 33,830 km^2 (Tamayo & West 1964), with two major subbasins—Río Pesquería and Río San Juan proper—that join near China, Nuevo León. The Río San Juan has been termed, freely translated, as a "first-order problem requiring immediate attention," and a "public collector of residual waters, without aquatic life signs, offensive to sight and smell and noxious to the ecology of the area" (INEGI 1981).

The Río San Juan originates along the heavily populated axis from Monterrey to Montemorelos, an area of extreme air and water pollution. The scarcity of water in northeastern México has resulted in this river being considered the only remaining water source for Monterrey. However, Nuevo León is required by law to let some water flow to Tamaulipas for agriculture. The Río Pesquería (Fig. 3) is scheduled to carry all residual water from Monterrey, treated and upgraded to meet agricultural standards. Industry will be obliged to treat water carrying pollutants not eliminated by common sewage treatment to meet standards of the World Health Organization, the U.S. Environmental Protection Agency, or the Secretaría de Desarrollo Social, whichever is more stringent. This water will be given to Tamaulipas.

The Río San Juan proper is the other large river in the basin. This stream will be captured in the new Reservoir El Cuchillo, just upstream of China and before the junction with Río Pesquería, then transferred to a treatment plant and provided to metropolitan Monterrey. There are no known plans to treat pluvial waters, however, which simply flow through towns, receiving garbage, oils and greases, pesticides, detergents, heavy metals, and other matter washed from the streets by rains, which are acidic because of the heavy air pollution in the basin. Although there is another strong program to control such air pollution, acid rain remains a problem that will never be completely solved. Besides, no standard treatment facility gets rid of all these contaminants. Also, most nearby areas in the basin are farmed for crops or cattle, providing their share of pollutants. Consideration should be given to the residual mud accumulated on river and reservoir bottoms over many years of irrational use of pesticides and other chemicals in the basin. A basin-wide restoration plan is needed.

In summary, both the quantity and quality of water in northern México are declining, at a time when the human population is exploding. The population grew from 5.5 to 8.3 million people (53% increase) in the border region between 1980 and 1990 (SEDUE/EPA 1992). Monterrey is expected to more than double in population from 1.9 million in 1980, to a projected 4.0 million by 2000, and to 5.1 million by 2010 (SDU 1986).

Biodiversity: The Fish Fauna of Northern Mexico and Its Endangered and Threatened Species

Biodiversity has not been part of recent considerations for development along the Méxican-U.S. border area (SEDUE/EPA 1992; Eaton & Hurlburt 1992; Schmandt & Mu 1992). Yet México has a continental fish fauna of around 500 species (Miller 1986; Contreras & Almada 1991), 30 of them undescribed forms. The arid and semiarid areas of México are inhabited by approximately 200 fish species; 170 are taxonomically but not ecologically well known, and 18 of the undescribed forms are new discoveries currently being described. The most recent such discoveries are in the following states: Nuevo León, 4 species in 1984 and 2 in 1988; Durango, 2 species in 1988; Coahuila, 2 species in 1990; Chihuahua, 1 species in 1990. Such biodiversity has been neglected by most recent reviewers (Flores & Jeréz 1988, 1989; McNeely et al. 1990), and only Ramamoorthy et al. (1993) deal with fish as an element of biodiversity. None of them refers to the rapid recent increase in fish discoveries.

At least 22 of 29 species we have specifically studied require water that is clean, fresh, highly oxygenated and running, and sand, gravel, or rubble bottom with little or no muddy layer—conditions that are being rapidly lost (Contreras 1975; 1978). When environmental conditions are not adequate because of anthropogenic impact, species disappear locally, and at extremes live in danger of extinction.

This situation was first reported in the 1960s (Miller 1961, 1963; Contreras 1969), when only four species were reported as recent extinctions and 36 species were clearly in danger. The American Fisheries Society's lists of endangered and threatened fish species in North America indicated 67 species for México in 1979 (Deacon et al. 1979); one decade later, this had risen to 123 species (Williams et al. 1989), representing an increase of 83% in 10 years. Extracting Mexican data from tables in Williams et al. (1989), six species were removed because they were found invalid, none of the listed species became extinct, one was upgraded, and five were degraded, so 63 are new threats or new forms already in danger. The number now exceeds 135 (Contreras et al. 1991).

At the beginning of 1989, 11 fish species had gone extinct in nature in northern México (Miller et al. 1989), and four more have done so since (unpublished data). The account of Miller et al. alone represents 47.8% of the 23 extinct fish species reported worldwide by McNeely et al. (1990). We have no world data with which to compare these increased extinction rates witnessed by us since 1989. Locally, one of the most degraded areas of México is Parras, where drying of the springs and species introductions have resulted in the loss of the entire native fish community, including five endemic species and two local populations (Contreras & Maeda 1985).

Fish communities have been monitored in the aforementioned Mexican states since 1963 at localities known from the literature since 1901–1903 (Meek 1902, 1904). By 1975, 27 localities had lost an average of 43.9% of their fish communities, with most of those remaining also showing losses of individuals (Contreras et al. 1976; Contreras 1991*a*, 1991*b*). The changes are complex and have not been quantitatively analyzed, although interpretive work continues (Contreras & Lozano 1991). A partial updating for some of those localities to 1982–1985 showed a local loss of about 68% of species (Pérez et al. 1987; Contreras, unpublished data).

Regional Planning and Basin Management

The critical resource in arid and semiarid regions is by definition water. Every action and pollutant release into the environment in any region may become an impact and may be transported downriver to faraway places (Contreras 1975). This includes surface and underground waters, which form a manageable natural unit. Development should be measured against water availability in both quantity and quality (including recirculation, recycling, recharge) on the one hand, and all uses, releases, and losses on the other. Minimum information necessary to measure sustainable availability includes trends in salinity, phreatic water level and river flows, and lowest average recharge. Strong consideration should be given to the fact that polluting water with toxic materials may damage people and biota directly, and that the indirect effects of releasing common salt and other corrosives (such as acids and alkalies) increases the costs and difficulties of treatment or use, be it domestic, agricultural, or industrial, or for biodiversity or total environmental protection.

México needs an integral and rational ecosystem-wide basin management plan for sustainable development, as has been carried out in some other countries for a long time (Cooper 1969; Contreras 1990*a*; Sadler 1990). This management must rest upon a highly professional environmental impact evaluation system (Contreras 1975, 1980; Medina & Sánchez 1977). Quality control will require biologically based monitoring. If water quality is adequate to support varied and higher life forms, it will generally support human populations as well.

Critical Limits to Development in the Area

During the past few years, many maquiladoras (industries developed by foreign investors due to lower labor costs in México and elsewhere) have opened in México; in the near future they are expected to increase by as many as 3,000–4,000, according to government sources, because of the North American Free Trade Agreement. This will result in increased human populations in an already heavily populated area with inadequate public services and a low-quality, declining water supply. It seems unlikely that the region can withstand such development, unless it is carefully regulated.

Water in the southwestern United States and northern México simply must be managed on the basis of sustainable yield over the long term, without sacrificing quality and biodiversity. If water management were based on a simple average runoff and recharge relative to use, the area would now be in crisis 50% of the time. If use management is based upon the highest anticipated runoff and recharge rather than the average, a permanent crisis will exist, with unstabilized equilibrium and no reserve for emergencies such as a protracted drought. If sustainable yields are established and adhered to, expansion of development will depend upon rational and proactive conservation and recycling of resources, including water. Proper waste management, both in quantity and quality, are essential, both for surface and groundwater supplies. Untreated sewage or other undesirable discharges cannot be allowed into either surface runoff or groundwater recharge, because, ultimately, people downflow will need the water in a form that is satisfactory in both quantity and quality. All these requirements are part of the quality of life (Contreras 1990*b*).

It cannot be overemphasized that there is a strong need for monitoring and enforcement of water and air quality and garbage disposal. There is also a need for treatment plans for of municipal pluvial discharges, restoration and management plans for the Rio Grande/Rio Bravo basin, and integral ecological monitoring—including inventories of flora and fauna—and status evaluations. This will assure that water quality and quantity are adequate for perpetuation of humans and other life forms within the basin. Due to its complexity, human importance, and size, this case may become a world example if well planned and properly implemented.

This holistic environmental position is even more important now that México faces large development expectations through the Free Trade Agreement, the Border Integral Environmental Plan, and expansion of the maquiladora industry. These will all modernize and internationalize the northern Mexican border but will conflict with the high priority recently given by the Mexican federal government to species conservation.

Conclusions and Recommendations

Under the described scenario, and applying broad ecological and environmental principles, one may reasonably conclude that the availability of adequate water supplies in terms of quantity and quality is the most critical factor limiting human development as we approach the twenty-first century, and not necessarily only for arid and semiarid areas. Population growth must not be allowed to exceed water supply on a long-term basis. Long-range water management policy must include waste disposal, conservation, treatment, recycling, artificial recharge of aquifers, and environmental integrity measured by biodiversity. Biological inventories must be conducted, and the long-term safety and integrity of all life forms must be assumed in any thoughtful water management plan or policy. The result would be conservation of the human environment in its widest dimensions. Conservation of biodiversity will likewise conserve human quality of life.

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Literature Cited

Brune, G. 1975. Major and historical springs of Texas. Texas Water Development Board Report, Austin, Texas.

Brune, G. 1981. Springs of Texas. Vol. I. Branch-Smith, Forth Worth, Texas.

Contreras-Balderas, S. 1969. Perspectivas de la Ictiofauna en las Zonas Aridas del Norte de México. Memorias del Primer Simposio sobre el Aumento de la Producción de Alimentos en Zonas Aridas. International Center for Arid and Semiarid Land Studies, Texas Technological Publications **3**:293–304.

Contreras-Balderas, S. 1975. Impacto ambiental de Obras Hidráulicas. Informe Plan Nacional Hidráulico. Secretaría de Recursos Hidráulicos, México; also, 1985, 2da. ed., Ediciones Imprenta Escolar, FCB/UANL, Monterrey, Mexico, and 1992, 3a. ed.ición, with additional readings, Instituto Tecnológico y de Estudios Superiores de Monterrey, Nuevo León, México.

Contreras-Balderas, S. 1978. Speciation aspects and man-made community composition changes in Chihuahuan desert fishes. Transactions of the First Symposium on the Biological Resources of the Chihuahuan Desert Region, United States Mexico **3**:405–431.

Contreras-Balderas, S. 1980. Interacción ecologia—decisión: Nuevos conceptos. Boletín informativo. Centro de Investigaciones Biológicas, Universidad Autónoma de Nuevo León, Monterrey **II(5)**:4–7.

Contreras-Balderas, S. 1990*a*. Impacto ambiental y manejo de Cuencas en la planificación. Foro Ciudades Industriales y Medio Ambiente (Mimeographed), Monterrey, México.

Contreras-Balderas, S. 1990*b*. La Calidad de Vida. Foro Ciudades Industriales y Medio Ambiente (Mimeographed), Monterrey, México.

Contreras-Balderas, S. 1991*a*. Testimony on public hearings of the integrated environmental border plan. Environmental Protection Agency, Laredo, Texas, and Secretaría de Desarrollo Urbano y Ecología, Nuevo Laredo, Mexico.

Contreras-Balderas, S. 1991*b*. Los peces de la Región Tarahumara Chihuahua/Durango y su uso como indicadores de impacto ambiental. Informe al Centro de Ecología Universidad Nacional Autónoma de México, Mexico City, Mexico.

Contreras-Balderas, S., and P. Almada-Villela. 1991. Fish biodiversity, water availability and regional planning (abstract). 1991 Annual Meeting of the American Society of Ichthyologists and Herpetologists, New York.

Contreras-Balderas, S., and M. L. Lozano-Vilano. 1991. Estado actual de los peces y el agua en el Noreste de México. First Binational Meeting on the Environment, Ciudad Acuña, Coahuila, Mexico.

Contreras-Balderas, S., and M. L. Lozano-Vilano. 1994. New Mexican cyprinid fish *Cyprinella alvarezdelvillari* sp. nv., from Rio Nazas Basin. Copeia, in press.

Contreras-Balderas, S., and A. Maeda. 1985. Estado actual de la ictiofauna nativa de la Cuenca de Parras, Coah., México, con notas sobre algunos invertebrados. Octavo Congreso Nacional de Zoología, Memorias **I**:59–67.

Contreras-B., S., V. Landa, T. Villegas, and G. Rodriguez. 1976. Peces, piscicultura, presas, polución, planificación pesquera y monitoreo en México. Danza de las P. Memorias del Simposio sobre Pesquerías en Aguas Continentales (México) **I**:315–346.

Contreras-Balderas, S., P. Almada-Villela, and D. A. Hendrickson. 1991. Peces amenazados de agua dulce de México (Threatened freshwater fishes of México). Abstract. XI Congreso Nacional de Zoología, Mérida, México.

Cooper, Ch. F. 1969. Ecosistem models in watershed management. Pages 309–324 in G. M. Van Dyne. The ecosystem concept in natural resource management, Academic Press, New York.

Deacon, J. E., G. Kobetich, J. Williams, S. Contreras, et al. 1979. Fishes of North America: Endangered, threatened or of special concern: 1979. Fisheries (Bulletin of American Fisheries Society) **4(2)**:29–44.

Eaton, D. J., and D. Hurlbut. 1992. Challenges in the binational management of water resources in the Rio Grande/Rio Bravo. Pages 1–138 in Policy report 2. U.S.–Mexican Policy Studies Program, University of Texas at Austin.

Edwards, R. E., and S. Contreras-B. 1991. Historical changes in the ichthyofauna of the Lower Rio Grande (Río Bravo del Norte), Texas and México. Southwestern Naturalist **36(2)**: 201–212.

Flores, R. 1990. Hidrogeología de la Comarca Lagunera. Ciclo de Conferencias, Universidad Juárez del Estado de Durango. Gómez Palacio, Durango, México.

Flores-Villela, O., and P. Jerez. 1988. Conservación en México: Síntesis sobre vertebrados terrestres, vegetación y uso del suelo. Instituto Nacional de Investigaciones en Recursos Bióticos/Conservación Internacional, Mexico City, Mexico.

Flores-Villela, O., and P. Jerez. 1989. Mexico's living endowment: An overview of biological diversity. Conservation International & Instituto Nacional de Investigaciones en Recursos Bióticos, Mexico City, Mexico.

INEGI (Instituto Nacional de Estadística, Geografía e Informática). 1981. Síntesis geográfica del estado de Nuevo León. Editorial INEGI, Memoria. Mexico City, Mexico.

INEGI. 1981. Síntesis geográfica del Estado de Zacatecas. Editorial INEGI, Memoria. Mexico City, Mexico.

INEGI. 1983. Síntesis geográfica del Estado de Coahuila. Editorial INEGI, Memoria. Mexico City, Mexico.

INEGI. 1983. Síntesis geográfica del Estado de Tamaulipas. Editorial INEGI, Memoria. Mexico City, Mexico.

INEGI. 1984. Síntesis geográfica del Estado de Baja California (Norte). Editorial INEGI. Mexico City, Mexico.

Maeda, L. 1990. Impacto ambiental regional y la salud en la comarca lagunera. Foro Ciudades Industriales y Medio Ambiente (Mimeographed), Monterrey, México.

Maeda, L. 1992. El hidroarsenicismo Crónico regional un estudio descriptivo. Consejo Cívico Asesor del Departamento de Ecología Municipal, Torreón, México.

McNeely, J. A., et al. 1990. Conserving the world's biological diversity. International Union for the Conservation of Nature, Gland, Switzerland. World Resources Institute, Conservation International, World Wildlife Fund–U.S., World Bank, Washington, D.C.

Medina, J. A., and R. Sánchez. 1977. Impacto ambiental de obras hidráulicas. Plan Nacional Hidráulico, Informes **17**:1–70.

Meek, S. E. 1902. A contribution to the ichthyology of Mexico. Field Columbian Museum Publications 65, Zoological Series **III(6)**:63–121.

Meek, S. E. 1904. The freshwater fishes of Mexico, north of the Isthmus of Tehuantepec. Field Columbian Museum Publications 93, Zoological Series **V**:i–lxiii, 1–252.

Miller, R. R. 1961. Man and the changing fish fauna of the American Southwest. Papers of the Michigan Academy of Sciences **46(1960)**:365–404.

Miller, R. R. 1963. Extinct, rare and endangered American freshwater fishes, XVI International Congress of Zoology **8**:4–11.

Miller, R. R. 1986. Composition and derivation of the freshwater fish fauna of Mexico. Anales de la Escuela Nacional de Ciencias Biològicas, México **30**:121–153.

Miller, R. R., J. D. Williams, and J. E. Williams. 1989. Extinctions of North American fishes during the past century. Fisheries **14(6)**:22–38.

NAFTA. 1992. North American Free Trade Agreement. U.S. Government, Washington, D.C.

PNH (Plan Nacional Hidráulico). 1975. Map of hydraulic resources in North Central México. Dirección General del Plan Nacional Hidráulico. Secretaria de Recursos Hidráulicos, México.

Pérez-Bernal, R., S. Contreras-Balderas, and M. L. Lozano-Vilano. 1987. Cambios de composición de especies de peces en comunidades del Este de México, desde 1903, o La Danza de las P, Revisada. Abstract. Annual Meeting of the Desert Fishes Council, Monterrey, Nuevo León, Mexico.

Ramamoorthy, T. P., R. Bye, A. Lot. 1993. Biological diversity of México: Origins and Distribution. Oxford University Press, New York.

SEDUE/EPA (Secretaría de Desarrollo Urbano/Environmental Protection Agency). 1992. Integrated Environmental Border Plan, Cooperative Plan SEDUE/EPA, Mexico City, Mexico.

SDU (Secretaría de Desarrollo Urbano). 1986. Plan director del desarrollo urbano del area metropolitana de Monterrey. Gobierno del Estado de Nuevo León, Secretaría de Desarrollo Urbano, Monterrey, Mexico.

Sadler, B. 1990. Sustainable development and water resource management. Alternatives **17(3)**:14–19, 21–24.

Schmandt, J., and Xing Ming Mu. 1992. Water and development in the lower Rio Grande Valley. LBJ School of Public Affairs, University of Texas, Austin, Texas.

Tamayo, J. L., and R. C. West. 1964. The hydrography of Middle America. Chapter 3 in Wauchope and West. Handbook of Middle American Indians. Vol. 2. Natural environment and early cultures. University of Texas Press, Austin, Texas.

Williams, J. E., J. E. Johnson, D. A. Hendrickson, S. Contreras-Balderas, J. D. Williams, M. Navarro-Mendoza, D. E. McAllister, and J. E. Deacon. 1989. Fishes of North America: Endangered, threatened or of special concern: 1989. Fisheries **14(6)**:2–21.