ATHALASSOHALINITY
(On the concept of salinity in inland waters)

J. Alcocer
Environmental Conservation & Improvement Project, UIICSE, UNAM, Campus Iztacala, UNAM, Apdo. Postal 314, Tlalnepantla, Estado de México, 05490.

E. Escobar
Benthic Ecology Laboratory, ICML, UNAM, Apdo. Postal 70-305, México, D.F. 04510.

ABSTRACT

Unlike what most people think, inland salt waters are quite many and widespread all over the world. Mostly located in semi-arid regions' endorheic basins, they also can be found at high latitudes (e.g., Antarctica). Inland saline water differs from sea water not only in their total dissolved salt content but also in the ionic composition and ionic rates. In this paper we present useful definitions, methodology and ideas related to inland salt lakes. Moreover, inland salt waters are presented as a unique ecosystem for macroscopic (*sensu* Margalef, 1978; 1981) ecological studies and as a potential source of natural resources e.g. salts, aquatic organisms such as algae (*Spirulina, Dunaliella*) and aquatic invertebrates (*Artemia*, corixid eggs —the Mexican ahuautle—), etcoetera.
KEY WORDS: Athalassohaline lakes, saline lakes, inland waters, salinity, definition, methodology.

RESUMEN

Contrariamente a lo que la mayoría de la gente piensa, los depósitos acuáticos salinos epicontinentales son muy numerosos y están ampliamente distribuidos en todo el mundo. Aunque la mayor parte está localizada en cuencas endorreicas de regiones semi-áridas, también pueden encontrarse en altas latitudes (p.e. en la Antártida). Las aguas salinas epicontinentales difieren de las marinas no sólo en la concentración total de sales disueltas, sino también en su composición iónica y en las relaciones entre éstos. En el presente trabajo se exponen definiciones, metodologías y elementos útiles para reconocer el concepto de salinidad en las aguas epicontinentales. Además, se presentan las aguas salinas epicontinentales como un ecosistema único para llevar a cabo estudios ecológicos macroscópicos (*sensu* Margalef 1978, 1981), así como una fuente potencial de recursos naturales, p.e. sales diversas, organismos acuáticos como algas (*Spirulina, Dunaliella*) e invertebrados (*Artemia*, huevos de coríxido -el ahuautle mexicano), etcétera.
PALABRAS CLAVE: Lagos atalasohalinos, lagos salinos, aguas epicontinentales, salinidad, definición, metodología.

INTRODUCTION

There are four types of drainage systems (Bayly & Williams, 1973): exorheic regions, where much of the rainfall finds its way back to the sea; arheic regions, in which little or no precipitation occurs or in which none is carried off superficially; endorheic regions, in which precipitation never reaches the sea; and cryptorheic system or underground waters.

Salts, marine or non-marine, are usually concentrated in the second and third drainage systems. The arheic regions scarcely hold ephemeral salty water bodies, while endorheic one harbor most of the saline waters in the world (Fig. 1). In Mexico there are several examples of endorheic basins holding salt lakes such as the Comarca Lagunera, the Mexico basin, and the Oriental basin (Fig. 2).

Many chemicals dissolve in rainwater as they pass through the atmosphere, and more are picked up as the water washes over plants and rocks and percolates through the ground before running into rivers and lakes (Burgis & Morris, 1987). If a lake is located in a close or endorheic basin, the water is lost by evapo-transpiration but the salts do not, and concentrates in the remaining water. This process is more evident in semi-arid regions where the salt lakes are most generally located (Williams, 1989), but the freezing of water is also a very important agent in originating this type of water.

Freshwater has an average salinity of 0.2 gl^{-1}, while marine water reaches a mean value of 34 gl^{-1}. Within this range, there are the so called "brackish waters", classified as oligohaline (0.1 to 1-2 gCl l^{-1}), mesohaline (1-2 to 10 gCl l^{-1}) and polihaline (10 to 17gCl l^{-1}), being S‰ = 2 Cl‰ (Margalef, 1983).

Some authors think that the term "brackish" should be used strictly for dilute sea water (Bayly, 1969) or mixtures of fresh and marine waters, although there have been several unfruitful symposia that have discussed this matter (Venice in 1958 and Israel in 1968, both quoted in Williams, 1981a).

"Inland water" is another disputed term. According to Bayly (1967 *in* Bayly, 1991) the strongest connotation of "inland waters" is in the sense of "remoteness from the sea". Thus he proposed a neutral term "athalassic" (Gk. *a*, not; *thalassa*, sea) to include "waters associated with land, irrespective of their salinity or position relative to coastline, which have never been joined to the sea during geologically recent times". On the other hand, "thalassic" waters are restricted to marine waters.

Athalassic saline waters are simple called "athalassohaline waters" describing non-marine waters with an appreciable salt content. This term was first introduced by Bond (1935 quoted by Hutchinson, 1957) concerning "inland saline lakes rich in anions (excepting Cl^-) and frequently in cations (excepting Na^+)", but Bayly's term has no connotation concerning ionic proportions.

Cole (1979), refers to NaCl rich waters similar to marine concentrations or diluted marine waters (brackish) as "thalassohaline", while "athalassohaline waters" have different ionic composition. According to Margalef (1983), "thalassohaline" waters are the last stage in the concentration of marine waters.

The limit between freshwater and "athalassohaline water" has been established by Williams (1964) at 3 gl^{-1}, although others refer to 5 gl^{-1} (Burgis & Morris, 1987). Beadle (1969) expresses that "setting a salinity limit to freshwater is thus a very arbitrary proceeding" but later Beadle (1974) proposed 5 gl^{-1} Nevertheless, Hammer *et al.* (1990), support Williams' limit and classified "athalassic saline waters" (Hammer *et al.*, 1983) as hyposaline (3-20

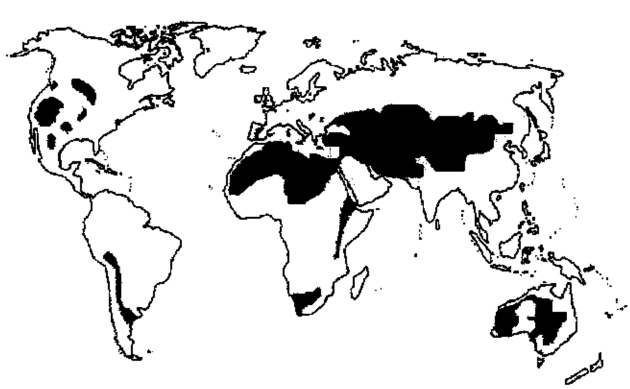

Figure 1. Distribution of natural salt lakes. The shadow areas are mostly arid/semi-arid and endorheic. (Modified from Williams, 1986).

Figure 2. Allocation of the most important endorheic basins in Mexico. (Modified from Reyes, 1979).

$g.l^{-1}$), mesohaline (20-50 gl^{-1}) and hypersaline (>50 gl^{-1}).

Besides the above information, the astatic, variable and unstable physical and chemical nature of most inland saline waters compared with freshwater or marine environments turn them into a different and unique environment (Williams, 1981a).

METHODS FOR MEASURING SALINITY IN INLAND WATERS

Knudsen (1901 *in* Riley & Chester, 1971) defined salinity (S‰) as "the weight in grams of the dissolved inorganic matter in one kilogram of sea water after all bromide and iodide have been replaced by the equivalent amount of chloride, and all carbonate converted to oxide. The total salt content is about 0.45% greater than its salinity, defined in this way", when compared with electrical conductivity as a salinity measure.

Since the linear relationship among density, salinity and chloride + bromide content, chlorinity (Cl‰) —the mass in grams of chlorine equivalent to the mass of halogens contained in one kilogram of sea water— is been used for measuring salinity (S‰ = 0.03 + 1.8050 Cl‰). Methodological advances has lead to define salinity according to electrical conductivity (Riley & Chester, 1971).

Inland water salinity is defined by Margalef (1983), as the quantity of the solids dissolved in one kilogram of water, expressed in grams.

Inland water salinity estimations are carried out mainly as Total Dissolved Solids (TDS) at different evaporation temperatures (103°C, 105°C, 110°C or 180°C), and secondly by electrical conductivity or by measuring specific gravity (hydrometer).

The technique for TDS can be found as technique 209B of the Standard Methods (APHA *et al.*, 1985) or as technique D-1888-78, particulate and dissolved matter, solids, or residue in water of the ASTM Standards (ASTM, 1989); the electrical conductivity method as technique 210A (APHA *et al.* 1985) or D-1125-82 (ASTM, 1989); and the hydrometric 210B (APHA *et al.*, 1985) or specific gravity method D-1429-86 (ASTM, 1989).

It is frequently very useful to analyze not only salinity but also main ionic constituents (K^+, Na^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, CO_3^{2-} and HCO_3^-) and other ions such as borates or silicates that are abundant in some waters. The best way to determine ionic composition of water is by atomic absorption and flame spectrophotometry and ionic chromatography (APHA *et al.*, 1985; ASTM 1989).

INLAND SALINE WATERS COMPOSITION

To recognize inland saline waters it is necessary to establish first what is known as common or standard freshwater. Livingstone (1963), calculated the world's rivers mean salt concentration in 120 ppm —as total dissolved solids (TDS)—, while Rodhé (1949), established the standard water composition (% in mEq) as follows:

ANIONS		CATIONS	
$CO_3^{2-}+HCO_3^-$	74.3	Ca^{2+}	63.5
SO_4^{2-}	15.6	Mg^{2+}	17.5
Cl^-	10.1	Na^+	15.6
		K^+	3.4
TOTAL	100	TOTAL	100

The usual ionic preponderance of surface waters is: cations Ca^{2+}>Mg^{2+}> Na^+>K^+ and anions CO_3^{2-}>HCO_3^->SO_4^{2-} >Cl^-, for a mean salinity of 120 mgl^{-1} (Wetzel, 1975). There are many factors modifying inland waters ionic composition, such as climate (hydric balance, evaporation-precipitation rate), geography (soil attributes), topography (drainage/catchment basin characteristics), biological activity (differential ionic uptake, biological-induced salt precipitation) and time —age— (volume abatement, concentration, differential salt precipitation). Nevertheless, freshwater is characterized by diluted concentrations of HCO_3^-, CO_3^{2-}, SO_4^{2-} and Cl^- of alkaline (Na & K) and alkaline-earth metals (Ca & Mg).

There are three main types of saline water (Hutchinson, 1957) according to anionic dominance: carbonate and bicarbonate (HCO_3^-, $CO_3^{=}$), sulfate ($SO_4^{=}$) and chloride waters (Cl^-), although many intermediate mixtures can be found.

As standard freshwater evaporates, $CaCO_3$ precipitates enriching itself proportionally in Cl^- and $SO_4^{=}$; later $CaSO_4.2H_2O$ (gypsum) precipitates enriching itself in Cl^-. In this way, the water passes from carbonate to sulphate-chloride and to chloride water.

If the bicarbonate concentration is high and the concentration of the alkaline and the alkaline-earth metals are similar, after all the $CaCO_3$ and most of the $CaSO_4.2H_2O$ have been precipitated, the main salts remaining in solution are Na_2CO_3 and $Na_2(HCO_3)_2$, resulting in carbonate or carbonate-chloride water (Hutchinson, 1957).

When marine water is evaporated —hypersaline waters— the ionic rates are altered by differential salt precipitation processes modifying the calcium concentration and therefore the pH. If evaporation continues, non-marine saline waters are produced (athalassohaline). During the last concentration stages, sodium and magnesium became the dominant cations; nevertheless magnesium salts are more soluble than those with sodium, thus enriching the water in magnesium (Margalef, 1983).

The differences between athalassohaline waters are given by total concentration and the quantitative relationships among the total ionic salinity different constitutive elements [(Ca^{2+}, Mg^{2+}, Na^+ & K^+)+(HCO_3^-, CO_3^{2-}, SO_4^{2-} & Cl^-)].

Most of saline waters are different in ionic composition from marine waters. Usually, the closer the body of water is to the coastline, the higher its sodium concentration is, and the farther it is from the coastline the higher is its calcium and magnesium concentration (Hutchinson, 1957). Nevertheless, the far-from-the-sea Caspian (Azerbaijan, Russian Federation, Kazakhstan, Turkmenistan, Iran) and Aral (Uzbekistan, Kazakhstan) Seas resemble dilute seawater but with a higher sulphate and magnesium concentration; however, on the other hand, the hypersaline Dead Sea (Israel) is dominated by magnesium chloride ($MgCl_2$) instead of sodium chloride (NaCl) as seawater (Margalef, 1983). Thus, generally speaking, sodium chloride type inland salt lakes parallel seawater but with a higher sulfate concentration. Alchichica and Atexcac in Puebla are good examples (Vilaclara *et al.*, 1993), but the neighboring El Carmen -Totolcingo- lagoon has sodium carbonate and sodium bicarbonate as dominant salts.

According to Cole (1979), out of the relative solubility of some compounds in distillate water at 10°C, the solubility of NaCl being equal to 1, the theoretical order of salt precipitation formed with the most abundant ions of inland waters is as follows (the relative solubility is showed in brackets).

The first salts to precipitate are $CaCO_3$ and $MgCO_3$ (0.0004), increasing the relative SO_4^{2-} and Cl^- content in the remaining liquid phase. $CaSO_4$ (0.006) is the next salt to precipitate enriching the Na^+ and Mg^{2+} relative content. These three species are characteristic of dilute waters due to their low solubility. Following in the precipitation order, Na_2SO_4 (0.3) increases the relative content in Cl^-. If there is still CO_3^{2-}, the next salt in precipitating is Na_2CO_3 (0.4) and after it, $MgSO_4$ (0.9). Finally the only salt remaining is NaCl (1.0). Although $MgCl_2$ (1.3) and $CaCl_2$ (1.5) have the highest relative solubility values, at this stage neither Ca^{2+} nor Mg^{2+} remain free, both having been previously complexed and precipitated jointly with CO_3^{2-} and SO_4^{2-}.

The Dead Sea (Cole, 1979) is one of the uncommonest places where the $MgCl_2$ (64%) and the $CaCl_2$ (36%) can be found; it reaches up to 285 gl^{-1} (Margalef, 1983). The most soluble salt ($CaCl_2$) is scarcely found in nature because Ca^{2+} is precipitated first as $CaCO_3$ (e.g. Don Juan Pond, Antarctica).

The main type of thalassohaline lakes are the salterns $(NaCl)^*$ and the bitterns (represented by Br^{2+} and Mg^{2+} salts). These two types of lakes are formed when most of the marine salts have been precipitated. On the other hand, the main types of athalassohaline lakes are dilute waters of $CaCO_3^{**}$ and $CaSO_4^{***}$ (these waters do not exist in concentrated form), marl lakes $(CaCO_3 \text{ and } MgCO_3)^{**}$, soda or alkaline lakes $(Na_2CO_3)^{***}$, potash lakes $(K_2CO_3)^{**}$, sulphate lakes $(CaSO_4)^{***}$, sodium-sulfate lakes $(Na_2SO_4)^{****}$, borax lakes ($Na_2B_4O_7$) and, finally, the triple water type with similar concentrations of CO_3^{2-}, Cl- and SO_4^{2-} (Cole, 1979; Hutchinson, 1957). Lakes marked by one asterisk (*) are generally known as soda lakes, by two asterisks (**) as carbonate lakes and by three asterisks (***) as sulphate lakes.

According to Hutchinson (1957), chloride-carbonate waters are developed by bacterial reduction of SO_4 to H_2S within bottom mud when they are exposed to air during low water level periods. It leads to a proportional enriching in CO_3 and Cl; the latter ion is usually carried by the wind from marine areas. Sulfate-chloride waters originate by normal $CaCO_3$ precipitation, leading to a predominance of SO_4^{2-} and Cl^-.

MACROSCOPIC STUDIES IN INLAND SALINE LAKES

The research of the attributes of ecosystems *in toto* provides significant information concerning their functioning. Margalef (1978, 1981) coined the term "macroscopic" in the design of this type of study. There is an inherent tendency (Margalef, 1963 & 1978, Odum, 1969) in ecosystem homeostasis maximization against environmental fluctuations; this change results in the increase of the complexity of ecosystems from an instable low complexity to a stable more complex ecosystem (Margalef, 1977 & 1983).

Unfortunately, natural succession takes long periods of time and the extrapolation of experimental ecosystems (microcosms) is highly criticized. Nevertheless, athalassohaline lakes are exposed to a wide range of environmental stress and perturbation, mainly expressed by salinity, resulting in ample spectra of stability and degree of complexity. This fact provides the tools for the examination and testing of the concept of the macroscopic attributes of ecosystems (Alcocer & Williams, 1993; Williams, 1972, 1981b & 1993).

Whole-ecosystem studies in freshwater are difficult and complex undertakings due to the great diversity of species involved, habitat heterogeneity, the lack of discreetness (no delimitation), and the complexity of trophic relationships (Williams, 1981a). In athalassohaline waters the former difficulties are minimized as follow (Cole, 1979; Bayly & Williams, 1973; Williams, 1972, 1981a & 1981b).

Inland salt waters have greatly decreased the diversity of species ($H' = 1/S‰$); highly saline lakes lack fish and macrophytes or at least its diversity is greatly reduced. Once eliminated most of the biotic components, the complexity of the trophic relationships is lessened and thereby the trophic-dynamic studies can be hastened.

Common shallowness of most salt waters exposed to the action of wind, mix the water throughout the volume of the lake. Therefore, substrate, and physical, chemical and biological stratification is avoided both vertically and horizontally. Inland salt lakes are the final water stage of endorheic basins. As a terminus lake, it is a closed system (no outlet) or, by definition, more discrete (well delimited) than any other ecosystem of similar size.

Doubtless, Lake Texcoco is the most studied Mexican saline lake. The first report we have of limnological studies carried out in Mexican inland salt lakes is the observation of the changes in the water level and the formation of a seiche in Lake Texcoco prior to 1519 (Deevey, 1957) and its salt content (Virlet d'Aoust, 1865 *in* Williams, 1986), as well as the description of the biota of the Mexico's basin lake complex (Alcocer-Durand & Escobar-Briones, 1991, Alcocer *et al.*, 1993).

Moreover, a suitable Mexican example to carrying out macroscopic studies on athalassohaline waters of different complexity is found in the crater-lakes of Los Llanos de Puebla (Alcocer & Escobar, 1990). Probably, another case could be found in the crater-lakes of the Valle de Santiago, Guanajuato.

INLAND SALINE LAKES AS A NATURAL RESOURCE

In México, the saline Lake Texcoco has been a very important place for exploiting aquatic resources. The Aztecs obtained fish, waterfowl, aquatic insects, from Lake Texcoco and other lakes of the Mexico basin as are depicted in the ancient Nahuatl codexes (Alcocer-Durand & Escobar-Briones, 1991, Alcocer *et al.*, 1993).

The main resources obtained from Lake Texcoco have been sodium chloride and sodium carbonate ("tequixquitl"); the blue-green algae *Spirulina* ("tecuitlatl"); the adults ("axayacatl") and eggs ("ahuautli") of corixid insects; the adults ("amoyotl", "moyotl" or "muyutl"), pupae ("puxi" or "poxi") and larvae ("izcahuitl") of ephydrid insects; the goodeid fish *Gyrardinichthys* spp *("mextlapique" or "cuitlapetlatl"); and waterfowl (jointly named "canauhtli") as mentioned by Alcocer-Durand and Escobar-Briones (1992).*

Williams (1981a) has established a wide range of economically exploited resources of salt lakes such as the following. One of the most important products extracted from inland mineral waters are salts. Borax (sodium borate), soda-ash (sodium carbonate), sodium sulphate and halite (sodium chloride) have long been obtained from salt lake sediments.

From clastic sediments certain types of clay can be obtained. Evaporative sediments (evaporites) have also been greatly exploited as a source of trona (sodium sesquicarbonate), soda-ash, gypsum (calcium sulphate), thenardite (sodium sulphate), halite, borates, lithium, zeolites (silicates), and recently uranium. Brines have also been exploited since ancient times to obtain potash (potassium chloride) and other salts similar to those extracted from evaporites.

Nowadays less-saline lakes are being considered for the irrigation of some salt-tolerant crop species. Highly saline waters cannot be considered for irrigation purposes but for aquaculture. Fish and invertebrate cultures are growing all over the world. *Artemia salina* is widely used as a live food for fish fry in aquaculture and for aquariums. Cultures of the algae *Spirulina* (e.g., Mexico and Africa) and *Aphanothece halophytica* could provide protein-rich food for animal and human consumption. Another salt lake algae, *Dunaliella salina*, is been cultured as a source of beta-carotene (source of provitamin A) (Alcocer & Williams, 1993, Williams, 1993).

Finally, grazing in arid and semi-arid areas of Mexico, specially by domesticated mammals (sheep and catle), become manifest in changes to run-off patterns. The clearing of deep-rooted trees and its replacement by shallow-rooted grasses and crop species frequently has led to changes in local hydrology. These changes lead to changes in the salinity and seasonality of run-off. Underlying groundwaters (often saline) may approach the land surface where capillarity action alone causes it to reach the surface (Alcocer & Williams, 1993; Williams, 1993). The soil salinization phenomena is multiplied when crop land is watering with salt-rich water, leading to salinization and sodicity problems (Ezcurra & Montaña, 1990; Toledo, 1990).

ACKNOWLEDGEMENTS

Authors would like to thank Dr. G. Vilaclara (UNAM Campus Iztacala) for helpful comments, and to Mr. J. Doshner (Facultad de Química, UNAM) for grammatical review of the manuscript. Special thanks are extended to Dr. W.D. Williams (The University of Adelaide) and to Dr. F.A. Comín (Universidad de Barcelona) for introducing us to the study of athalassohaline lakes.

REFERENCES

ALCOCER-DURAND, J. & E. ESCOBAR-BRIONES, 1990. The drying up of the Mexican Plateau axalapazcos. *Salinet*, **4**: 34-36.

——— 1991. Freshwater biological research in Mexico: a brief historical review. *Freshwater Forum*, **1**(2): 109-114.

———, 1992. The aquatic biota of the now extinct lacustrine complex of the Mexico Basin. *Freshwater Forum*, **2**(3): 171-183.

ALCOCER, J. y W.D. WILLIAMS, 1993. Lagos salinos mexicanos. *En*: Salazar-Vallejo, S.I. y González, N.E. (eds.). *Biodiversidad marina y costera de México*. pp. 849-865. Com. Nal. Biodiversidad y CIQRO. México.

ALCOCER, J., M. CHÁVEZ y E. ESCOBAR, 1993. La Limnología en México (historia y perspectiva futura de las investigaciones limnológicas). *Ciencia*, **44**: 441-453.

APHA, AWWA & WPCF, 1985. *Standard methods for the examination of water and wastewater*. APHA. Baltimore. 1268 p.

ASTM, 1989. *1989 annual book of ASTM standards*. 11.01(I) Water. A.S.T.M. Philadelphia. 591p.

BAYLY, I.A.E., 1969. Salt and brackish waters. Introductory comments. *Verh. int. Verein. Theor. Angew. Limnol.*, **17**: 419-420.

———, 1991. On the concept and nature of athalassic (non-marine) saline waters. *Salinet*, **5**: 76-80.

BAYLY, I.A.E. & W.D. WILLIAMS, 1973. *Inland waters and their ecology*. Longman Australia. Victoria. 314 p.

BEADLE, L.C, 1969. Osmotic regulation and the adaptation of freshwater animals to inland saline waters. *Verh. int. Verein. Limnol.*, **17**: 421-429.

———, 1974. *The inland waters of tropical Africa*. Longman. London. 365 p.

BURGIS, M. & P. MORRIS, 1987. *The natural history of lakes*. Cambridge University Press. Cambridge. 218p.

COLE, G.A., 1979. *Textbook on Limnology*. The C. V. Mosby Company. San Louis. 426p.

DEEVEY, E.S., 1957. Limnologic studies in Middle America, with a chapter on Aztec limnology. *Trans. Conn. Acad. Arts Sci.*, **39**: 213-328.

EZCURRA, E. y MONTAÑA, C. 1990. Los recursos naturales renovables en el norte árido de México. pp. 297-327 *En:* E. Leff (Ed.). *Medio ambiente y desarrollo en México*. Colección México: actualidad y perspectivas. CIIH, UNAM/Porrúa. México.

HAMMER, U.T., J. SHAMESS, & R.C. HAYNES, 1983. The distribution and abundance of algae in saline lakes of Saskatchewan, Canada. *Hydrobiologia*, **105**: 1-26.

HAMMER, U.T., J.R. SHEARD, J.R. & J. KRANABETTER, 1990. Distribution and abundance of littoral benthic fauna in Canadian prairie saline lakes. *Hydrobiologia*, **197**: 173-192.

HUTCHINSON, E.G. 1957. *A treatise on Limnology*. Vol. I. Part. 2. *Chemistry of lakes*. John Wiley and Sons. New York. 1015 p.

LIVINGSTONE, D.A., 1963. *Chemical composition of rivers and lakes*. U.S. Geol. Surv. Prof. Paper 440-G. U.S. Government Printing Office. Washington. 64 p.

MARGALEF, R., 1963. On certain unifying principles in ecology. *Amer. Nat.*, **97**: 357-374.

———, 1977. *Ecología*. Ediciones Omega. Barcelona. 951p.

———, 1978. *Perspectivas de la teoría ecológica*. Blume. Barcelona. 110 p.

———, 1981. *Ecología*. Editorial Planeta. Barcelona. 252 p.

———, 1983. *Limnología*. Ediciones Omega. Barcelona. 1010 p.

ODUM, E.P., 1969. The strategy of ecosystem development. *Science*, **164**: 262-270.

REYES, M., 1979. Geología de la cuenca de Oriental, estados de Puebla, Veracruz y Tlaxcala. *Colección Científica Prehistoria*, **71**. SEP/INAH. México. 62p.

RILEY, J.P. & R. CHESTER, 1971. *Introduction to marine chemistry*. Academic Press. London. 465 p.

RODHE, W. 1949. The ionic composition of lake waters. *Verh. int. Verein. Limnol.*, **10**: 377-386.

TOLEDO, V.M. 1990. El proceso de ganaderización y la destrucción biológica y ecológica de México. pp. 191-227. *En:* E. Leff (Ed.). *Medio ambiente y desarrollo en México*. Colección México: actualidad y perspectivas. CIIH, UNAM/Porrúa. México.

VILACLARA, G., CHÁVEZ, M. LUGO, A. GONZÁLEZ H. & M. GAYTAN, 1993. Comparative description of crater-lakes basic chemistry in Puebla state, Mexico. *Verh. Internat. Verein. Limnol.*, **25**: 435-440.

WETZEL, R.G., 1975. *Limnology*. W.B. Saunders Company. Philadelphia. 743p.

WILLIAMS, W.D. 1964. A contribution to lake typology in Victoria, Australia. *Verh. int. Ver. Limnol.*, **15**: 158-163.

———, 1972. The uniqueness of salt lake ecosystems. *In:* Kajak, Z. & Hillbricht-Ilkowska, A. (eds.). *Productivity problems of freshwaters*. pp. 349-361. IBP-UNESCO. Poland.

———, 1981a. Inland salt lakes: An introduction. *Hydrobiologia*, **81/82**: 1-14.

———, 1981b. The limnology of saline lakes in Western Victoria: a review of some recent studies. *Hydrobiologia*, **81/82**: 233-260.

———, 1986. Limnology, the study of inland waters: a comment on perceptions of studies of salt lakes, past and present. *In:* P. De Decker, & W.D. Williams, (eds.). *Limnology in Australia*. pp. 471-484. CSIRO. Melbourne.

———, 1989. International consortium for salt lake research. Proposal. *Salinet*, **1**: 2-3.

———, 1993. Conservation of salt lakes. *Hydrobiologia*, **267**: 291-306.

Recibido: 5 de Octubre de 1992.
Aceptado: 15 de Enero de 1993.