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Article · January 1998
DOI: 10.1080/14634989808656925

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Aquatic Ecosystem Health & Management

ISSN: 1463-4988 (Print) 1539-4077 (Online) Journal homepage: http://www.tandfonline.com/loi/uaem20

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To cite this article: J. Alcocer & U.T. Hammer (1998) Saline lake ecosystems of Mexico, Aquatic Ecosystem Health & Management, 1:3-4, 291-315

To link to this article: http://dx.doi.org/10.1080/14634989808656925

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Aquatic Ecosystem Health and Management 1 (1998) 291–315

Aquatic Ecosystem Health & Management

Saline lake ecosystems of Mexico

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Abstract

This paper aims to draw attention to the need to better know and understand Mexican saline lakes. It does this by outlining their distribution, abundance and location and their physical, chemical and biological characteristics. The influence of climatic factors on saline lakes is discussed. To sharpen the focus of the general discussion, a few Mexican saline lakes are discussed in more detail in each of the indicated topics. Saline lakes are found throughout Mexico, with the greatest number in the northwest and the least in the southeast, and from sea level to altitudes above 2000 m. Mexican saline lakes widely fluctuate morphometrically. The majority are tiny, shallow, and temporal with small volumes. Some are large or deep, and perennial with large volumes. Polymixis is common in shallow lakes while deeper ones are monomictic. Temperature and dissolved oxygen fluctuate widely. Alkaline waters are frequent. Mirroring high primary productivity rates, water is often green and turbid but other colors (blue, sepia, purple, yellow) and clear water are also found. Most lakes are sodium chloride or alkali carbonate types. Salts resulting from the combination of sodium with chloride, carbonates and sulfates are common and, to a lesser extent, salts of calcium, potassium, magnesium, lithium and boron are present. Species richness in Mexican saline lakes decreases as salinity rises. Hyposaline lakes display a more diverse biota than hypersaline ones. Organisms commonly found in Mexican saline lakes are: blue-green algae (e.g., *Spirulina geitleri, Phormidium tenue*), rotifers (*Brachionus* spp.), anostracans (*Artemia* spp.), copepods (e.g., *Diaptomus, Leptodiaptomus*), corixid bugs (e.g., *Corisella, Krizousacorixa, Trichocorixella*), ephydrids (e.g., *Ephydra hians*), the neotenic salamander (e.g., *Ambystoma* spp.), atherinids (e.g., *Chirostoma* spp.), goodeids (e.g., *Goodea* spp.), cyprinodontids (e.g., *Cyprinodon* spp.), poecilids (e.g., *Gambusia* spp.), and the Caribbean pink flamingo (*Phoenicopterus ruber ruber*).

Keywords: Athalassohaline; Plankton; Nekton; Benthos; Macrophytes; Vertebrates

1. Introduction

Saline lakes are not rare phenomena in Mexico, yet we associate inland lakes, ponds and groundwater with freshwater resources. To distinguish salt from freshwater, Williams (1964) proposed $3\ g\ l^{-1}$, a limit widely recognized among saline inland water limnologists. In spite of their abundance, distribution and importance (see Alcocer and Williams, 1993), Mexican saline lakes, with only a few notable exceptions (i.e., Texcoco, Alcocer and Williams, 1996), have not attracted much attention from limnologists, and few are the subject of active research (e.g., Alchichica crater-lake). There is little doubt that this reflects the general lack of attention accorded salt lakes by limnologists, itself a reflection of the fact that salt lakes are often located far from where limnologists live (except for some such as Cuitzeo and Texcoco, as mentioned by Alcocer and Williams, 1993).

Worldwide, inland salt water is not markedly less in volume than freshwater (Shiklomanov, 1990),

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PII: S1463-4988(98)00011-6

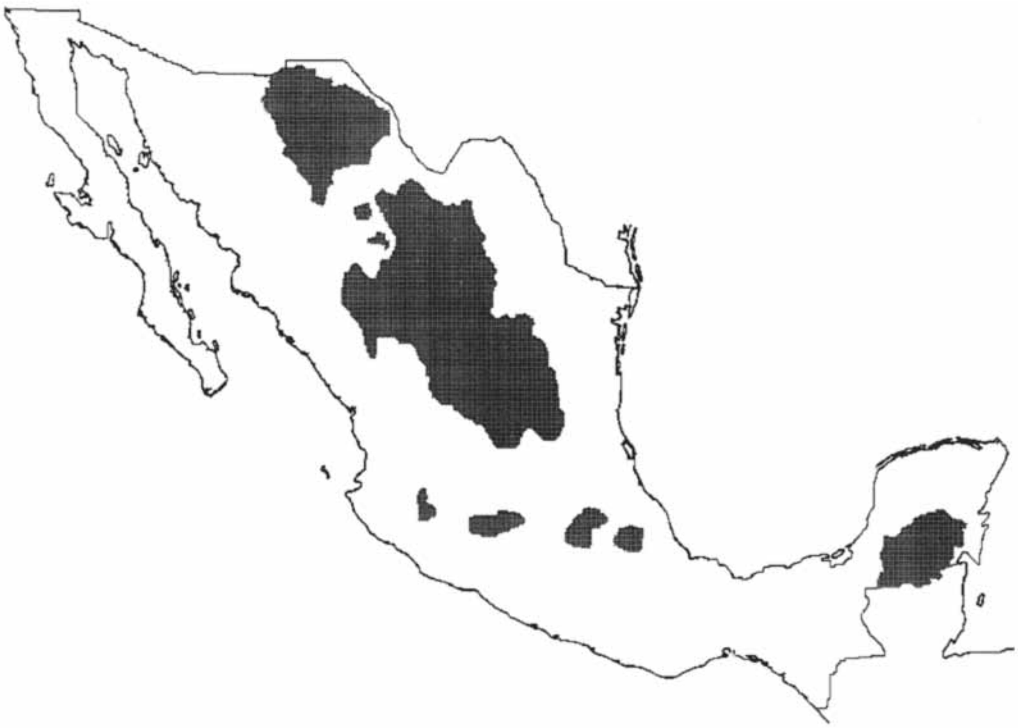

Fig. 1. Location of the major endorheic basins in Mexico where most inland saline lakes are found.

0.006% of global water as compared with 0.007%, respectively. Although there is no information available, it could be expected that the same proportion would be true for Mexican salt versus freshwater since four of the eight (2nd, 5th, 6th, 8th) largest Mexican lakes are saline. In spite of this fact, Mexican Government statistics [INEGI (Instituto Nacional de Estadística), 1995] regarding surface water availability consider just two water types: fresh and brackish (coastal lagoons and estuaries).

Saline lakes are commonly found in endorheic basins of semi-arid regions, mostly in wide belts located between 20° and 40° latitude in both hemispheres. Almost 65% of Mexico (central and northern portions) fits within this range. Drainageless basins of this kind cover extensive areas of Mexico (Fig. 1) including the states of Baja California Norte and Sur, Coahuila, Chihuahua, Durango, Nuevo León, San Luis Potosí, Sonora and Zacatecas. These ecosystems, which originated in the Cenozoic, cover an area of about 1,050,000 km^2 (Ezcurra and Montaña, 1990).

There are two types of saline lakes, coastal and inland. Mexico has both types (Table 1, Fig. 2). Nonetheless, there is no information available from the states of Aguascalientes, Distrito Federal, Hidalgo, Morelos, Nuevo León, Queretaro and Tlaxcala regarding the presence of saline lakes. This derives more from a lack of investigations than from a true saline lake deficiency. For instance, Totolcingo Lake is at the border of the states of Puebla and Tlaxcala. Since the lake serves as the boundary between the states, it could be ascribed to both of them. Although El Carmen town (also named 'Tequixquitla' meaning 'place of tequezquite or soda') where the name of the lake comes from, is in Tlaxcala, but is usually thought of as belonging to Puebla. Another similar case is Texcoco at the boundary of Mexico and the Distrito Federal.

1.1. Coastal saline lakes

Saline lakes have no direct communication with the sea. Solar evaporation ponds or salinas along the coasts, where salt is precipitated by seawater

Table 1
Location of the major Mexican saline lakes and their reported main water type or lacustrine evaporites. Data compiled from Alcocer and Williams (1993), Alcocer and Williams (1996), Alcocer et al. (1997), Ewald (1985), González (1956), Orozco and Madinaveitia (1941), Páez (1995), Valero (1985), UNAM (Universidad Nacional Autónoma de México) (1966, 1968), Vilaclara et al. (1993). [(ST = State, I = Inland, C = Coastal). (BCN = Baja California Norte, BCS = Baja California Sur, CAMP = Campeche, CHIH = Chihuahua, CHIS = Chiapas, COAH = Coahuila, COL = Colima, DGO = Durango, GRO = Guerrero, GTO = Guanajuato, JAL = Jalisco, MEX = México, MICH = Michoacán, NAY = Nayarit, OAX = Oaxaca, PUE = Puebla, QROO = Quintana Roo, SIN = Sinaloa, SLP = San Luis Potosí, SON = Sonora, TAB = Tabasco, TAMS = Tamaulipas, VER = Veracruz, YUC = Yucatán, ZAC = Zacatecas)]. Localities named as 'salinas' represent more a 'saline lake district' than a single water body. Such is the case of the Salinas de Santa María in Zacatecas, integrated by the lakes Santa María, Saldivar, La Colorada, Santa Clara, La Doncella, Los Prietos, San José and more than forty-five small saline ponds

ST	Lake, pond, salina, river or locality	Main water type or lacustrine evaporites	
COAH	Bahía de Ometepec	NaCl	C
	Ensenada	NaCl	C
	Laguna de los Volcanes	NaCl	I
	Laguna Salada	NaCl	I
	Meneadero	NaCl	C
	Mexicali	NaCl	I
	San Quintín	NaCl	C
BCS	Comondú	NaCl	I
	Guerrero Negro	NaCl	C
	Isla del Carmen	NaCl	C
	La Paz	NaCl	C
	Morro Hermoso	NaCl	C
	Ojo de Liebre	NaCl	C
CAMP	Champotón	NaCl	C
	Isla del Carmen	NaCl	C
	Salinas Real	NaCl	C
CHIH	Cuchillo Parado	NaCl	I
	La Ascención	NaCl	I
	Laguna Charco Salado	NaCl	I
	Laguna de Jaco	NaCl, Na_2SO_4, $CaSO_4$	I
	Laguna Naranja	NaCl	I
	Laguna de Palomas	NaCl, $CaSO_4$, $CaCO_3$	I
	Laguna de Patos	NaCl	I
	Laguna de la Vieja	NaCl	I
	Laguna de San Blás	NaCl	I
	Laguna de Bavícora	NaCl	I
	Laguna el Gigante	Na_2CO_3, Na_2SO_4, $CaCO_3$	I
	Laguna las Arenosas	Na_2CO_3, Na_2SO_4, $CaCO_3$	I
	Laguna las Pampas	$CaCO_3$, $CaSO_4$, $MgCO_3$	I
	Laguna Salada	NaCl	I
	Lucero	$CaCO_3$, NaCl	I
	Ojinaga	NaCl, $NaNO_3$, KNO_3	I
	Santa María	NaCl	I
	Trinidad	NaCl	I
	Villa Ahumada	NaCl	I
CHIS	Cuxtepec	NaCl	I
	Ixtapa	NaCl	I
	Lagunas Guayatungo-Huamuchil	NaCl	C
	Tapachula	NaCl	C
	Tonalá	NaCl	I
	Zinacatán	NaCl	I
COAH	Castañas	NaCl	I

Table 1 (*continued*)

ST	Lake, pond, salina, river or locality	Main water type or lacustrine evaporites	
COAH	Hundido	$MgSO_4$, $MgCl_2$, $CaSO_4$	I
	Laguna el Coyote	$CaSO_4$, Na_2SO4, $CaCO_3$, NaCl	I
	La Laguneta	NaCl	I
	Laguna la Leche	Na_2CO_3, Na_2SO_4, $CaCO_3$	I
	Laguna el Yeso	$CaSO_4$, NaCl	I
	Laguna de Mayrán	NaCl	I
	Laguna del Rey	$CaSO4$, NaCl, Na_2SO_4	I
	Laguna de Viesca	NaCl, Na_2SO_4, $NaNO_3$, KNO_3	I
	Parras	NaCl	I
	Sierra Mojada	NaCl	I
COL	Colima	KNO_3	I
	Cuyutlán	NaCl	C
	Manzanillo	NaCl	C
	Real y Tecomán	NaCl	C
DGO	Bolsón de Mapimí	NaCl	I
	Las Liebres	Na_2CO_3, Na_2SO_4, $CaCO_3$	I
	Mezquital	NaCl	I
	Puerto Rico	$CaCO_3$, $CaSO_4$, $MgCO_3$	I
GRO	Alahuistlán	NaCl	I
	Cascalán	NaCl	C
	Copala	NaCl	C
	Chutla	NaCl	C
	Ixcateopan	NaCl	I
	Potosí-Timban	NaCl	C
	Salado	NaCl	I
	Salinas	NaCl	C
	Salina Real	NaCl	C
	San Marcos	NaCl	C
	Santo Domingo	NaCl	C
GTO	Dolores Hidalgo	NaCl	I
	Lago La Alberca	Na_2CO_3, NaCl, Na_2SO_4	I
	Lago Rincón de Parangueo	Na_2CO_3, NaCl	I
	San Miguel Allende	NaCl	I
JAL	Ameca	NaCl	I
	Atoyac	NaCl	I
	La Huerta	NaCl	C
	Laguna de Sayula	Na_2CO_3, NaCl, Na_2SO_4, KCl	I
	Techaluta	NaCl	I
	Tomatlán	NaCl	C
MEX	Cuautitlán	Na_2CO_3, NaCl	I
	Ixtapa	NaCl	I
	Ixtapan de la Sal	NaCl	I
	Ixtapan del Oro	NaCl	I
	Lago de Texcoco	Na_2CO_3, NaCl	I
	Lago de Xaltocan	Na_2CO_3, NaCl	I
	Lago de Zumpango	Na_2CO_3, NaCl	I
	Temascalcingo	NaCl	I
	Tonatico	NaCl	I
MICH	Arará	NaCl	I
	Costa de Pámaro	NaCl	C
	Lago de Cuitzeo	Na_2CO_3, NaCl, Na_2SO_4, KCl	I

Table 1 (*continued*)

ST	Lake, pond, salina, river or locality	Main water type or lacustrine evaporites	
MICH	Tiquicheo	NaCl	I
NAY	Isla Madre	NaCl	C
	Ixtapa	NaCl	C
	Lago Isabela	NaCl	I
	Punta Raza	NaCl	C
	Tecuala	NaCl	C
OAX	Astata	NaCl	C
	Chipehua	NaCl	C
	Huamelula	NaCl	C
	Huatulco	NaCl	C
	Nanche Salinas	NaCl	C
	Piedra Blanca	NaCl	C
	Pinotepa	NaCl	C
	Salina Cruz	NaCl	C
	Salinas del Mar Muerto	NaCl	C
	Salinas de Tututepec	NaCl	C
	Salinas del Zapotal	NaCl	C
	San Dionicio del Mar	NaCl	C
	San Ildefonso	NaCl	I
	San Pedro	NaCl	
	Santa María Xadoní	NaCl	C
	Silacayupan	NaCl	I
	Tehuantepec	NaCl	I
	Teotitlán del Camino	NaCl	I
	Teposcolula	NaCl	I
	Tlacolula	NaCl	I
	Tlaxiaco	NaCl	I
	Tezoatlán	NaCl	I
	Vieja	NaCl	C
PUE	Acatlán	NaCl	I
	Chiautla de la Sal	NaCl	I
	Chila de la Sal	NaCl	I
	Lago de Alchichica	NaCl, Na_2CO_3	I
	Lago de Atexcac	NaCl, Na_2CO_3	I
	Laguna El Carmen	Na_2CO_3, NaCl, Na_2SO_4, KCl	I
	Laguna El Salado	Na_2CO_3, NaCl, Na_2SO_4, KCl	I
	Laguna Tecuitlapa Sur	Na_2CO_3	I
	Piaxtla	NaCl	I
	Río Salado	NaCl, $CaCO_3$	I
	Salinas de Ajuchitlán	NaCl	I
	Salinas de San Antonio Texcala	NaCl	I
	Salinas de Zapotitlán	NaCl	I
	Tehuacán	NaCl	I
QROO	Isla Mujeres	NaCl	C
	Laguna de Chichancanab	$CaSO_4$, NaCl	I
SIN	Alhome	NaCl	C
	Altata	NaCl	C
	Carobobi	NaCl	C
	Ceuta	NaCl	C
	Elota	NaCl	C

Table 1 (*continued*)

ST	Lake, pond, salina, river or locality	Main water type or lacustrine evaporites	
SIN	Guasabe	NaCl	C
	Higueras	NaCl	C
	Huizache	NaCl	C
	Rosario-Chametla	NaCl	C
	San Pablo	NaCl	C
	Yaquirahuato-Altamira	NaCl	C
SLP	Moctezuma	NaCl	I
	Peñón Blanco-Salinas	NaCl	I
	Ramos	NaCl	I
	Santa María	NaCl	I
	Tapado	NaCl	I
SON	Agiabampo	NaCl	C
	Arizpe	NaCl	I
	Bahía de Adair	NaCl	C
	Caborca	NaCl	I
	El Pinacate	NaCl	C
	Guaymas	NaCl	C
	Huatabampo	NaCl	C
TAB	Ixtapangajoya	NaCl	I
TAMS	Aldama	NaCl	C
	Altamira	NaCl	C
	Laguna Madre	NaCl	C
	La Purificación	NaCl	C
	Matamoros	NaCl	C
	Pánuco	NaCl	C
	San Fernando	NaCl	C
	Soto la Marina	NaCl	C
	Tampico	NaCl	C
	Tula	NaCl	I
VER	Coatzacoalcos	NaCl	C
	Jaltipan	NaCl	I
	Laguna de Tamiagua	NaCl	C
	Minatitlán	NaCl	I
YUC	Acanceh	NaCl	I
	Celestún	NaCl	C
	Dzidzantún	NaCl	I
	Dzmul	NaCl	C
	Progreso	NaCl	C
	Río Lagartos	NaCl	C
	Sinanché	NaCl	I
	Tizimín	NaCl	I
ZAC	Laguna de Fresnillo	NaCl	I
	Salinas de Santa María	NaCl	I
	Santa Rita	NaCl	I
	Villa de Cos	NaCl	I

evaporation, are artificial saline lakes. Regarding the coastal salinas of Mexico, Ewald (1985) stated that the Pacific coast is more propitious for building up salinas than the Gulf of Mexico coast and certainly coastal saline lakes are more numerous along the Pacific coast than on the Gulf. The physical geography of the Mexican west coast allows people to obtain rather pure sodium chloride at many places. Humidity and precipitation are higher in the east than on the west coast of Mexico. Further, the topography

Fig. 2. The distribution of inland and coastal Mexican saline lakes, indicated by black dots.

and hydrography of the Gulf coast do not favor salt making.

The most important salinas on the Pacific coast are those from the Gulf of Tehuantepec in Oaxaca, Laguna de Cuyutlán in Colima, and the north of Sinaloa and Sonora where geographic and hydrographic conditions favor salinas construction. Jalisco, Nayarit and the southern part of Sinaloa have many salinas but these are not as extensive as those to the north. Climatic and morphological factors favor salinas formation on the eastern coast of Baja California, such as those in the Isla del Carmen and Bahía de Ometepec. On the northwestern coast of Baja California there are some large salinas such as in the Bahía de San Quintín, and the huge salinas of Guerrero Negro where the largest Mexican solar plant is placed. Salinas in Chiapas, Guerrero and Michoacán are unimportant.

Laguna Madre, on the Gulf of Mexico, provides an immense coastline for salinas development. Veracruz, Tabasco and Campeche have limited salinas. Finally, since pre-Colombian times, the Península de Yucatán with its excellent potential for saltmaking has been the most famous salt producer of Mesoamerica. The salinas of the Yucatán Península begin north of Campeche near Celestún, and follow the shore as far as east of El Cuyo on Río Lagartos. On the east coast of the Península, there are only small salinas such as those on Cozumel or Isla Mujeres.

1.2. Inland saline lakes

Although saline lakes are found throughout Mexico, there is a general pattern in their abundance and distribution. Precipitation decreases from the southeast ($\geq$ 1,800 mm yr^{-1}) to the north and northwest (90 to 150 mm yr^{-1}) (Bassols, 1977; Sánchez et al., 1989), and saline lake abundance relates inversely to precipitation abundance, being more numerous in the north-northwest. Saline lakes range from Baja California Norte (e.g., Laguna Salada and Laguna de los Volcanes) in the northwest to Chiapas (Ixtapa and Zinacantán) and Quintana Roo (e.g., Laguna de Chichancanab) in the south and southeast respectively.

There is a general distribution and abundance pattern for Mexican saline lakes, decreasing in number from the north-northwest to the south-southeast associated with geomorphological features as well as with climate.

Most of Mexico (north and central areas) lies in the arid and semi-arid climate belt so that more than 50% of Mexico is arid or semi-arid. The association of endorheic basins and a semi-dry climate over more than a half of the Mexican territory (north and central Mexico), favor the existence of many saline lakes. A more humid climate inhibits the occurrence of saline lakes in the southern and southeastern areas. This pattern is clear in Table 1.

Baja California and the northwestern part of Sonora display the lowest annual precipitation making the formation of saline lakes difficult. The Sierras and plains of the north of the Mexican Plateau which include the states of Chihuahua and Coahuila, and the northern parts of Zacatecas, Durango and San Luis Potosí is a vast region delimited by the Sierra Madre Oriental and Occidental displaying several endorheic basins and dry or semi-dry climate. This area, covered by the Thethis Sea in the past, held abundant and large lakes. Nowadays there are only large, shallow, mostly ephemeral saline playa-lakes left. This is in this area where the greatest concentration of saline playa-lakes is found (Ewald, 1985). Among the largest lagunas in this zone (Chihuahua–Coahuila–Durango), are Jaco, Las Palomas, Hundido, Del Rey, El Coyote, La Leche, El Gigante, Las Liebres, Las Arenosas, Puerto Rico, and Las Pampas.

The central plateau, in the southern portion of the Mexican Plateau which has a semi-dry temperate climate, includes parts of the states of Durango, Zacatecas, Aguascalientes, Guanajuato and Queretaro. Although there are many endorheic basins in this area, water scarcity prevents the formation of large and abundant saline lakes as seen in the northern portion of the Mexican Plateau. There are several saline lakes in the Trans-Mexican Volcanic Belt (Nayarit, Jalisco, Michoacán, Guanajuato, Mexico, Morelos, Puebla, Tlaxcala). Active tectonism and vulcanism on this huge expanse of high level land have built many endorheic basins. Some better known saline lakes are in this region: Sayula, Cuitzeo, Texcoco and Totolcingo.

South of the Trans-Mexican Volcanic Belt in the states of Guerrero, Oaxaca, Chiapas, Veracruz, Tabasco and Campeche the climate turns more humid so saline lakes become less abundant. In spite of this factor, there are some saline lakes, some of them associated with the Jurassic salt domes of Tehuantepec. The Yucatán Península (Campeche, Yucatán, Quintana Roo), a Tertiary and Quaternary flat limestone plain, has no surface drainage. Most of the few water bodies in the area are fresh. Nonetheless, saline (anchialine) meromictic solution sinkholes (or 'cenotes') are common through the encounter of fresh and seawater traveling underground mainly propelled by tidal movements. A special case is Chichancanab lake that overlies a gypsum deposit.

2. Mexican saline lakes

To date, limnological studies in Mexico have been devoted mainly to freshwater resources (i.e., the largest lakes such as Chapala, Pátzcuaro, Zirahuén, Mexico). Nonetheless, saline Texcoco Lake has received much attention associated with its proximity to Mexico City and the problems this fact represents (for further details see Alcocer and Williams, 1996). A compilation of the evolution of limnological research (fresh and saline) throughout Mexican history is presented by Alcocer-Durand and Escobar-Briones (1991) and Alcocer et al., (1993a).

The following characterization of Mexican saline lakes is restricted to published literature of inland saline water bodies. Hard-to-get 'grey' literature is quoted only when it provides relevant material. Salt-rich seeps, springs and wells exist in abundance throughout the Mexican territory (Ewald et al., 1994); they are mostly associated with mountainous or volcanic areas of the Trans-Mexican Belt southward. Unfortunately, there is almost no information (Table 2) regarding these natural resources due to their small contribution to the local economy. These sources of salts are locally exploited but have not been investigated.

Only a few Mexican saline lakes have been scientifically studied, so the information included in this work pertains for the most part to them. Following is a brief limnological introduction of each.

1. Isabela saline crater-lake is at 21°52'N and 105°54'W on Isabela Island, 32 km away from

the Nayarit coast in the Mexican Pacific. Water surface is approximately 7 m above sea level. The shore is very narrow or absent. *Crataeva tapia* and *Euphorbia schlechtendalii* forest totally covers the internal slope of the crater. Pluvial precipitation feeds the lake but seawater intrusion is clearly another probable source. The climate on the island is between tropical subhumid and semi-dry with a summer rainy season.

2. Cuatro Ciénegas endorheic basin (26°59'N, 102°04'W, 740 m.a.s.l.) comprises a small 1200 km^2 area in central Coahuila. The aquatic habitats of Cuatro Ciénegas range from springs to permanent streams and lakes to ephemeral playa-lakes. Although most of them are freshwater, a few are saline: Laguna Salada, Laguna Grande, other temporal unnamed playas-lakes, and two small, artificial pools north of and connected to Laguna Salada. The floor of the basin lies about 740 m above sea level. Mountains surrounding it rise to more than 3000 m. The climate is arid with an average annual rainfall of less than 200 mm.
3. Cuitzeo lake (19°53' to 20°04'N, 100°09' to 100°50'W, 1820 m.a.s.l.) is a tecto-volcanic lake, at the northeast portion of Michoacán. It could have been formed by volcanic damming of an ancient Lerma river tributary in an intermountain valley. The climate in the area is dry, steppe-like (600 mm y^{-1} precipitation), with a hydric deficit of about 310 mm. The most important rivers are situated on the east and southern parts of the lake. Originally the lake occupied an endorheic basin that was artificially opened on the northern part of the basin to drain into Yuriria lake and then to the Balsas river. Surrounding terrain is lacustrine; saline soils sustain xerophytes and halophytic vegetation. Some places, mostly on the west side, display saline efflorescences containing soda.
4. Valle de Santiago, at the southernmost part of Guanajuato, has a lake district. In this endorheic basin there used to be four crater-lakes: Rincón de Parangueo, San Nicolás, La Alberca and Cíntora. San Nicolás and Cíntora have already dried up, probably due to groundwater extraction (their principal water source). Rincón de Parangueo (20°26'N, 101°14'W, 1705 m.a.s.l.) and La Alberca (20°21'N, 101°12'W, 1716 m.a.s.l.) are saline. The climate is semi-dry (675 mm) with a negative hydric balance. Steppe-like vegetation grows over saline soils.
5. Zumpango, Xaltocan, San Cristobal and Texcoco saline lakes belong to an ancient huge lake-complex that once occupied the central portion of the Mexico basin. The lake complex was formed through the enclosure of the Mexico basin depression by volcanic mountain building in the southern area. Texcoco is at the lowest part of the basin, Zumpango, Xaltocan and San Cristobal at the north, and the freshwater Xochimilco and Chalco are in the southern portion. An artificial cut on the NW portion of the Mexico basin transformed it from an endorheic into an exorheic basin. Texcoco (19 to 20°N, 98 to 99°W, 2240 m.a.s.l.) shrank from 2000 to 70 km^2. Today the local climate is semi-dry with a rainy summer. It has a negative hydric balance (pluvial precipitation of 600 mm y^{-1}, evaporation of 1800 mm y^{-1}). The surrounding terrain is lacustrine; saline soils maintain halophytic vegetation and soda saline efflorescences are common in the landscape. Several rivers and springs, discharging mainly on the east and northeast sides of Texcoco, feed the lake.
6. There once were six saline water bodies on the Oriental basin in the states of Puebla, Tlaxcala and Veracruz. At the lowest portion of the basin, Totolcingo (also El Carmen or Oriental) is a saline playa-lake at the boundary of Puebla and Tlaxcala states (19°09' to 19°26'N, 97°33' to 97°47'W, 2300 m.a.s.l.). Tepeyahualco or El Salado (19°25' to 19°28'N, 97°23' to 97°32'W, 2,310 m.a.s.l.) was also a saline playa-lake northeast of Totolcingo in Puebla. A negative hydric balance characterizes the central portion of the Oriental basin. Lacustrine terrain surrounding both playa-lakes is saline, with xerophytes and saline efflorescences composed mostly of soda. Groundwater and to a lesser extent pluvial precipitation fed both playa-lakes. Groundwater over extraction has negatively influenced the lakes resulting in their drying up. Totolcingo is nowadays an episodically filled lake. Tepeyahualco terrains are today agricultural land (Alcocer et al., 1998a).

   There are six crater-lakes in the Oriental basin. Four of them are in Los Llanos de San Juan at the northern portion of central Puebla, the other

Table 2
2. Location of some Mexican saline (i.e., salinity > 3 g l^{-1}) springs and wells (S/W), indicating salinity as total dissolved solids (TDS, in mg l^{-1}) and water type (major ions). Modified fromUNM (Universidad Nacional de México (1946). (BCN = Baja California Norte, CHIH = Chihuahua, CHIS = Chiapas, COAH = Coahuila, D.F. = Distrito Federal, DGO = Durango, MEX = México, OAX = Oaxaca, PUE = Puebla, TAMS = Tamaulipas)

State	S/W	Name	TDS	Water type
BCN	S	Laguna de los Volcanes	15023	ClNa
MEX	W	Lago de Texcoco	3986	ClNa
OAX	S	Agua Fría	16834	ClNa
	S	Magdalena Etla	17518	ClNa
	S	Magdalena Tetipac	23188	ClNa
PUE	S	Alpontzonga	9213	ClNa
	S	Laguna de Alchichica	7235	ClNa
CHIS	S	El Burrero	10580	$ClSO_4Na$
MEX	S	Ixtapan de la Sal No. 1	5412	$ClSO_4Na$
	S	Ixtapan de la Sal No. 2	5340	$ClSO_4Na$
PUE	S	Salinas de San Antonio No. 1	50784	$ClSO_4Na$
	S	Salinas de San Antonio No. 2	51724	$ClSO_4Na$
	S	Salinas de San Antonio No. 3	52244	$ClSO_4Na$
	S	Salinas de San Antonio No. 4	51240	$ClSO_4Na$
	S	Salinas de San Antonio No. 5	52112	$ClSO_4Na$
	S	Salinas de San Antonio No. 6	51686	$ClSO_4Na$
	S	Salinas de San Antonio No. 7	50566	$ClSO_4Na$
MEX	S	Los Salitres	6559	$ClSO_4Ca$
COAH	S	Agua de Bilbao	266687	SO_4Na
DGO	W	Cartagena	3318	SO_4Na
	W	Cerro Colorado	94568	SO_4Na
PUE	S	Alcaparrosa	11016	SO_4Na
COAH	W	El Oasis	3579	SO_4Ca
CHIH	S	Santa Rosalía	3059	SO_4Ca
COAH	S	La Azufrosa	4256	SO_4CaNa
TAMS	S	Agua de Camargo	3499	SO_4CaNa
CHIH	S	Ojo Caliente	3129	SO_4Mg
PUE	S	Manantial del Tlaltengo No. 1	4260	HCO_3SO_4Ca
	S	Manantial del Tlaltengo No. 2	5388	HCO_3SO_4Ca
D.F.	W	El Horno	3240	CO_3ClNa
	W	Pozo Tláhuac No. 1	5984	CO_3ClNa
	W	Pozo Tláhuac No. 2	5637	CO_3ClNa

two are in Los Llanos de San Andrés, at the south. Los Llanos de San Juan climate is semi-arid (precipitation less than 400 mm y^{-1}) while in Los Llanos de San Andrés precipitation is higher (600 to 700 mm y^{-1}). Alchichica (19°25'N, 97°24'W, 2305 m.a.s.l.) and Atexcac (19°20'N, 97°27'W, 2360 m.a.s.l.) in Los Llanos de San Juan are saline. In Los Llanos de San Andrés, within the crater of the freshwater Tecuitlapa crater-lake (19°07'N, 97°32'W, 2,370 m.a.s.l.), there are two saline ponds: Tecuitlapa Norte (also named Atlacoya) and Tecuitlapa Sur. These saline lakes are also groundwater fed.

2.1. Physical characteristics

2.1.1. Latitude and altitude

Saline lakes are distributed throughout the arid, semi-arid, temperate, dry tropical and humid tropical zones of Mexico, spanning more than 15° of latitude and longitude. Mexico has an uneven water distribution altitudinally since 80% of inland waters is below 500 m above sea level, and just 5% is above 2000 m [INEGI (Instituto Nacional de Estadística), 1995]. Mexican saline lakes are also found in a wide altitudinal range. Isabela crater-lake on Isabela Island (Alcocer et al., 1998b), Nayarit, and several coastal salinas are at or near sea level. There are many examples of saline lakes at or above 2000 m. Examples are Jaco, Las Palomas, Hundido, Del Rey, El Coyote, La Leche, El Gigante, Las Liebres, Las Arenosas, Puerto Rico and Las Pampas in the Zacatecas basin (Ewald, 1985; Páez, 1995). Other examples along the Trans-Mexican Volcanic Belt are Texcoco, Xaltocan and Zumpango in the Mexico basin (Alcocer-Durand and Escobar-Briones, 1992; Alcocer and Williams, 1996) and Alchichica, Atexcac and El Carmen in the Oriental basin (Alcocer and Escobar, 1990; Alcocer et al., 1998a).

2.1.2. Lake morphometry

Little morphometric data is available from Mexican saline lakes. Fresh water attracts more attention than saline water because the former is more 'useful'. This is also characteristic of other saline lake regions (Hammer, 1986). Their ephemerality and the emphasis on surveys for the collection of material for biological purposes also result in less attention to saline lakes.

2.1.2.1. Area Saline lakes vary widely in area from large playas (e.g., on the Mexican Plateau) to widely distributed small ponds. Texcoco is perhaps the best known Mexican saline lake. It was a huge lake that covered 700 km^2 of the Mexico basin in 1521, but it has been reduced to 70 km^2 (15 km^2 permanent, 55 km^2 temporal) at present (Alcocer and Williams, 1996). Other immense playa-lakes are Totolcingo (Puebla-Tlaxcala) with an inundation area of about 290 km^2 (Alcocer et al., 1998a) and Sayula (Jalisco) with 168 km^2 (Delgadillo, 1996); these lakes are also greatly reduced today. The largest Mexican saline lake now is Cuitzeo in Michoacán, which ranks second in size only to freshwater Chapala Lake. It has widely fluctuated from 1,260 km^2 in 1946 to total dryness, with a mean surface area around 420 km^2 (Ceballos et al., 1994; Chacón, 1993; Chacón and Alvarado, 1995). Additional playa-lakes are also to be found in the Bolsón de Mapimí area in the Chihuahuan desert (Páez, 1995), e.g., La Leche (43.26 km^2) and Las Palomas (38.81 km^2).

Mexican saline crater-lakes display small surface areas. For example, Alchichica and Atexcac in Puebla cover 1.81 and 0.29 km^2, respectively (Arredondo-Figueroa et al., 1983) and Rincón de Parangueo and La Alberca in Guanajuato have areas of 0.724 km^2 and 0.181 km^2 (Green, 1986), respectively.

2.1.2.2. Volume There is scarce information regarding Mexican salt lake volume. According to Orozco and Madinaveitia (1941) La Alberca holds 1,000,000 m^3. More accurate information is given by Arredondo-Figueroa et al. (1983) for Alchichica (69,920,000 m^3) and Atexcac (6,150,000 m^3). Clearly the greatest volumes of saline water occur in the largest saline lakes such as Cuitzeo, and the largest playa-lakes of the Mexican Plateau. Volume widely fluctuates (seasonally, annually, etc.) in shallow saline lakes.

2.1.2.3. Depth Most of the Mexican saline lakes are shallow (i.e., < 5 m); for example, Texcoco has a mean depth of a few centimeters (Alcocer and Williams, 1996), Sayula a water layer of 0.3 m (Delgadillo, 1996), and in Cuitzeo the maximun depth is 3 to 4 m (0.26 m mean) (Ceballos et al., 1994; Chacón, 1993; Chacón and Alvarado, 1995. However, as in some other world saline crater-lakes have high mean and maximum depths (Hammer, 1986), Alchichica, which has a maximum depth around 64 m and mean depth of 39 m (Arredondo-Figueroa et al., 1983), is the deepest known Mexican natural lake, fresh or saline (Alcocer and Escobar, 1990). Other deep crater-lakes are La Alberca (50 m) (Green, 1986), Atexcac (maximum depth, 39 m; mean depth, 26 m; Arredondo-Figueroa et al., 1983) and Isabela (17.5 m, Alcocer et al., 1998a). Nonetheless, other crater-lakes are shallow, e.g., Rincón de Parangueo at 2 m (Green, 1986). Some of these lakes were deeper but groundwater extraction has reduced their volume. Ancient water-level marks are evident in these crater-lakes indicating depths up to 20 m greater than present, e.g., Rincón de Parangueo.

Morphometric parameters depend upon lake surface level elevation. If this changes, all other parameters also change. Saline lakes located in endorheic (termini) semi-arid basins commonly display surface level variation. Texcoco (Alcocer and Williams, 1996), El Carmen (Alcocer et al., 1998a), and Cuitzeo (Ceballos et al., 1994; Chacón, 1993; Chacón and Alvarado, 1995) show water level fluctuations between a few centimeters (or even total dryness) up to 5 m. Some lakes infrequently dry out, while others are seasonally or perennially astatic (e.g., Tecuitlapa Sur and Tecuitlapa Norte, in Puebla, respectively).

2.1.3. Transparency and color

Information regarding optical properties of Mexican saline lakes is scant and is restricted to Secchi disc transparency measurements and apparent color. Ceballos et al. (1994), Chacón (1993) and Chacón and Alvarado (1995) report Secchi disc transparency measurements of Cuitzeo to be from less than 0.1 m up to 0.97 m with a mean value of 0.36 m. Low transparencies are related to basin erosion carrying into the lake huge amounts of clay, and turbidity from suspended sediments in the shallow lake. Isabela crater-lake Secchi disc transparency is less than 0.1 m due to a high concentration of photosynthetic organisms (Alcocer et al., 1998b). Green (1986) described La Alberca and Rincón de Parangueo Secchi depths of 1 m and 0.6 m, respectively, associated with dense blue-green blooms.

In contrast, Secchi disc transparencies of the deep Alchichica and Atexcac lakes (Arredondo et al., 1984; Ramírez-García and Vázquez-Gutiérrez, 1989) reach high values (Z_{SD} = 3.6 to 8.0 m and 4.7 ± 1.3 m, respectively). Nonetheless, during brief periods of *Nodularia spumigena* blooms, transparency is greatly reduced. Transparent, clear, saline-lake water is not the rule but the exception. Alchichica maximum transparency values were found in winter, whereas minimum values occurred in April (Arredondo, 1995).

The color of Cuitzeo's water is turbid greenish brown produced by the combination of clays and blue-green algae (Ceballos et al., 1994; Chacón and Alvarado, 1995). Green (1986) described the color of Rincón de Parangueo as dark green, and La Alberca as pea-green (Green, pers. comm.); both colors are derived from the presence of huge amounts of the blue-green *Spirulina* and *Oscillatoria*, respectively. Isabela crater-lake has a pea-soup green color produced by photosynthetic bacteria (Alcocer et al., 1998b).

Our observations on the color of saline lakes noted, in Tecuitlapa Sur, a distinct deep sepia or dark brown probably due to the presence of colloidal silica. Waters of Tecuitlapa Norte and some areas of Texcoco (such as in the exterior ponds of 'El Caracol' solar evaporator) are pea-soup green because of the abundance of *Spirulina*. In other ponds of 'El Caracol', sulphur bacteria tint the water purple. Alchichica and Atexcac deep water is dark blue grading into turquoise toward shallow areas, but during brief periods of high productivity *Nodularia spumigena* changes water color into pea-soup green. El Carmen water color is pale yellow, similar to the color of Texcoco's groundwater brines.

2.1.4. Thermal characteristics

Polymixis is a common condition for most saline lakes (Hammer, 1986) and Mexican saline lakes share this characteristic. They are mostly shallow, and exist in regions of considerable wind which mixes them to the bottom either continually or on a daily basis. Cuitzeo is described as warm and polymictic (Ceballos et al., 1994; Chacón, 1993; Chacón and Alvarado, 1995)with an average temperature of 18°C (Chacón, 1993). Maximum temperature ranges from 27.1°C (bottom) to 29.5°C (surface), while minimum temperatures are 15.0°C to 16.4°C, at the bottom and surface, respectively (Ceballos et al., 1994). As expected in a shallow, warm polymictic lake, there is virtually no vertical (surface to bottom) temperature difference (<1.5°C) during the colder (December) or the warmer (June) months. Other large, shallow, saline lakes such as Texcoco, Zumpango, Tepeyahualco or Totolcingo should also be warm and polymictic.

Arredondo et al. (1984) classify the deep Alchichica crater-lake (64 m) as warm polymictic with 'alternated periods of mixing and thermal discontinuities' until winter when the lake circulates completely. Arredondo (1995) further explains that a 'slight' stratification is present in Alchichica throughout the year except in winter when the lake is homothermal. Stratification is best defined in summer with a temperature difference of 4.8°C between surface and bottom. At mixing, temperature variation from surface to bottom is 1°C. Apparently, Arredondo et al. (1984) and Arredondo (1995) misinterpreted Alchichica's thermal regime. Their data suggest monomixis instead of polymixis. Alchichica, like other deep lakes, stratifies as shown by Alcocer and co-workers (unpublished data). It is a warm monomictic lake with a winter-to-early-spring (three months) circulation period, but is stratified throughout the rest of the year.

Atexcac (mean depth, 39 m) seems to display a comparable warm monomixis pattern. Macek et al. (1994) followed the sequential development of a thermocline in Atexcac, from a completely mixed water column in January to clearly defined stratification in May. Littoral areas of Alchichica and Atexcac are warmer than surface limnetic waters with temperatures of 18.3 ± 4.0°C up to 24.9 ± 1.3°C (Alcocer et al., 1993b, Alcocer et al., 1993c, Alcocer et al., 1998c; Lugo et al., 1993, Lugo et al., 1998).

The first record of a Mexican insular meromictic lake was presented by Alcocer et al., 1998b). Isabela crater-lake is meromictic, with three well-defined strata separated by sharp pycnoclines. Surface water was warm (32°C), reaching a subsurface (0.5 to 1 m) maximum temperature of 33°C, declining gradually to 26.7°C at the maximum depth (17.5 m). Temperature and conductivity profiles suggested a very stable stratification. The height of the walls surrounding the lake, 7 to 9% of the lake diameter, prevents wind mixing. The very stable stratification of the lake suggests that molecular processes could be more important than turbulent diffusion in vertical water column transport (i.e., gases, nutrients).

Cole and Minckley (1968) found a simple inverse stratification thermal profile in a small (3.5 × 5.0 × 0.5 m), artificial pool for salt harvesting near Laguna Salada, Cuatro Ciénegas. This 'anomalous' profile ranged from 24°C at surface to 47°C at the bottom. From surface to bottom, the mean rate of increase was 0.5°C cm^{-1}, and between 15.5 and 30.5 cm the gradient amounted to 0.8°C cm^{-1}. Contrasting upper (14.63 g l^{-1}) and lower (111.26 g l^{-1}) salinities explain this seemingly anomalous condition. The dense, saline bottom water accumulates heat.

2.1.5. Oxygen concentration

Chacón (1993) reported 1.8 mg l^{-1} as the mean dissolved oxygen (DO) concentration in Cuitzeo, while Ceballos et al. (1994) found 6.1 mg l^{-1} (41% saturation) to be the mean. This lake displays a wide variation from virtual anoxia to oxygen supersaturation (>15 mg l^{-1}). Highest DO concentrations were at 17:00 hrs, while the lowest (anoxic) was between midnight and sunrise. There were horizontal variations in DO values, with the lowest concentrations on the west (saline) side of the lake, and the highest on the eastern (freshwater) portions. This fact is interesting since although salinity is an important factor to be considered in evaluating DO concentrations, the eastern basin receives large quantities of sewage increasing the biochemical oxygen demand. Thus a decrease in its DO concentration would be expected.

The upper stratum of Alchichica displays the highest DO concentrations (7 to 7.5 mg l^{-1}) during the summer supersaturation. The lowest surface concentrations, attained at the end of the summer, average 5.8 mg l^{-1}. Below 20 m, DO is low or even lacking (percentage saturation < 50%). An anaerobic hypolimnion develops from 30 m to the bottom in autumn. During the early stages of winter overturn, DO diminishes as the oxycline disappears (Arredondo, 1995; Arredondo et al., 1984). The littoral zones of Alchichica and Atexcac display higher DO concentrations, from 6.9 ± 1.5 mg l^{-1} (100 ± 22 percent saturation) to 8.1 ± 2.4 mg l^{-1} (120 ± 35 percent saturation) (Alcocer et al., 1993b, Alcocer et al., 1993c, Alcocer et al., 1998c; Lugo et al., 1993, Lugo et al., 1998).

Macek et al. (1994) described the associated development of thermo- and oxyclines in Atexcac. During November, Atexcac showed a well-established oxycline in which DO declined from 6.0 mg l^{-1} at 25 m to 0.8 mg l^{-1} at 30 m. The lake was completely mixed on January with constant oxygen concentration (6 mg l^{-1}) throughout the water column. A minimum DO concentration of 5.9 mg l^{-1} was noted above the bottom. An oxycline between 10 and 15 m formed in March. The concentration at the surface (10.2 mg l^{-1}), caused by active photosynthesis, decreased to 7.7 mg l^{-1} at 15 m. Storms and cold weather mixed the lake down to 10 m in April. Below 20 m, DO decreased to < 2 mg l^{-1}. Warmer weather during May did not modify the oxycline.

At the Isabella crater-lake surface DO is 6 mg l^{-1} (nearly 100% saturation). This value rises to 7.5 mg l^{-1} (145% saturation) at 0.5 m, and falls to 0 at 2.5 m. Most of the volume of this meromictic lake (2.5 to 17.5 m) therefore lacks DO. Accumulation of phototrophic microorganisms, carrying out high rates of primary production at 0.5 m, could be responsible for this subsurface DO maximum (Alcocer et al., 1998b).

2.2. Chemical characteristics

In pre-Colombian times, natives had discovered that different salts could be harvested from saline lakes. Undoubtedly, 'salt' – pure sodium chloride – and 'tequezquite' – impure mixtures of sodium carbonate, bicarbonate, chloride and sulphate – were the most relevant salts to ancient Mexicans. Aztecs developed a sequential precipitation of the salts from Texcoco lake. In this way, they extracted small amounts of the 'priceless' sodium chloride assigned to season rulers' meals. Village people had to use 'trivial' tequezquite instead of salt. Salt has played an important role in Mexican economy as explained by Ewald (1985). During the first half of this century, the chemical composition of saline lake waters, saline efflorescences (mostly tequezquite) and salt extraction procedures were analyzed (e.g., Zárate, 1917; Flores, 1918; Lozano, 1942).

Dissolved salts in most Mexican saline lakes are sodic (chiefly chlorides, carbonates and sulphate) and, in a lesser proportion, salts of calcium, potassium, magnesium, lithium and boron (Table 1). The importance of the bromine and iodine are almost unappreciated, but boron could be considered an important resource. In the central and north-central portions of Mexico (e.g., Chihuahua, Coahuila, Puebla, Jalisco, Michoacán), impure combinations of $NaHCO_3$, Na_2CO_3, NaCl, Na_2SO_4, KCl, $Na_2B_4O_7$ and other minor salts, extensively known as 'tequezquite', are important. Sodium and potassium nitrates, locally known as 'salitre', have been found in saline lakes from Coahuila, Chihuahua, Zacatecas, Durango, Sonora, Guanajuato, Hidalgo, Colima and Michoacán.

2.2.1. Salinity in Mexican saline lakes

Isabela is a hypersaline lake (68 to 112.5 mS cm^{-1}). The conductivity gradient of the lake begins almost immediately below the water surface. There are three well-defined water masses (0.5 to 2.5 m, 4.5 to 12 m and 13 to 17.5 m), separated by three sharp chemoclines (Alcocer et al., 1998b).

Cuitzeo's mean salinity reaches 3.592 g l^{-1} (as total dissolved solids, TDS) with a conductivity of 6595 μS cm^{-1} (Chacón, 1993). The lake displays a horizontal salinity gradient (Ceballos et al., 1994) from the eastern, most diluted basin (0 to 0.23 g l^{-1}, 616.3 μS cm^{-1}) to the more saline waters of the western basin (5 to 5.6 g l^{-1}, 7715.4 μS cm^{-1}). The most important tributaries are on the southeastern portion of the lake. From that point, water flows to the western portion which functions as a natural evaporator pond. In spite of the presence of saline springs (4,112.5 μS cm^{-1}) flowing to the SE shore of Cuitzeo, evaporation is the most important factor in raising salinity (Chacón and Alvarado, 1995).

In Guanajuato, La Alberca crater-lake is hyposaline with conductivity values up to 2300 μS cm^{-1}. In Rincón de Parangueo, conductivity is as high as 25,000 μS cm^{-1} (Green, 1986).

Taylor (1943) reports Alchichica water salinity to be 8.3 g l^{-1}. Alvarez (1950) cited 8.2 g l^{-1} for Alchichica and 7.5 g l^{-1} for Atexcac. Arredondo et al. (1984) measured 7.1 g l^{-1} in Alchichica. Vilaclara et al. (1993) reported 8.5 $\pm$ 0.2 g l^{-1} (13,000 $\pm$ 500 μS cm^{-1}) and 6.8 $\pm$ 0.2 g l^{-1} (11,000 $\pm$ 300 μS cm^{-1}) in Alchichica and Atexcac, respectively. Salinity values for Alchichica and Atexcac reported by Ramírez-García and Novelo (1984), Ramírez-García and Vázquez-Gutiérrez (1989) and Arredondo (1995) are overestimated (Alcocer, 1995). Littoral zone salinities of Alchichica and Atexcac are slightly lower than those of the corresponding limnetic zones; freshwater influents are probably the causative agents (Alcocer et al., 1993b, Alcocer et al., 1993c, Alcocer et al., 1998c; Macek et al., 1994).

The salinity of Totolcingo ranged from 0.7012 to 0.8012 g l^{-1}, while in Tepeyahualco it was 0.754 g l^{-1} (Alvarez, 1950; Reyes, 1979). Nonetheless, salinity reaches above 10 g l^{-1} (Alcocer et al., 1997). Vilaclara et al. (1993) described Tecuitlapa Norte with salinity at 16.3 $\pm$ 0.4 g l^{-1} and conductivity at 17,800 $\pm$ 3,000 μS cm^{-1}.

2.2.2. The chemical composition of Mexican saline waters

The origin of salts in closed basins is variable; the salts themselves vary considerably. The closer the lake is to the sea, the higher its NaCl content. Inland saline lakes display higher HCO_3/CO_3 and SO_4 concentrations compared with Cl. The chemical composition of Mexican saline lakes, ponds, salinas, springs and other saline aquatic environments is presented in Tables 1 and 2. It is evident from Table 1 that coastal lakes are NaCl dominated. In inner salinas NaCl is usually the dominant water type. This is more an artifact than a reality, because the bibliographic sources from which the data were obtained focus mostly on NaCl-harvesting areas. As mentioned, tequezquite-laden lakes (dominated by non-NaCl salts) are common in the arid regions of Mexico.

2.2.3. Other chemical parameters

2.2.3.1. pH Cuitzeo's mean pH value is about 8.9 but may reach up to pH 10 in summer (Ceballos et al., 1994). Vertical pH differences are small (i.e., surface and bottom pH values average 8.9 and 8.6, respectively). According to Chacón (1993) and Chacón and Alvarado (1995) the lake shows horizontal pH differences. The diluted eastern basin averages 7.9 pH units, and the more concentrated western basin reaches up to 11.5 pH units.

Alchichica, Atexcac and Tecuitlapa Norte are alkaline. The first two are well-buffered with mean pH values of 9.0 $\pm$ 0.1 in the former and 8.2 $\pm$ 0.1 in the later (Ramírez-García and Novelo, 1984; Ramírez-García and Vázquez-Gutiérrez, 1989; Vilaclara et al., 1993). The astatic nature of Tecuitlapa Norte is accompanied by a more unstable pH regime (10.7 $\pm$ 0.7 pH units). In spite of the variable abundance of aquatic macrophytes, the littoral zone of Alchichica (9.0 $\pm$ 0.1) and Atexcac (8.4 $\pm$ 0.2) are well buffered (Alcocer et al., 1993c; Alcocer et al., 1998a; Lugo et al., 1993; Lugo et al., 1998). Alvarez (1950) mentioned higher pH values for Alchichica (10.2) and Atexcac (10.0).

In Totolcigo, Alvarez (1950) measured 8.2 pH units. Later, Reyes (1979) found it ranged from 8.8 to10.15 as the lake concentrated. El Carmen well and spring water, which feeds Totolcigo, averaged 8.0 to 8.3 pH units (SPP, Secretaria de Programacion y Presupuesto, 1984a,b). Reyes (1979) reported Tepeyahualco pH to be around 8.5 units.

The pH of Isabela crater-lake fluctuates from basic (9.3) in the surface well-oxygenated waters to slightly acid (6.4) in the deep anoxic layers (Alcocer et al., 1998b). High rates of primary production at the surface, and anaerobic decomposition in the deep waters, explain this behavior.

2.2.3.2. Minor chemical constituents Chacón (1993) measured high nitrogen concentration in Cuitzeo, dominated by the reduced forms ($N\text{-}NO_3 = 0.26\ mg\ l^{-1}$, $N\text{-}NO_2 = 0.29\ mg\ l^{-1}$, $N\text{-}NH_4 = 2.38\ mg\ l^{-1}$). Nonetheless, Ceballos et al. (1994) refer to much higher quantities, with a mean of about $23.8\ mg\ N\text{-}NO_3\ l^{-1}$ (W basin $= 26.0\ mg\ N\text{-}NO_3\ l^{-1}$, E basin $= 0.47\ mg\ N\text{-}NO_3\ l^{-1}$). Nitrogen concentration in Isabela is high ($N\text{-}NO_3 = 4.6\ mg\ l^{-1}$ aerobic and $10.3\ mg\ l^{-1}$ anaerobic; $N\text{-}NO_2 = 0.4\ mg\ l^{-1}$ aerobic and $0.5\ mg\ l^{-1}$ anaerobic; and $N\text{-}NH_4 = 2.6\ mg\ l^{-1}$ aerobic and $5.2\ mg\ l^{-1}$ anaerobic), but less than those mentioned from Cuitzeo (Alcocer et al., 1998b).

According to Ceballos et al. (1994) and Chacón (1993) Cuitzeo's phosphorus concentration is extremely high with a mean concentration of $0.46\ mg\ l^{-1}$ (W basin $= 0.86\ mg\ l^{-1}$, E basin $= 0.23\ mg\ l^{-1}$). This fact is associated with organic matter pollution and the soda alkaline water type. Nonetheless, these concentrations seem insignificant when compared with Isabela (Alcocer et al., 1998b) at $40.8\ mg\ l^{-1}$ in the aerobic superficial layer and $96.9\ mg\ l^{-1}$ in the anaerobic monimolimnion.

Crater-lakes, owing to their volcanic nature, are usually high in silica. This is the case of Isabela with $133\ mg\ l^{-1}$ in the aerobic layer and $109\ mg\ l^{-1}$ in the anaerobic stratum (Alcocer et al., 1998b). A high concentration of dissolved silica was measured in Atexcac (1.39 $\pm$ 0.07 mM) by Vilaclara et al. (1993), but it was also present in lower quantities in Alchichica (0.01 $\pm$ 0.01 mM) and Tecuitlapa Norte (0.57 $\pm$ 0.13 mM). Macek et al. (1994) assumed a thermal water input throughout the bottom of Atexcac to be responsible for its high silica concentration.

Ceballos et al. (1994) found $4.2\ mg\ l^{-1}$ boron in Cuitzeo. Vilaclara et al. (1993) also found boron in the saline waters of Alchichica (3.79 $\pm$ 0.83 mM), Atexcac (5.37 $\pm$ 0.56 mM) and Tecuitlapa Norte (0.93 mM).

2.3. Aquatic biota

Without doubt the most studied Mexican saline lake is Texcoco. No other Mexican saline lake has been under study for such a long time (pre-Colombian times to the present) and by several Mexican and foreign researchers. The ancient nahuatl codexes contain the first reports of Texcoco lake organisms, as well as fishing, hunting, culture and preservation methods (Alcocer-Durand and Escobar-Briones, 1992; Deevey, 1957).

2.3.1. Algae

Since pre-Colombian times, natives named 'tecuitlatl', 'amomoxtli' and 'cocolin' as edible algae harvested from the lake complex of the Mexico basin (Alcocer-Durand and Escobar-Briones, 1992). Ortega (1972) considers 'tecuitlatl' an ancient name replaced by 'cocolin'. The most famous alga produced in Texcoco is the blue-green *Spirulina geitleri*, maybe the original 'tecuitlatl'. 'Amomoxtli', it is composed of *Nostoc commune*, while 'cocolin' is a complex mixture of *Phormidium tenue* and *Chroococcus turgidus* in the main, but also containing *Nodularia*, *Oscillatoria*, *Anabaena*, *Spirulina* and microinvertebrates such as nematodes and rotifers (Ortega, 1972; Ortega et al., 1995).

Probably the best known paper on the algae of Mexican saline lakes is Bradbury's (1971) work on the paleolimnology of Lake Texcoco. This research showed Texcoco was originally a large, cool and probably deep freshwater lake. After that, it has fluctuated from fresh to saline, and from a large lake to small saline pools. Nowadays, a drier climate and human impacts have almost desiccated it to a rainy season inundation terrain (Alcocer and Williams, 1996). Alcocer and Williams (1993) listed a large number of algae in Texcoco. Sámano (1934); Sámano (1940), Ortega (1972) and Ortega et al. (1995) list the following algae from the lake: Cyanophyceae (*Nostoc*), Xanthophyceae (*Vaucheria*), Euglenophyceae (*Euglena sanguinea*), Chlorophyceae (*Chlorella minuta, Coelastrum microporum, C. reticulatum, Hydrodictyon reticulatum, Kirchneriella contorta, K. obesa, Oedogonium, Scenedesmus abundans var. longicauda, S. acuminatus, S. quadricauda var. longispina, Phytophora*), Zygophyceae (*Closterium aciculare, C. acutum, C. lineatum, C. gracile, C. jenneri, C. leiblenii, C. moniliferum, C. parvulum, Pleurotaenium trabecula, P. ehrenbergii, Sirogonium*), Cyanophyceae (*Nostoc commune*). Additional species are mentioned by Alcocer and Williams (1993).

Alcocer et al. (1998b) found phytoflagellates, mainly *Cryptomonas*, inhabiting the Isabela phytoplanktonic microbial community. The presence of this group was restricted to the oxic layer of the lake. A low transparency, high nutrient concentration and water color identifies Isabela as a highly productive lake where primary production is carried out by photosynthetic bacteria instead of blue-green algae (Alcocer et al., 1998b).

Green (1986) found the phytoplankton of La Alberca to be dominated by the filamentous blue-green alga *Oscillatoria* sp.; a few cells of *Actinastrum* sp. were also present. Rincón de Parangueo was overwhelmingly dominated by *Spirulina* and a small amount of *Anabaena*. Secchi disc transparency, water color, almost single species blue-green blooms and a clogged phytoplankton net, induced Green (1986 and pers. com.) to identify La Alberca and Rincón de Parangueo as eutrophic.

A total of 41 genera compose the Cuitzeo phytoplanktonic community (Ceballos et al., 1994), which is classified in five divisions (number of genera): Cyanophyta (10), Chrysophyta (15), Euglenophyta (2), Chlorophyta (12) and Pyrrophyta (2). *Merismopedia* and *Anabaenopsis*, *Synedra* and *Navicula*, *Euglena*, *Scenedesmus* and *Kirchneriella*, and *Peridinium* are representative genera of each division respectively. The same authors reported that the number of species has been reduced progressively to 25 genera because of pollution. Cuitzeo is considered a hypertrophic lake (Ceballos et al., 1994) because of its high nutrient concentrations. Blue-green blooms (*Anabaena aphanizomenoides*, *Anabaenopsis arnoldi*, *Oscillatoria* and *Merismopedia*) are often developed but recent observations revealed an overwhelming dominance of *Oscillatoria*.

Arredondo et al. (1984) identified 23 genera composing Alchichica's phytoplankton (14 Chrysophyta, 5 Cyanophyta, 4 Chlorophyta). The most numerous group was Chrysophyta (90.2% of total abundance), followed by Cyanophyta (7.4%) and Chlorophyta (2.4%). *Chaetoceros similis*, *Stephanodiscus niagarae*, *Coscinodiscus* and *Cyclotella striata* (Chrysophyta), *Nodularia spumigena* (Cyanophyta) and *Cosmarium* (Chlorophyta) are the representative organisms of each group. Macek et al. (1994) described a brief *Nodularia spumigena* bloom in Atexcac (February). Other dominant algae were *Eutetramorus fottii*, *Oocystis* and *Cyclostephanus dubius*. Alchichica was cataloged by Garzón (1990) as oligo-mesotrophic according to its chlorophyll *a* concentration (6 mg m^{-3}).

Atexcac is oligotrophic based on a mean chlorophyll *a* concentration of less than 5 mg m^{-3}, while Tecuitlapa Norte is hypertrophic averaging 1500 mg m^{-3} (Vilaclara et al., 1993). Both Tecuitlapa and Tecuitlapa Norte display perennial *Microcystis* and *Spirulina*, respectively, blue-green blooms.

2.3.2. Zooplankton

2.3.2.1. Protozoa There is scant information on Mexican saline lake protozoa. Alcocer et al. (1998b) found heterotrophic flagellates (*Monas*, Bodo) and Hypotricha (*Euplotes*?) and Oligotricha (*Strobilidium*) ciliates to be important components of the Isabela planktonic microbial community. These groups were present in the narrow superficial well-oxygenated layer of the lake.

Green (1986) found a large holotrich ciliate, which fed upon *Spirulina*, abundant in Rincón de Parangueo. The same author also reports for La Alberca small numbers of a large holotrich ciliate (the same species as in Rincón de Parangueo?), and also a species of *Vorticella*. Alcocer and Williams (1993) noted *Amoeba limax*, *Oxytricha bifaria* and *Oxytricha pellionella* in Texcoco.

Lugo et al. (1998) studied the littoral protozoan assemblages of Alchichica and Atexcac crater-lakes. They found 87 species, 44 in Alchichica and 43 in Atexcac. In the first lake there were 17 flagellates, 17 ciliates and 10 sarcodines; in the latter there were 20 ciliates, 16 flagellates and 7 sarcodines. The flagellate *Bodo caudatus* and the ciliate *Cyclidium glaucoma* were the main species in Alchichica. In Atexcac dominant species were the flagellates *Cryptomonas ovata* and B. *caudatus* and the ciliates *C. glaucoma* and *Stylonychia notophora*. Most of the protozoan species found in both lakes feed on bacteria. Considerably fewer species were omnivores, photosynthetic autotrophs, and algivores. Just one species was categorized as a predator. Macek et al. (1994) cited *Strombidium, Mesodinium, Rhabdostyla nebulifera* and *Cothurnia oblonga* as dominating the ciliate assemblage of Atexcac.

Lugo et al. (1993) found the trophic status of Alchichica and Atexcac through the *G* value, i.e., the colonization rate of polyurethane foam units by protozoans, an indicator of the trophic status of lakes. This value characterized Alchichica as oligo-mesotrophic and Atexcac as oligotrophic. Both trophic statuses coincided with those reported by Garzón (1990), Vilaclara et al. (1993) and Macek et al., (1994) based on chlorophyll *a* concentrations.

2.3.2.2. Rotifers Rotifers dominated the Cuitzeo zooplankton with up to 97% of the total. Seventeen rotifer species occur in Cuitzeo. The eastern basin had 15 rotifer species including ten *Brachionus* spp. In the western basin, there were 11 rotifer species, including five *Brachionus* spp. In the central portion, the less diverse, there were just 5 rotifer species, three of them *Brachionus* spp (Ceballos et al., 1994). *Brachionus pterodinoides*, *B. angularis*, *Keratella cochlearis*, *Pedalia*, *Filinia* and *Asplanchnopus* are representative rotifers from Cuitzeo. The number of rotifer species has been reduced progressively and the dominant species have changed to *Asplanchna brightwellii*, *Keratella cochlearis*, *Filinia longiseta* and *Lepadella rhomboides* (Ceballos et al., 1994).

Two rotifer species were present in La Alberca and Rincón de Parangueo, *Hexarthra polyodonta* and *Brachionus inermis*. Of these, *H. polyodonta* was much more abundant (99%) than *B. inermis* (1%) in the former lake, but their relative importance was reversed (2% and 98%, respectively) in the latter. *Hexarthra* was rarely observed in Atexcac (Macek et al., 1994).

Several rotifers have been found in Texcoco. The most common are cited by Alcocer and Williams (1993) as *Brachionus angularis, B. angularis caudatus, B. dimidiatus inermis, B. plicatilis, B. pterodinoides, Colurella adriatica, C. obtusa, Lecane aspasia, Lepadella patella, Monostyla closterocerca, M. hamata, Philodina roseola, Rotaria elongata* and *Trichocerca pusilla*.

2.3.2.3. Crustacea

2.3.2.3.1. Anostracans and Notostracans Castro and Castro (1994) have identified *Artemia* in ten Mexican states. There is little information concerning Mexican *Artemia* although this was a famous organism in Texcoco. The *Artemia* population of Texcoco (*A. franciscana*) was introduced, while the populations from Las Salinas de Hidalgo, San Luis Potosí and Cuatro Ciénegas de Carranza, Coahuila are native inland strains. The other populations come from coastal areas: Guerrero Negro and Pichilingue (Baja California Sur), Yavaros

(Sonora), Bahía de Ceuta (Sonora), Altamira (Tamaulipas), Salina Cruz (Oaxaca), Laguna del Mar Muerto (Chiapas) and San Crisanto (Yucatán). Olguín (1993) reports some attempts to culture Yucatán native *Artemia* population semi-intensively. Olivares et al. (1994) studied the energy budget of *A. franciscana* from a hypersaline lagoon in Baja California (probably from Guerrero Negro). *Triops lacusanus* is the only notostracan cited from a Mexican saline lake (Texcoco) (Alcocer and Williams, 1993).

2.3.2.3.2. Cladocerans *Daphnia* and *Moina* are present in low numbers in Cuitzeo (Ceballos et al., 1994). *Daphnia* was also found in Texcoco (Alcocer and Williams, 1993). The cladocerans *Daphnia* and *Ceriodaphnia* appeared in very low numbers at 20 to 30 m in Atexcac (Macek et al., 1994).

2.3.2.3.3. Copepods Only one copepod species, *Diaptomus albuquerquensis*, was present in the planktonic samples of La Alberca, and none were found in Rincón de Parangueo (Green, 1986). Laguna Salada, Cuatro Ciénegas, contains a single copepod species, *Diaptomus connexus*, when slightly saline ($12.89\ g\ l^{-1}$). This species was replaced by the harpacticoid copepod *Cletocamptus albuquerquensis* when the lake reached higher salinity ($300\ g\ l^{-1}$) (Cole and Minckley, 1968). *Diaptomus* and *Cyclops* represent the copepods identified from the Cuitzeo zooplankton (Ceballos et al., 1994).

As in most of the previous lakes, Macek et al. (1994) report just one copepod species inhabiting Atexcac, *Diaptomus sicilis*, However, J. Reid (Smithsonian Institution, pers. comm.) thinks this species was misidentified and that it is properly identified as *Leptodiaptomus novamexicanus*. It was present throughout the sampling period reaching maximum abundance ($40\ ind\ l^{-1}$) from February to March associated with a *Nodularia spumigena* bloom.

Alchichica contains a copepod species, *Leptodiaptomus novamexicanus*, first described by Osorio (1942) as *Diaptomus garciai*.

2.3.2.3.4. Ostracods Although this group is frequently captured in zooplankton samples, we prefer to consider it as benthic. Hammer (1986) noted that in North America ostracods tend to be benthic or littoral inhabitants. In shallow saline lakes planktonic and benthic communities are mixed by wind action. Such should be the case for *Cypria* and *Lymnocythere* from Cuitzeo, described as zooplanktonic organisms by Ceballos et al. (1994).

2.3.3. The benthic community

A new species of *Thalassocypris* (Ostracoda, Cyprididae) and the corixid bug *Trichocorixa reticulata* inhabit the upper oxic layer of Isabela (Alcocer et al., 1998b). Although Isabela is 17.5 m deep, the chemocline must be working as a functional shallow bottom (2.5 m) for ostracods and corixids.

Taxonomic knowledge of the benthic organisms of Cuitzeo is poor. Most of the references are in regard to macroinvertebrates (Ceballos et al., 1994) including molluscs, crustaceans, nematodes, annelids or insect larvae. Two ostracods (*Limnocythere* and *Potamocypris*) and one hemipteran (*Buenoa*) are often mentioned. *Hyalella* is a dominant organism and forms around 40 percent (up to 99% in the western basin and up to 55% in the eastern portion) of the community of 40 taxa.

Several groups inhabit Texcoco (Alcocer and Williams, 1993). These include Coelenterata (*Hydra oligactis*), Oligochaeta (*Bdellodrilus illuminatus*), Ostracoda (*Entocythere heterodonta*), Amphipoda (*Gammarus*), Decapoda (*Cambarellus montezumae*), Diptera (*Ephydra hians*), Coleoptera (*Gyrinus parcus, Hydrophilus insularis, Megadytes fallax, Rhantus mexicanus, Thermonectus basilaris, Tropisternus oculatus, T. tinctus*), Hemiptera (*Corisella edulis, C. mercenaria, C. tarascana, C. texcocana, Gerris marginatus, Graptocorixa abdominalis, G. gerhardi, Hydrometra martini, Krizousacorixa azteca, K. femorata, Morphocorixa lundbladi, Notonecta montezumae, N. unifaciata, Ranatra americana, Trichocorixella mexicana, Trichocorixa parvula*) and Odonata (*Aeshna, Lestes, Sympetrum*).

The Aztec denomination of most of these organisms of Texcoco and the way they used to be eaten is described by Alcocer-Durand and Escobar-Briones (1992). The most famous Mexican aquatic insect group is the Corixidae or 'axayacatl'. Jackzewski (1931) and Hungerford (1948) discuss corixids of Texcoco and Zumpango. Deevey (1957) mentioned what seems to be the first picture of a corixid in a 16th century manuscript. Ancona (1933) reports *Krizousacorixa femorata* and *K. azteca* to be the most common corixids in Texcoco producing the 'ahuautle' (empty corixid egg shells commonly consumed on watch days or during vigil). Hutchinson (1993) showed that both species were replaced by *Corisella mercenaria* and *C. edulis* when Texcoco's water level dropped.

Benthic macroinvertebrate communities of Alchichica and Atexcac have been investigated by Alcocer (1995) and Alcocer et al., (1993b, 1993c, 1998c). Fifty taxa (44 in Alchichica and 21 in Atexcac) were identified with oligochaetes, amphipods, chironomids and hirudineans as the dominant organisms. These four groups made up to 99% in number and biomass. Dominant species were the tubificid worm *Limnodrilus hoffmeisteri*, the amphipod *Hyalella azteca*, and the chironomids *Tanypus (Apelopia)* in Alchichica and *Stictochironomus* in Atexcac. Insects predominated with 41 species out of a total of 50. By far the most diverse group were chironomids making up 18 species (14 in Alchichica and 7 in Atexcac). Salinity and plant type and coverage were the most important environmental parameters in explaining the differences in density and biomass. Jansson (1979) described a new corixid species from Alchichica, *Krizousacorixa tolteca*.

Cole and Minckley (1968) mentioned the presence of corixids in the northern part of Laguna Salada, Cuatro Ciénegas, when the salt concentration was 12.89 g l^{-1}. Excepting a harpacticoid copepod, there were no metazoans in Laguna Salada when it was hypersaline (300 g l^{-1}).

2.3.4. Aquatic macrophytes

Often, saline lakes are surrounded by soda mudflats or saline efflorescences. Salt tolerant terrestrial vegetation grow on these saline soils; as well, semiaquatic macrophytes develop in the marginal areas of saline lakes. The littoral zone often displays the greatest plant species diversity. Hyposaline lakes (e.g., Cuitzeo and Texcoco) hold more plant species than hypersaline ones (e.g., there are none in Isabela or Tecuitlapa Norte). Mesohaline lakes display a variable number of plant species between hypo and hypersaline types.

Many macrophyte species inhabit Cuitzeo (Ceballos et al., 1994). Representative species are as follows: *Atriplex linifolia, Azolla* sp., *Ceratophyllum demersum, Cyperus digitatus, C. imbricatus, C. laevigatus, C. reflexus* var. *fraternus, C. semiochraceus, Distichlis spicata, Eichhornia crassipes, Eleocharis densa, E. montevidensis, E. rostellata, Heteranthera limosa, H. peduncularius, Hydrocotyle ranunculoides, H. verticillata, Hydromystria laevigata, Jaequeria bellidiflora, Juncus ebracteatus, J. effusus, Leersia hexandra, Lemna aequinoctialis, L. gibba, Lilaeopsis shaffneriana, Marsilea, Najas guadalupensis* var. *guadalupensis, N. flexilis, Nymphoides fallax, Panicum sucosus, Phragmites australis, Pistia stratiotes, Potamogeton pectinatus, P. foliosus* var. *foliosus, Polygonum punctatum, Ranunculus cymbalaria, R. dichotomus, Sagittaria latifolia, Scirpus validus, S. californicus, S. americanus, Spirodela polyrrrhiza, Sporobolus funceus, S. indicus, Suaeda torreyana, Triglochin mexicana, Typha dominguensis, T. latifolia, Wolffiella lingulata* and Zannichellia *palustris*.

There is a large list of macrophytes in Texcoco. Among them are *Agrostis verticillata, Argemone ochroleuca, Anthericum, Aster pauciflorus, Atriplex muricata, Azolla* sp., *Buteloua simplex, Cnicus niveles, Cynodon dactylon, Cyperus niger, Chenopodium mexicanum, Chenopodium murale, Chromatium ruizi, Distichlis spicata, Echinochloa crus-galli, Eichhornia crassipes, Eleocharis montevidensis, Eragrostis obtusiflora, Gnaphalium inernatum, Hordeum jubatum, Hydrocotyle ranunculoides, Hydrocotyle umbellata, Juncus balticus, J. effusus, Jussieva repens, Lemna gibba, L. minor, Leptochloa fascicularis, Marsilia mexicana, Mimulus glabratus, Muhlenbergia tenuiflora, Nymphaea elegans, N. mexicana, Paspalum distichum, Polygonum acre, P. interruptus, P. monospeliensis, Potamogeton angustisimus, P. pectinatus, Ranunculus hychrochardides, Rumex maritimus, R. obtusifolius, Sagittaria macrophylla, Scirpus californicus, S. lacustris, S. maritimus, S. paludosus, S. pungens, S. validus, Sida difusa, Sium erectum, Sonchus oleraceus, Sporobolus indicus, S. piramidatus, Suaeda maritima, S. nigra, S. torreyana, Triglochin striatum, Typha latifolia, Xanthocephalum centuroides, X. humile* and *Zannichellia palustris*.

Four macrophyte species populate Atexcac while two occur in Alchichica (Ramírez-García and Novelo, 1984; Ramírez-García and Vázquez-Gutiérrez, 1989). Both lakes share *Ruppia maritima* and *Cyperus laevigatus*. *Phragmites australis* and *Potamogeton pectinatum* are also found in Atexcac. Samples of *P. pectinatus* from Alchichica are in the Missouri

Botanical Garden (MO) and the Escuela Nacional de Ciencias Biológicas (ENCB) herbaria. Out of the four plant species from Atexcac, just *P. australis* and *C. laevigatus* were abundant all the year around; the other two were temporal and meager.

2.3.5. Vertebrates

2.3.5.1. Fish Texcoco, and probably the other saline lakes of the northern Mexico basin (e.g., Zumpango; Alvarez, 1950), contained three families of fish (Alvarez, 1970; Alvarez and Navarro, 1957; Martín del Campo, 1955; Rojas and Pérez, 1985). *Chirostoma humboldtianum*, *Chirostoma jordani* and *Chirostoma regani* belong to the Atherinidae, *Girardinichthys viviparus* to the Goodeidae and *Algancea tincella*, *Notropis aztecus*, *Evarra eigenmani*, *E. tlahuacensis* and *E. bustamantei* to the Cyprinidae. Atherinidae (silversides) are named 'charal' and 'pescado blanco' (white fish) according to size, with the former the smaller.The most abundant fish was the goodeid or 'mexclapique'. Cyprinids were named 'xohuilin'. Further introduced species to Texcoco are two carps *Ctenopharyngodon idellus* and *Cyprinus carpio*, and one tilapia species *Sarotherodon mossambicus* (Alcocer and Williams, 1993). Contreras (1990) and Espinosa et al. (1993) classified *Girardinichthys viviparus* as a threatened species, and *Evarra eigenmani*, *E. tlahuacensis* and *E. bustamantei* as threatened species and probably extinct (Miller, 1986).

Ten to twenty-one fish species belonging to six families have been reported from Cuitzeo (Ceballos et al., 1994; Chacón and Alvarado, 1995). Some of them are doubtful records such as *Lampetra spadiceus* and *L. geminis* (Petromyzontidae), *Notropis calienti* and *N. sallaei* (Cyprinidae), *Oreochromis aureus* (Cichlidae), and *Chirostoma bartoni* (Atherinidae), the endemic silversides species of La Alberca, Guanajuato. Native species belong to the following four families: Atherinidae (*Chirostoma jordani* and *C. compressum*, although it seems the latter species is actually extinct), Goodeidae (*Goodea atripinnis*, *Xenoteca variata*, *Zoogonecticus quitzeoensis*, *Skiffia bilineata* (according to Espinosa et al., 1993) or *S. lermae*, *Allophorus robustus*, *Hubbsina turneri*, *Neoteca bilineata* and *Alloteca dugesii*), Cyprinidae (*Algancea tincella*), and Poecilidae (*Poeciliopsis infans*). There are also three introduced species, *Cyprinus carpio* and *Carassius auratus* (Cyprinidae), and *Oreochromis niloticus* (Cichlidae).

Jordan and Evermann (1896–1900) described a new species of silverside from La Alberca, *Chirostoma bartoni*. This fish is an endemic species of this crater-lake (Barbour, 1973) and has recently been catalogued as a threatened species (Contreras, 1990; Espinosa et al., 1993).

Miller (1976) described *Cyprinodon alvarezi* (Cyprinodontidae) from El Potosí in Nuevo León. This pupfish is endemic to the El Salado basin where several saline lakes exist. The species has been catalogued as in risk of extinction (Espinosa et al., (1993). Other species of the families Cyprinidae (*Cyprinella*, *Notropis*), Cyprinodontidae (*Cyprinodon*) and Poecilidae (*Gambusia*) are endemic or common to endorheic basins of Chihuahua, Coahuila, Nuevo León and Durango (Espinosa et al., 1993). Some of them thrive in saline lakes of the northern part of Mexico such as in Laguna Salada, Cuatro Ciénegas, where Cole and Minckley (1968) found *Gambusia marshi*, *G. longispinis* and an undescribed species of *Cyprinodon*. The harsh environment and stress from human activities jeopardize the existence of both aquatic resources and fish fauna. Most of these species are considered in risk of extinction, or at least threatened (Contreras, 1990; Espinosa et al., 1993).

Atherinid specimens from Alchichica crater-lake were described as *Poblana alchichica* by de Buen (1945). However, Alvarez (1950) treated the form as a subspecies, *P. alchichica alchichica*, and recognized a sister subspecies, *P. a. squamata*, from Quechulac crater-lake. He also described *P. letholepis* from La Preciosa crater-lake. Echelle and Echelle (1984) cited an unpublished document in which Barbour considered *Poblana* a junior synonym of *Chirostoma*. A genetic analysis of the atherinid fish fauna in the Central Plateau of Mexico by Echelle and Echelle (1984) suggested that *Poblana* and *Chirostoma* should be treated as *Menidia*. Miller (1986) accepted *Poblana alchichica* and *P. letholepis* as valid species. Guerra (1986) compared *Chirostoma* and *Poblana* morphometrically and regarded them as distinguishable genera. Guerra also suggested that *P. letholepis* was a subspecies of *P. alchichica* (*P. a. letholepis*), meaning there should be three subspecies of *P. alchichica*. At present, two silversides inhabit saline lakes of the Oriental basin, the endemic species of Alchichica (*Poblana alchichica*) and the widely distributed *Chirostoma jordani* in El Carmen (Alvarez, 1950; Barbour, 1973; Guerra, 1986). Contreras (1990) and Espinosa et al. (1993) catalogued *Poblana alchichica* as a threatened species. Tepeyahualco could have contained silversides when inundated (Alcocer et al., 1998a). The other saline lakes of the Oriental basin (i.e., Atexcac crater-lake, Tecuitlapa Norte and Tecuitlapa Sur) lack fish fauna.

At the southeastern extreme of Mexico, in Yucatán, is the hyposaline lake Chichancanab which contains five endemic species of Cyprinodon (*C. beltrani*, *C. labiosus*, *C. maya*, *C. simus* and *C. verecundus*) and only one other fish (a poecilid) (Contreras, 1990; Espinosa et al., 1993; Miller, 1986). Contreras (1990) and Espinosa et al. (1993) report the Cyprinodon group of species as threatened.

Fish are important parts of the diet in many parts of Mexico where saline lakes occur. Introduced fish species in Mexican saline lakes, mostly carps and tilapias, compete with native species. Most of the species present in Mexican saline lakes are subject to local or commercial fisheries. Cuitzeo has two fisheries zones (Ceballos et al., 1994; Chacón and Alvarado, 1995). The first is associated with the shallow littoral areas where aquatic macrophytes are abundant, and the second exploits the deeper limnetic area which lacks macrophytes. The littoral area supports a diverse and profuse fishery reaching up to 1.36 ton ha^{-1}. Except tilapias and carps, most of the captures are non-commercial species such as the goodeid *Goodea atripis* which makes up to 54% of the total harvest. *Chirostoma jordani* dominates the limnetic fisheries with up to 680 kg ha^{-1} harvested. The fisheries in the more saline western basin of Cuitzeo are dominated by atherinids; the other species (tilapias, carps, goodeids) are captured more abundantly in the fresher eastern basin (Bernal-Brooks, pers. com.). According to Ceballos et al. (1994) while the introduced-tilapia fishery has been increasing since 1978 to the present, the native *Chirostoma jordani* fishery has dropped from almost 100% in 1974 to 9% in 1989.

Non-commercial species of goodeids are abundant in Texcoco and Zumpango, but silversides or 'charales' is of special interest for its white meat and delicate flavor. They are also harvested in La Alberca, Texcoco, El Carmen and Alchichica saline lakes.

2.3.5.2. Amphibia Amphibians are infrequently reported as inhabitants of saline lakes except for hyposaline ones. Nonetheless, they tend to be restricted to one or few species. The Anuran *Rana montezumae*, an endemic species of the Trans-Mexican Volcanic Belt (Flores-Villela, 1993) is commercially harvested in Cuitzeo (Ceballos et al., 1994). In Texcoco the following species of Anura have been reported by Alcocer and Williams (1993): *Bufo compactilis*, *Hyla eximia*, *Rana montezumae*, *R. halecina*, *R. pipiens* and *Scaphiopus multiplicatus*. However, Flores-Villela (1993) does not report *R. halecina* or *R. pipiens*. When the rainy season begins in dry terrains of Tepeyahualco, many frogs could be seen jumping at night (Alcocer, pers. obs.).

There is a confusion over the name 'axolotl' since it has been associated with several large, neotenic species in central and eastern Mexico. According to Brandon (1989) the name axolotl must be tied to *Ambystoma mexicanum* only, a freshwater species indigenous to Xochimilco and Chalco. There are other ambystomatid salamanders inhabiting Mexican saline lakes. The salamander of Texcoco and Zumpango, *Ambystoma velasci* = *Ambystoma lacustris*, is endemic to the Trans-Mexican Volcanic Belt, but it is considered a subspecies of the widely distributed tiger salamander *Ambystoma tigrinum* (Flores-Villela, 1993).

Calderón and Rodríguez (1986) reported *Ambystoma lacustris* (*Ambystoma velasci*) and *Ambystoma mexicanum* as inhabiting, or having inhabited, the saline Zumpango and Texcoco lakes. *Ambystoma mexicanum* is mostly a freshwater species; nonetheless the past connection among the six lakes complex of the Mexico basin (Alcocer-Durand and Escobar-Briones, 1991; Alcocer et al., 1993a) perhaps explains why the lake complex shared a common biota. Dyer and Brandon (1973) found the intestinal nematode *Falcaustra elongata* parasitizing the salamander of Zumpango.

Taylor (1943) described and named a new species of neotenic salamander, *Ambystoma subsalsum*, endemic from Alchichica crater-lake in Puebla. Several years later Brandon et al. (1981) found

Taylor's description did not apply to the Alchichica salamander but to the widely dispersed *Ambystoma tigrinum*. Nonetheless, the population of *Ambystoma* in Alchichica merited recognition at the species level as *Ambystoma taylorii* (Brandon et al., 1981; Brandon, 1989; Flores-Villela, 1993). *Ambystoma* feeding on benthic organisms was seen by Macek et al. (1994) in Atexcac. Dyer and Brandon (1973) also report an intestinal nematode (*Hidruris siredonis*) parasitizing the salamanders of Alchichica.

Brandon et al. (1981) found *Ambystoma tigrinum* or *Ambystoma tigrinum*-like species inhabiting the large saline playa-lake Tepeyahualco. *Ambystoma tigrinum*-like skeletons are often found in the dry shoreline of Totolcingo (Alcocer et al., 1997).

Extensive harvesting (e.g., El Carmen and Alchichica) for local food and sometimes intensive fisheries of salamanders (e.g., Zumpango and Texcoco) are found in saline and freshwater lakes throughout the Mexican Plateau. *Ambystoma* has been appreciated in Mexican cooking since pre-Hispanic times for its white meat and delicate flavor. It is also used as a medicine in respiratory diseases.

Most of the lentic species of *Ambystoma* in Mexico are highly vulnerable to extinction having been subjected to several hundred years of habitat destruction (Brandon, 1989). This is particularly true of the saline lakes Texcoco and Zumpango in the Mexico basin, and Totolcingo and Tepeyahualco in the Oriental basin. (SEDUE, Secretaría de Desarrollo Urbano y Ecología, 1987) catalogues these Mexican *Ambystoma* species as in 'extinction risk'.

2.3.5.3. Aquatic birds According to Hammer (1986) birds use saline lakes as a food source, and for nesting sites and resting areas. They are also used as staging areas during migration. Texcoco lake is an important place for migrating and resident birds. Sixty-eight waterfowl species have been registered in the area, and sixty-five species are associated with the marginal wetland area. Alcocer and Williams (1993) reported the most important species: *Anas*, *Anser*, *Aythia*, *Ceryle*, *Egretta*, *Fulica*, *Grus*, *Larus*, *Nycticorax*, *Pelecanus*, *Rallus* and *Tringa*. The number of birds increases in fall and winter due to the arrival of migratory birds coming from Alaska, Canada and the United States following the 'central migratory route' (SARH, Secretaría de Agricultura y Recursos Hidraúlicos, 1987). The highest number of species and individuals is reached during the first half of spring (Chávez and Huerta, 1985; González, 1985). Before 1985, the number of migratory birds reaching Texcoco was calculated at less than 20,000 individuals, but after that year the number has been increasing up to at least 350,000 birds each year (Valero, 1985). Alcocer and Williams (1996) discussed human activities threatening the bird community of Texcoco and conservation measures.

Sayula playa-lake is another important Mexican water-body that waterfowl (migratory and resident) inhabit. Delgadillo (1996) reports Pelecanidae, Podicipedidae, Anatidae, Ardeidae, Threskiornithidae, Ciconiidae, Elamine, Laridae, Recurvirostridae, Charadriidae, Scolopacidae, Columbidae, Hirundinidae, Laniidae, Icteridae and Fringillidae as migratory birds. Resident families include Anatidae, Cathartidae, Accipitridae, Threskiornithidae, Phasianidae, Ardeidae, Rallidae, Jacanidae, Charadriidae, Columbidae, Cuculidae, Mimidae, Icteridae, Ploceidae and Corvidae.

Taylor (1966) described 36 bird species from the Cuatro Ciénegas basin; Contreras-Balderas (1984) increased the number of species to 61. Some of them (Alcocer and Kato, 1995), surely inhabit both saline and freshwater aquatic bodies of the area (springs, rivers, lakes and ponds).

The most famous Mexican aquatic bird, because of its beautiful color and grace, is probably the Caribbean pink flamingo, *Phoenicopterus ruber ruber*. This species inhabits the coasts of the Yucatán Peninsula (Laguna de Términos, Campeche to Bahía del Espíritu Santo, Quintana Roo), mostly the north coast from Celestún and Río Lagartos in the northwest to Holbox and Cabo Catoche in the northeast.

2.3.5.4. Mammalia Several mammal species are associated with the soda mud-flats and marshland of Texcoco and the tufa towers in Alchichica. The Alchichica area features plentiful voles (*Microtus mexicanus*) and hares (pers. obs.). Reported from the Texcoco area (Alcocer and Williams, 1993) were *Didelphis marsupiales* (Marsupalia), *Cryptotis magna* (Insectivora), *Lepus californicus*, *L. callotis*, *Sylvilagus cunicularius*, *S. floridanus* (Lagomorpha), *Spermophillus mexicanus*, *Microtus mexicanus*, *Peromyscus maniculatus*, *P. lanotis*, *Rattus* *norvegicus* (Roedentia), *Mustela frenata* (Carnivora), and bats. Bats are primarily terrestrial but are intimately associated with water (Schum, 1982). Chacón and Alvarado (1995) report, as common inhabitants of Cuitzeo marshland, the squirrels (*Spermophyllus aureogaster, S. variegatus*), rabbits (*Sylvilagus floridanus*), opossums (*Didelphis virginiana*), foxes (*Urocyon cinereoargenteus*), skunks (*Conepatus mesoleucus*), badgers (*Nasua nasua*) and weasels (*Mustela frenata*).

Acknowledgements

The authors thank Dr. M. Munawar for providing the opportunity to contribute to the proliferation of knowledge concerning Mexican saline lake ecosystems, unknown even to most Mexican scientists, and Prof. W.D. Williams for introducing one of us (J.A.) to the limnology of saline lakes. The senior author thanks the Dirección de Asuntos del Personal Académico of the Universidad Nacional Autónoma de México (project DGAPA IN204597) and Consejo Nacional de Ciencia y Tecnología (project CONACYT 25430-T) which partially supported this investigation.

References

Alcocer, J., 1995. Análisis Holístico de la Comunidad de Macroinvertebrados Bentónicos Litorales de Seis Lagos-cráter con un Gradiente de Salinidad. D.Sc. thesis. Facultad de Ciencias, Universidad Nacional Autónoma de México. México, 106 pp.

Alcocer, J., Escobar, E., 1990. The drying up of the Mexican Plateau axalapazcos. Salinet 4, 36–44.

Alcocer-Durand, J., Escobar-Briones, E., 1991. Freshwater biological research in Mexico: a brief historical review. Freshwater Forum 1(2), 109–114.

Alcocer-Durand, J., Escobar-Briones, E., 1992. The aquatic biota of the now extinct lacustrine complex of the Mexico basin. Freshwater Forum 2(3), 171–183.

Alcocer, J., Kato, E., 1995. Cuerpos acuáticos de Cuatro Ciénegas, Coahuila. In: G. de la Lanza & J.L. García (Eds.), Lagos y Presas de México. Centro de Ecología y Desarrollo, México, pp. 177–193.

Alcocer, J., Williams, W.D., 1993. Lagos salinos mexicanos. In: S.I. Salazar-Vallejo, – N.E. González (Eds.), Biodiversidad Marina y Costera de México. Comisión Nacional para la Biodiversidad y CIQRO, México, pp. 849–865.

Alcocer, J., Williams, W.D., 1996. Historical and recent changes in Lake Texcoco, a saline lake in Mexico. Int. J. Salt Lake Res. 5, 45–61.

Alcocer, J., Chávez, M., Escobar, E., 1993a. La Limnología en México. (Historia y perspectiva futura de las investigaciones limnológicas). Ciencia 44, 441–453.

Alcocer, J., Lugo, A., Estrada, S., Ubeda, M., Escobar, E., 1993b. La macrofauna bentónica de los axalapazcos mexicanos. Actas del VI Congreso Español de Limnología 33: 409–415.

Alcocer, J., Lugo, A., Estrada, S., Ubeda, M., Escobar, E., 1993c. Littoral chironomids of a Mexican Plateau athalassohaline lake. Verh. Internat. Verein. Limnol. 25, 444–447.

Alcocer, J., Lugo, A., Escobar, E., Sánchez, M., 1997. The microbenthic fauna of a former perennial and now episodically filled Mexican saline lake. Int. J. Salt Lake Res. 5, 261–274.

Alcocer, J., Lugo, A., Sánchez, M.R., Chávez, M., Escobar, E., 1998a. Threats to the saline lakes of the Oriental basin. Mexico. by human activities. Verh. Internat. Verein. Limol. 26, 1383–1386.

Alcocer, J., Lugo, A., Sánchez, M.R., Escobar, E., 1998b. Isabela crater-lake: a Mexican insular saline lake. Hydrobiologia, in press.

Alcocer, J., Lugo, A., Ubeda, M., Estrada, S., Peralta, L., Montoya, M.J., Escobar, E., 1998c. Littoral benthos of the saline crater-lakes of the basin of Oriental, Mexico. Int. J. Salt Lake Res, in press.

Alvarez, J., 1950. Contribución al conocimiento de los peces de la región de los Llanos, estado de Puebla (México). An. Esc. nac. Cienc. biol. Méx. 6 (1–4), 81–107.

Alvarez, J., 1970. Peces Mexicanos (Claves). Instituto Nacional de Investigaciones Biológicas y Pesqueras, Comisión Nacional Consultiva de Pesca, México, 165 pp.

Alvarez, J., Navarro, L., 1957. Los Peces del Valle de México. Comisión Nacional para el Fomento e la Piscicultura Rural, México, 62 pp.

Ancona, H.L., 1933. El ahuatle de Texcoco. An. Inst. Biol. Univ. Nac. Méx. 4, 51–69.

Arredondo, J.L., 1995. Los axalapazcos de la cuenca Oriental, Puebla. In: G. de la Lanza, J.L. García (Eds.), Lagos y Presas de México. Centro de Ecología y Desarrollo, México, pp. 65–87.

Arredondo-Figueroa, J.L., Borrego-Enríquez, L.E., Castillo-Domínguez, R.M., Valladolid-Laredo, M.A., 1983. Batimetría y morfometría de los lagos 'maars' de la cuenca de Oriental, Puebla. México. Biótica 8 (1), 37–47.

Arredondo, J.L., Vera, O., Ortíz, A.O., 1984. Análisis de componentes principales y de cúmulos, de datos limnológicos, en el lago de Alchichica. Puebla Biótica 9 (1), 23–39.

Barbour, C.D., 1973. The systematics & evolution of the genus *Chirostoma* Swainson (Pisces. Atherinidae). Tulane Studies Zool. Bot. 18(3), 97–141.

Bassols, A., 1977. Recursos naturales de México. Nuestro Tiempo, México, 345 pp.

Bradbury, J.P., 1971. Paleolimnology of Lake Texcoco, Mexico. Evidence from diatoms. Limnol. Oceanogr. 16(2), 180–200.

Brandon, R.A., 1989. Natural history of the axolotl and its relationships to other ambystomatid salamanders. In: J.B. Armstrong, G.M. Malacinski (Eds.), Developmental biology of the axolotl. Oxford University Press, New York, pp. 13–21.

Brandon, R.A., Maruska, E.J., Rumph, W.T., 1981. A new species of neotenic *Ambystoma* (Amphibia, Caudata) endemic to Laguna Alchichica, Puebla. Mexico. Bull. S. Calif. Acad. Sci. 80(3), 112–125.

Buen, F. de., 1945. Investigaciones sobre ictiología mexicana. I. Atherinidae de aguas continentales de México. An. Inst. Biol. Univ. Nal. Autón. Méx. 16, 475–532.

Calderón, I.A., Rodríguez, M.T., 1986. Estado actual de las especies del género *Ambystoma* (Amphibia: Caudata) de algunos lagos y lagunas del Eje Neovolcánico Central. Bachellor Theses. ENEP Iztacala, UNAM, México. 55 pp.

Castro, T., Castro, J., de Lara R., 1994. La Universidad Autónoma Metropolitana-Xochimilco y la investigación de *Artemia* spp. en México. Boletín Informativo de la Sociedad Mexicana de Planctología A.C. 4.

Ceballos, J.G., Ortega, M.R., Medina, M., Martínez, M., Rodríguez, L.S., González, S., 1994. Análisis Limnológico del Lago de Cuitzeo, Michoacán, México. Universidad Michoacana de San Nicolás de Hidalgo, México. 45 pp.

Chacón, A., 1993. Pátzcuaro un Lago Amenazado. Bosquejo Limnológico. Universidad Michoacana de San Nicolás de Hidalgo, Morelia, 144 pp.

Chacón, A., Alvarado, J., 1995. El lago de Cuitzeo, In: G. de la Lanza, J.L. García (comps), Lagos y Presas de México. Centro de Ecología y Desarrollo, México, pp. 117–127.

Chávez, M.T., Huerta, A., 1985. Estudios ecológicos previos a la creación de un refugio de vida silvestre en el ex-lago de Texcoco Biósfera 1, 18–22.

Cole, G.A., Minckley, W.L., 1968. ''Anomalous'' thermal conditions in a hypersaline inland pond. J. Arizona Acad. Sci. 5(2), 105–107.

Contreras-Balderas, A.J., 1984. Birds from Cuatro Ciénegas, Coahuila. México. J. Arizona-Nevada Acad. Sci. 19, 77–79.

Contreras, S., 1990. Lista anotada de especies de peces mexicanos en peligro o amenazados de extinción. In: J.L. Camarillo, F. Rivera (Eds.), Areas Naturales Protegidas en México y Especies en Extinción. Escuela Nacional de Estudios Profesionales Iztacala. Universidad Nacional Autónoma de México, México, pp. 211–217.

Deevey Jr., E.S., 1957. Limnological studies in Middle America with a chapter on Aztec limnology. Trans. Conn. Acad. Arts Sci. 39, 213–328.

Delgadillo, A.M., 1996. Avifauna de la Laguna de Sayula. Boletín Humedales de México (9), 4–6.

Dyer, W.G., Brandon, R.A., 1973. New host records of *Hidruris siredonis*, *Falcaustra elongata* and *F. mascula* from Mexican salamanders. Proc. Helminth. Soc. Wash. 40(1), 27–30.

Echelle, A.A., Echelle, A.F., 1984. Evolutionary genetics of a 'species flock': atherinid fishes on the Mesa Central of Mexico. In: A.A. Echelle, I. Kornfield (Eds.), Evolution of Fish Species Flocks. University of Maine Press, Orono, ME, pp. 93–110.

Espinosa, H., Gaspar, M.T., Fuentes, P., 1993. Listados Faunísticos de México. III. Los Peces Dulceacuícolas Mexicanos. Instituto de Biología de la Universidad Nacional Autónoma de México, México, 98 pp.

Ezcurra, E., Montaña, C., 1990. Los recursos naturales renovables en el norte árido de México. In: E. Leff (Coord), Medio Ambiente y Desarrollo en México, vol. 1. CIIH-UNAM-Porrúa Colección México: actualidad y perspectivas, México, pp. 297–327.

Ewald, U., 1985. The Mexican Salt Industry 1560–1980. A Study in Change. Fischer, Stuttgart.

Ewald, U., Seele, E., Alcocer, J., 1994. Tequezquite-A story with loose ends. (The occurrence of natural soda in Mexico). J. Salt-History 2, 71–100.

Flores, T., 1918. El tequesquite del lago de Texcoco. An. Inst. Geol. Méx. 5, 1–62.

Flores-Villela, O., 1993. Herpetofauna Mexicana. Annotated List of the Species of Amphibians and Reptiles of Mexico, Recent Taxonomic Changes and New Species. Carnegie Mus. Nat. Hist. Spec. Publ., vol. 17, pp. 1–73.

Garzón, M.A., 1990. Caracterización Saprotrófica de los Lagos Cráter de la Región de Los Llanos, Pue. Bachellor's thesis. ENEP Iztacala, Universidad Nacional Autónoma de México, México, 101 pp.

González, J., 1956. Riqueza Minera y Yacimientos Minerales de México. Congreso Geológico Internacional, XX Sesión. Banco de México, México, 497 pp.

González, E., 1985. El pato mexicano IcyT 7(107), 26–27.

Green, J., 1986. Associations of zooplankton in six crater lakes in Arizona, Mexico and New Mexico. J. Zool. Lond. (A) 208, 135–159.

Guerra, C., 1986. Análisis taxonómico poblacional de peces aterínidos (*Chirostoma y Poblana*). de las cuencas endorréicas del extremo sur del Altiplano Mexicano. An. Esc. Nac Cienc. biol. Méx. 30, 81–113.

Hammer, U.T., 1986. Saline Lake Ecosystems of the World. Dr. W. Junk Publishers, Dordrecht, 616 pp.

Hungerford, H.B., 1948. The Corixidae of the Western hemisphere. Univ. Kansas Sci. Bull. 32, 1–827.

Hutchinson, G.E., 1993. A Treatise on Limnology. The Zoobenthos, vol. 4. Wiley, New York, 944 pp.

INEGI (Instituto Nacional de Estadística Geografía e Informática), 1995. Estadísticas del Medio Ambiente. México 1994. INEGI, México, 447 pp.

Jackzewski, T., 1931. Studies on Mexican Corixidae. Ann. Mus. Zool. Polon. 9, 187–220.

Jansson, A., 1979. A new species of *Krizousacorixa* from Mexico (Heteroptera, Corixidae). Pan-Pacific Entomol. 55(4), 258–260.

Jordan, D.S., Evermann, B.W., 1896 –1900. The fishes of North and Middle America. Bull. U.S. Nat. Mus. 47(1-4), 1–3313.

Lozano, R., 1942. Minerales No-metálicos. Núm. 1. Explotación Industrial de las Sales Sódicas de Algunos Lagos Mexicanos. Sociedad Geológica Mexicana, México, 13 pp.

Lugo, A., Alcocer, J., Sánchez, M.R., Escobar, E., 1993. Trophic status of tropical lakes indicated by littoral protozoan assemblages. Verh. Internat. Verein. Limnol. 25, 441–443.

Lugo, A., Alcocer, J., Sánchez, M.R., Escobar, E., 1998. Littoral protozoan assemblages from two Mexican hyposaline lakes. Hydrobiologia, in press.

Macek, M., Vilaclara, G., Lugo, A., 1994. Changes in protozoan assemblage structure and activity in a stratified tropical lake. Mar. Microb. Food Webs 8, 235–249.

Martín del Campo, R., 1955. Productos biológicos del Valle de México. Rev. Mex. Est. Antropol. 14, 53–77.

Miller, R.R., 1976. Four new pupfishes of the genus *Cyprinodon* from Mexico, with a key to the *C. eximius* complex. Bull. S. Calif. Acad. Sci. 75(2), 68–75.

Miller, R.R., 1986. Composition and derivation of the freshwater fish fauna of México. An. Esc. nac. Cienc. biol. Méx. 30, 153–212.

Olguín, M., 1993. Semi-intensive culture of *Artemia* in Koholoché, Yucatán, México: a pilot study. Salinet 8, 47–52.

Olivares, E., Buckle, L.F., Díaz, F., 1994. An energy budget for *Artemia franciscana* under laboratory conditions. Int. J. Salt Lake Res. 3(1), 1–7.

Orozco, F., Madinaveitia, A., 1941. Estudio químico de los lagos alcalinos. El origen del carbonato sódico. An. Inst. Biol. Univ. Nal. Autón. Méx. 12, 429–438.

Ortega, M.M., 1972. Study of the edible algae of the Valley of Mexico. Botanica Marina 15, 162–166.

Ortega, M.M., Godínez, J.L., Garduño, G., Oliva, M.G., 1995. Ficología de México. Algas Continentales. AGT Editor, México, 221 pp.

Osorio, B.F., 1942. Un nuevo ''*Diaptomus*'' del Mexico central (Copepoda, Diaptomidae). Rev. Brasil. Biol. 2(2), 147–154.

Páez, M.N., 1995. Estudio de las Relaciones Suelos Salinos y Estados de Superficie del Bolsón de Mapimí: Comparación con la Playa de la Reserva de la Biósfera, Durango. Bachelor's thesis. Universidad Juárez del Estado de Durango, México, 96 pp.

Ramírez-García, P., Novelo, A., 1984. La vegetación acuática vascular de seis lagos-cráter del estado de Puebla, México. Bol. Soc. Bot. Méx. 46, 75–88.

Ramírez-García, P., Vázquez-Gutiérrez, F., 1989. Contribuciones al estudio limnobotánico de la zona litoral de seis lagos cráter del estado de Puebla. An. Inst. Cien. Mar y Limnol. Univ. Nal. Autón. Méx. 16(1), 1–16.

Reyes, M., 1979. Geología de la Cuenca de Oriental. Estados de Puebla, Veracruz y Tlaxcala. SEP-INAH. Colección Científica Prehistoria 71, México, 62 pp.

Rojas, T., Pérez, J.G., 1985. La Cosecha del Agua en la Cuenca de México. La Pesca en el Medio Lacustre y Chinampero de San Luis Tlaxialtemalco. CIESAS, Museo Nacional de Culturas Populares. Cuadernos de la Casa Chata 116, México, 142 pp.

Sámano, A., 1934. Contribuciones al conocimiento de las algas verdes de los lagos del Valle de México. An. Inst. Biol. Univ. Nal. Autón. Méx. 5, 149–160.

Sámano, A., 1940. Algas del Valle de México. Parte 2. An. Inst. Biol. Univ. Nal. Autón. Méx. 11, 41–50.

Sánchez, V., Castillejos, M., Rojas, L., 1989. Población, Recursos y Medio Ambiente en México. Fundación Universo Ventiuno, Colección Medio Ambiente 8, México, 141 pp.

SARH (Secretaría de Agricultura y Recursos Hidráulicos) (1987). El lago de Texcoco, refugio de fauna silvestre. SARH and Comisión del Lago de Texcoco. México.

Schum, G.M., 1982. Mammalia. In: S.H. Hurlbert, A. Villalobos-Figueroa (Eds.), Aquatic biota of Mexico, Central America and the West Indies. San Diego State University, San Diego, CA, pp. 525–529.

SEDUE (Secretaría de Desarrollo Urbano y Ecología) (1987). Status UICN para especies de fauna silvestre. Dir. Gral. Conserv. Ecol. Rec. Nat. SEDUE, México.

SPP (Secretaría de Programación y Presupuesto).(1984a). Carta hidrológica de aguas superficiales. Hoja Veracruz E14-3. Escala 1: 250, 000. SPP-INEGI. México.

SPP (Secretaría de Programación y Presupuesto).1984b Carta hidrológica de aguas subterráneas. Hoja Veracruz E14-3. Escala 1: 250, 000. SPP-INEGI. México.

Shiklomanov, I.A., 1990. Global water resources. Nat. Resour. 26, 34–43.

Taylor, E.H., 1943. A new ambystomid salamander adapted to brackish water. Copeia 3, 151–156.

Taylor, W.K., 1966. Avian records from central Coahuila, Mexico, primarily from the Cuatro Cienegas area. Southwest. Nat. 11(1), 136–137.

UNM (Universidad Nacional de México), 1946. Análisis de Aguas Procedentes de Diversos Manantiales y Pozos de la República, Practicados en los Laboratorios de este Instituto. Catálogo de Análisis Serie Fisico-Química No. 2, Instituto de Geología de la Universidad Nacional de México, México, 53 pp.

UNAM (Universidad Nacional Autónoma de México), 1966. Carta metalogénica de la República Mexicana. Cloruro sódico y potásico. Escala 1: 2, 000, 000. UNAM, Instituto de Geologia, México.

UNAM (Universidad Nacional Autónoma de México), 1968. Yacimientos de azufre, cloruro de sodio, sales de sodio y magnesita. Escala 1: 2, 000, 000. UNAM, Instituto de Geologia, México.

Valero, J.M., 1985. Rescate de una ciudad devastada. IcyT 7(107), 17–19.

Vilaclara, G., Chávez, M., Lugo, A., González, H., Gaytán, M., 1993. Comparative description of crater-lakes basic chemistry in Puebla state, Mexico. Verh. Internat. Verein. Limnol. 25, 435–440.

Williams, W.D., 1964. A contribution to lake typology in Victoria, Australia. Verh. Internat. Verein. Limnol. 15, 158–163.

Zárate, J.C., 1917. Las salinas de México y la industria de la sal común. An. Inst. Geol. Méx. 2, 1–71.