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ASSESSMENT OF WATER QUALITY OF LAKE XOLOTLAN (MANAGUA; NICARAGUA) WITH BENTHIC DIATOMS FROM THE LITTORAL ZONE

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ZUSAMMENFASSUNG

Die Diatomeenbiozönose im Litoral des Lago Xolotlán (Lago de Managua) wurde analysiert. 62 taxonomische Einheiten konnten bestimmt werden. Die Kieselalgengesellschaften waren auf Grund extrem variabler Umweltbedingungen - verschiedene Substrattypen, Zonen intensiven Wellenschlages, ruhige Buchten, unterschiedliche Intensitäten organischer und toxischer Belastung - sehr heterogen ausgebildet. Entsprechend der floristischen Affinität konnten vier Hauptgruppen der benthischen Diatomeen differenziert werden. Mit Hilfe des Saprobiensystemes nach PANTLE und BUCK (1955), ZELINKA und MARVAN (1966), SLÁDECEK (1973), sowie LANGE-BERTALOT (1979) wurde die Gewässergüte im Litoral abgeschätzt. Im gesamten untersuchten Litoralbereich wiesen Artenspektrum und relative Individuenhäufigkeiten des Kieselalgenaufwuchses auf die außerordentliche organische Belastung des Sees hin. Die Biozönose indizierte eine übermäßig schwere organische Belastung im Bereich vor Managua (Entnahmeorte 7 und 8). Eine mäßige organische Belastung wurde nur im nördlichen Küstenbereich, bei San Francisco Libre (12) und Santa Gertrudis (10) festgestellt.

ABSTRACT

The diatom community in the littoral zone of Lake Xolotlán (L. Managua) was studied. Sixty-two diatom species were identified. The diatom biocenosis showed a great heterogeneity along the coast line due to the varied environmental conditions generated by different intensities of organic and toxic pollution, different types of substrate, unequal wave action and other factors. Four groupings of benthic associations were identified according to the floristic affinity. The system of saprobic organisms was applied, following LANGE-BERTALOT (1979), ZELINKA and MARVAN (1966), SLÁDECEK (1973) and PANTLE and BUCK (1955) for the estima-

tion of water quality. The composition and diversity of benthic diatom communities reveal the strong impact of organic polution, affecting the whole lake. The biocenosis inidicates a heavy organic pollution in front of Managua (sampling sites 7,8) and a moderate pollution only in the northern shore near San Francisco Libre (12) and Santa Gertrudis (10).

1. INTRODUCTION

Lake Xolotlán is the smaller one of the two Central American Lakes in the Nicaraguan rift valley. The hydrochemical character is dominated by sodium bicarbonate. The lake is situated in a volcanic area and undergoes a naturally salinization process. It is heavily contaminated by untreated domestic waste from the capital Managua, by heavy metals (mercury) from industries near the shore and by pesticides from agricultural activities in the catchment area.

Table 1. Basic data of Lake Xolotlán (according to LACAYO, 1991)

Hydromorphological data		**Physical and chemical data; meansfrom 11 sampling stations (1988-1989)**	
Latitude (center of lake)	12°30' N	pH	9.22
Longitude (center of lake)	86°45' W	Conductivity	1773 µmhos.cm^{-1}
Elevation (mean)	37.84 m asl	Turbidity	15 75 NTU
Lake surface area at 37,84 m asl	1016 km^2	Secchi disc	0.31 m
Watershed basin area	6668 km^2	Ca^{2-}	7.5 mg/l
Total volume	7.97 x 10^6 m^3	Mg^{2-}	18.7 mg/l
Maximum depth	26 m	Na^-	402.6 mg/l
Mean depth	7.8 m	K	56.5 mg/l
Maximum length	58.4 km	Fe^{2-}	0.57 mg/l
Maximum width	32.7 km	Cl^-	237 mg/l
Climate		B^{3-}	2.31 mg/l
Mean annual air temperature	27.3 °C	NO_{3-}	3.12 mg/l
Daily air temperature fluctuation	10 °C	NO_{2-}	0.13 mg/l
Mean annual wind velocity	2.71 m/sec	SO4	41 4 mg/l
Mean annual precipitation	1140 mm	O_2	7.8 mg/l
Mean annual evaporation	2395 mm	$PO4^{3-}$	0.14 mg/l

The pollution has reached a level that public health is threatened. The water has become unsuitable for agricultural use. On request of the Nicaraguan government and subsidized by European countries a project to study the extent of pollution and the ecological status of the Lake was started. One of the major goals of the project was, to generate limnological data in order to support the lake`s management and facilitate measures to improve its water quality (MEULEMANS, 1991).

2. METHODS

Selection of sampling sites was done along the coast line of Lake Managua trying to include all types of substrates and all influential zones of major economic activities (Fig. 1).

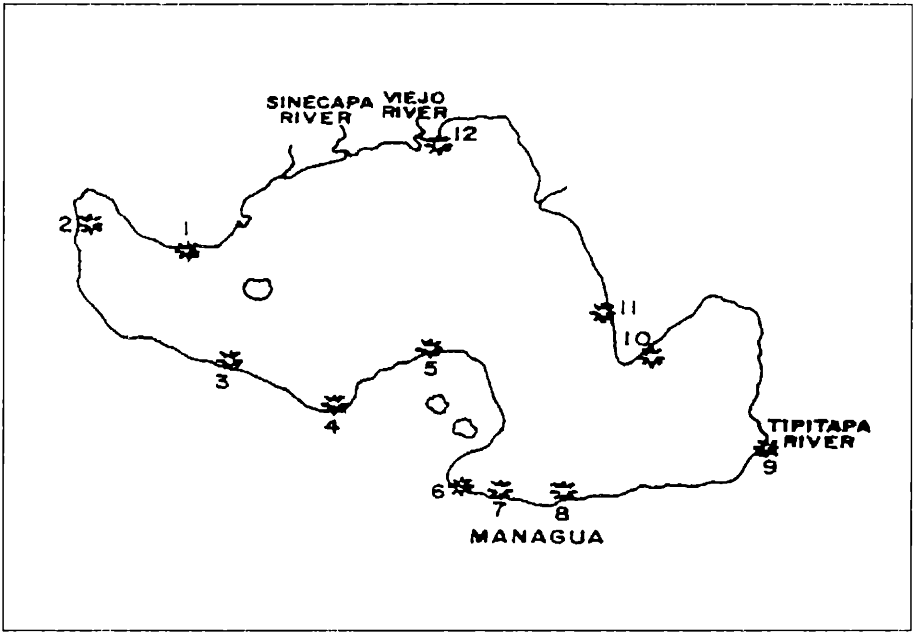

Fig. 1 Location of sampling sites

The morphologic properties, the economic activity of the neighbourhood and the pollution sources from twelve sampling stations were determined (Tab. 2).

The samples were taken during November and October 1987 from fixed rocks, stones, mud and - in one occasion - from macrophytes in the eulittoral and superior infralittoral zone.

The diatoms were separated from inorganic particles by sedimentation and afterwards treated with sulphuric acid, potassium dichromate and hydrogen peroxid. The cleaned diatoms were mounted in Pleurax, determinated according to KRAMMER& LANGE-BERTALOT (1986), LANGE-BERTALOT (1977), LANGE-BERTALOT (1978), LANGE-BERTALOT (1979), LANGE-BERTALOT (1980), LANGE-BERTALOT & SIMONSEN (1978) and ROUND (1979) and counted with a Zeiss ICM 405 microscop with interference contrast at an enlargement of 10 x 100

Tab.2: Description of sampling sites

Sampling sites	Substrate	Wave action	Macroph.	Human Perturbation
1 - Planta Geotérmica	rocky littoral, with sandy sediments	strong	-	thermal contamination
2.- Puerto Momotombo	sandy littoral, with some rocks	strong	-	organic pollution, fishing
3.- Boquerón	rocky and sandy littoral	none	-	organic pollution by garbage
4.- Mateare	rocky littoral	moderate	+	fishing and farming activity, rubbish dump
5.- Corpus Christi	rocky littoral	strong	-	fishing
6.- Vuelta de Guitarra	rocky littoral	moderate	+	contamination by solid residues and fuel
7 Penwalt	sandy littoral	moderate		toxic pollution (mercury)
8.- Rubén Darío	rocky littoral	strong	+	heavy organic and toxic pollution
9.- Bahia Tipitapa	muddy substrate	none	+ water hyacinth	organic pollution
10.- Santa Gertrudis	rocky littoral, with sandy sediments	moderate	+	fishing and cattle activity
11.- San Ramón	sandy sediment	moderate	+	-
12.- San Francisco Libre	rocky littoral	strong	+	fishing and cattle activity

The taxonomic distance was calculated and a grouping analyses was done starting from the similarity matrix. A phenogram was built following the method of the „pair group" and average bond (SOKAL, 1961) and the diversity of the Bacillariophyceae (according to MARGALEF, 1951) was calculated.

For the assessment of saprobiological water quality, three systems were employed:

1.- The tolerance of diatoms to water pollution (LANGE-BERTALOT, 1979).
2.- The saprobic valency (ZELINKA and MARVAN, 1961 and SLADECEK, 1973)
3.- The saprobic index (PANTLE and BUCK, 1955).

The Lange-Bertalot method is based on the tolerance of Bacillariophyceae to different pollution levels. By grouping diatoms with similar tolerance in three categories their percentage within the community can be used as indicator for water quality:

1.- Most tolerant species, actively growing under oligo- to polysaprobic conditions.
2.- Less tolerant species, actively growing under oligo- to alphamesosaprobic conditions.
3.- Sensitive species, dominating wherever mesosaprobic or better conditions develop.

After counting, the sum of the relative abundance of „differentiating“ species was calculated, considering the three categories.

The determination of the water quality class was done according to the following pattern:

IV· Predominance of more tolerant species; less tolerant species below 10 %.

III-IV· Predominance of more tolerant species; less tolerant species over 10 % and never more than 50 %.

III: Predominance of less tolerant species over 50%; sensitive species never more than 10 %.

II-III: Sensitive species over 10 % but always below 50 %.

II: Sensitive species always over 50 %.

The remaining two methods according to ZELINKA & MARVAN (1961), SLADECEK (1973) and PANTLE & BUCK (1955) are based on the saprobic system that distinguishes essentially four saprobity levels as a result of different levels of organic pollution and intensities of organic degradation in the water. The saprobity levels are correlated to four water quality classes:

water quality cass I (oligosaprobic)	degree of pollution: non to very slight
water quality class II (ß-mesosaprobic) -	degree of pollution: moderatly polluted
water quality class III (α-mesosaprobic) -	degree of pollution: heavily polluted
water quality class IV (polysaprobic) -	degree of pollution: extremely polluted

3. RESULTS AND DISCUSSION

A total of 62 genera, species and varieties of Bacillariophyceae were identified. This small number of taxa can be explained by the extreme environmental conditions - high salt content, intensive organic and toxic pollution. The dominant species (at least 5 % of total abundance) are listed in Fig. 2 with indications of their relative abundances at the 12 sampling points.

3.1 CHARACTERISTIC DIATOM POPULATIONS IN THE LITTORAL ZONE

The following phenogram presents the groupings of the diatom community. It shows four main groups, determining the similarity of the diatom associations regarding their sampling sites (Fig. 3).

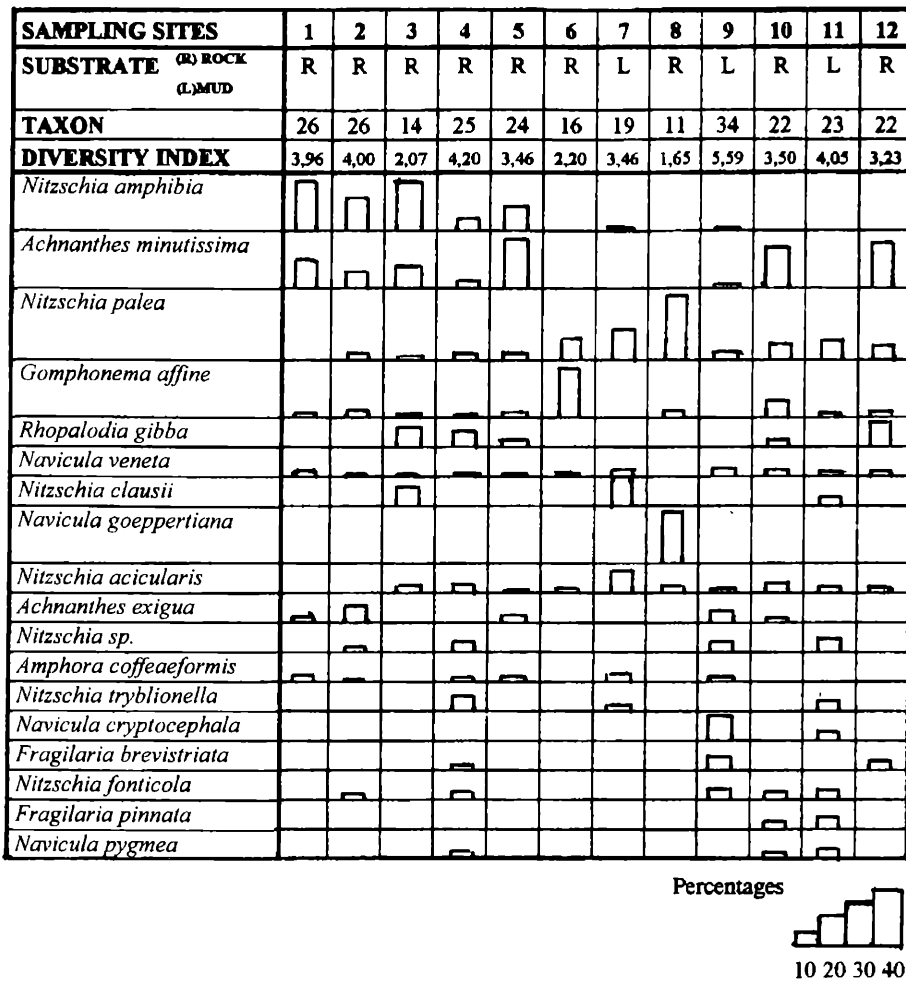

Fig.2: Relative abundances of diatoms in the littoral of Lake Xolotlán

Group I: Includes populations developing on rocks and stones under mesosaprobic conditions. They are characterized by low to intermediate values of the diversity index (2.1 - 4.0) and low numbers of diatom taxa (14 - 26).

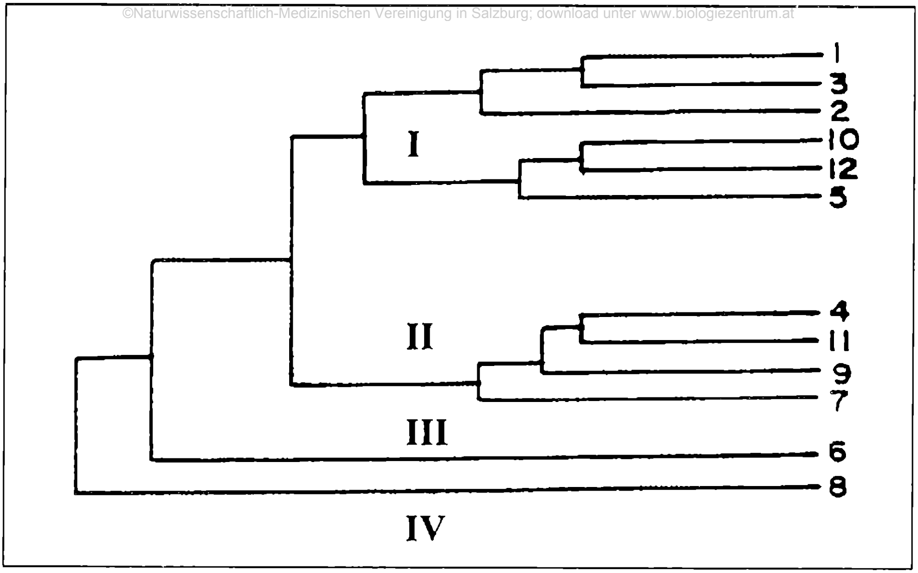

Fig. 3: Grouping analysis according to the relative abundances of diatom communities

Group I consists of 3 subgroups:

Subgroup 1. Geothermic Plant (1) and Boquerón (3).

These communities reflect a major influence of local pollution. *Nitzschia amphibia* predominates. It is a cosmopolitan species tolerant to alpha-mesosaprobic conditions. *Achnanthes minutissima* comes in second place. Both represent 60 % of the total abundance.

Subgroup 2: Puerto Momotombo (2).

It is linked to the nucleus of Geothermic Plant and Boquerón. It is also influenced by local pollution, although the dominance of *Nitzschia clausii* and *Achnanthes exigua* (partly replacing *Achnanthes minutissima*) and the replacement of *Nitzschia amphibia* by *Nitzschia clausii* makes it different from subgroup 1. *Nitzschia clausii* is frequently present in saline waters and reproduces very fast in alpha-mesosaprobic waters.

Subgroup 3: Santa Gertrudis (10), San Francisco Libre (12) and Corpus Christi (5).

There is a nucleus formed by Santa Gertrudis and San Francisco Libre that is linked with Corpus Christi to form this subgroup.

These communities seem to be slightly affected by diffuse local pollution. The predominant diatom is *Achnanthes minutissima*, a species that better develops under optimal oxygen provision and under beta-mesosaprobic conditions. Predominance of *Achnanthes minutissima* over *Nitzschia amphibia* may be the result of mechanical and physiological factors. Communities of the littoral zone are exposed to a strong wave action. Hence *Achnanthes* is in a better competitive situation than *Nitzschia*, which keeps moving without adhesion to the substrate by means of mucilage secretion. This part of the coast seems to be less affected by pollution and for this reason, *Nitzschia amphibia* is less abundant here than in subgroup 1.

Group II: Communities in a littoral zone with little wave action and high sedimentation rates under alpha-mesosaprobic and polysaprobic conditions, with intermediate to higher values of the diversity index (3,5- 5,6) and low to intermediate number of diatom taxa (19 - 34).

Group II consists of 2 subgroups:

Subgroup 1: Tipitapa (9) and a nucleus formed by San Ramón (11) and Mateare (4).

These groups include assemblages developing on rocks in a quiet bay (Mateare) as well as associations growing on fine sediment (San Ramón and Tipitapa). Due to the low water turbulance, diverse associations develop, with a significant representation of phytoplanctonic species. No species reaches a great abundance but there is a great number of dominant species.

Subgroup 2: Penwalt (7).

Characterized by a low number of species and low values of abundance. The dominant Bacillariophyceae are: *Nitzschia palea, Nitzschia acicularis, Nitzschia veneta.* LANGE-BERTALOT (1979) points out that *Nitzschia palea* and *Nitzschia veneta* grow vigorously under polysaprobic conditions.

Group III: Vuelta de Guitarra (6).

Represents a particular assemblage. It does not show any affinity with other littoral associations. The number of species and diversity is low. The diatoms grow on rocks, with *Gomphonema affine* predominating (tropical species, tolerant to high ionic concentrations). Also dominant are the species *Nitzschia clausii* and *Nitzschia palea.*

Group IV: In front of Managua City (8).

This is a peculiar community, with the lowest number of species and diversity. Two predominant species (*Nitzschia palea* and *Navicula goeppertiana*) make up 80 % of the biocenosis.

Group III and IV are affected by heavy organic and toxic pollution.

3.2 ASSESSMENT OF WATER QUALITY IN THE LITTORAL OF LAKE XOLOTLÁN

The abundance of three species (*Achnanthes minutissima*, *Nitzschia amphibia* and *Nitzschia palea*) belonging to the three categories according to LANGE-BERTALOT (1979) may serve as example to indicate the various degrees of contamination in the coastal zone of the lake. Their species specific tolerance limits against decreasing water quality are known and therefore represent outstanding bioindicators for different degrees of pollution.

Table 3 Biological water quality assessment according to different methods.

Sampling stations	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
3a) According to Lange-Bertalot (1979) *Species groups*												
More tolerant taxa	14.9	8.2	5.1	11.2	6.9	22.1	28.6	83.4	11.4	11.3	13.8	8.1
Less tolerant taxa	43.5	53.8	46.2	30.4	28.0	21.8	25.2	1.4	35.6	8.4	19.0	5.6
Sensitive taxa	20.5	9.6	18.2	3.2	37 1	0.0	1.4	0.0	3.1	30.8	0.0	36.8
Indifferent taxa	21.1	28.4	30.5	55.2	28.0	56.1	44.8	15.2	49.9	49.5	67.2	49.5
Water quality class	**II-III**	**III**	**II-III**	**III**	**II-**	**III-IV**	**III-IV**	**IV**	**III**	**II-**	**-**	**II**
3b) According to Zelinka & Marvan (1961) and Sladecek (1973) *saprobity level*												
xenosaprobic	1		1		1					1		1
oligosaprobic	2	2	2	1	3				1	2	1	3
ß-mesosaprobic	4	5	4	3	4	3	3	3	4	4	3	4
α-mesosaprobic	3	3	3	6	2	6	7	6	5	3	6	2
polysaprobic						1		1				
Saprobity index / S	**1.95**	**2,15**	**1.95**	**2.60**	**1.65**	**2.75**	**2.0**	**2.75**	**2.45**	**1.95**	**1.60**	**1.65**
3c) According to Pantle and Buck (1955)												
Saprobity index / S	**2.43**	**2.28**	**2.23**	**2.48**	**2.31**	**2.56**	**2.77**	**2.55**	**2.56**	**2.30**	**2.73**	**2.19**

Achnanthes minutissima grows actively in San Francisco Libre (12), Santa Gertrudis (10) and Corpus Christi (5), reaching relative abundances higher than 30 %. In Boquerón and Planta Geotérmica (1) it still finds advantageous conditions for its growing, contributing with a 20 %. In Puerto Momotombo (2), the relative abundance is lower than 10 %. In other localities *Achnanthes* is absent indicating a deterioration of water quality. Optimal conditions for this algae are given in beta-mesosaprobic waters. It is not present, when conditions are alpha-mesosaprobic.

Nitzschia amphibia reaches optimal development in Planta Geotérmica (1) and Boquerón (3), with a relative abundance about 40 %. In Puerto Momotombo (2) and Corpus Christi (5) abundance decreased to 20 %. In Mateare (4) relative abundance is 12 %. This diatom can still grow when the water is heavily polluted (alpha-mesosaprobic conditions). Its absence in other localities is caused by a deterioration of water quality towards polysaprobic conditions (in front of Managua) or when conditions improve (San Francisco Libre 12).

Nitzschia palea develops very well in front of Managua (Rubén Darío Theatre - 8) where it makes up more than 40 %. Adequate conditions favour it in front of Penwalt (7) reaching 20 % and also in Vuelta de Guitarra (6) and San Ramón (11) with more than 10 %. In Puerto Momotombo (2), Corpus Christi (5), Tipitapa (4), Santa Gertrudis (10) and San Francisco Libre (12) the species is present with 5-10 %. This species develops more successfully in polysaprobic water and consequently, its presence suggests a more pronounced organic pollution in front of Managua and better water conditions in the remaining littoral localities.

Considering the total diatom community (Fig. 4 and Tab. 3) a predominance of the more tolerant taxa (*Nitzschia palea* and *Navicula goeppertiana*) with about 80 % is observed in front of Ruben Dario Theatre (8) - indicating polysaprobic conditions (IV, excessively polluted). Towards Penwalt (7) and Vuelta de Guitarra (6) the relative abundance of the more tolerant taxa decreases to 29 and 23 % and the less tolerant species increases to 25 and 22 %, indicating a slight improvement of water quality between alpha-mesosaprobic and polysaprobic conditions (III/IV, very heavily polluted). Towards the east at Tipitapa (9) the relative abundance of more tolerant taxa decreases to nearly 10 % reaching alpha-mesosaprobic degree (III, heavily polluted).

The less polluted region is San Francisco Libre (12), followed by Santa Gertrudis (10) and Corpus Christi (5). At these sampling stations the abundance of the sensitive taxa (*Achnanthes minutissima*) varies between 30 and 40 % and the more tolerant taxa hardly reach 10 %, indicating beta-mesosaprobic conditions (II, moderately polluted) but at the two last localities a tendency to beta/alpha-mesosaprobic conditions (II/III, critically polluted) is observed.

In the zone between Planta Geotérmica (1) and Mateare (4) less tolerant taxa (*Nitzschia amphibia*) dominate, reaching relative abundances between 30 and 50 % indicating beta/alpha-mesosaprobic conditions (II/III, critically polluted). However, there is a tendency towards alpha-mesosaprobic (III, heavily polluted) in front of Puerto Momotombo (2) and Mateare (4), obviously caused by local pollution sources.

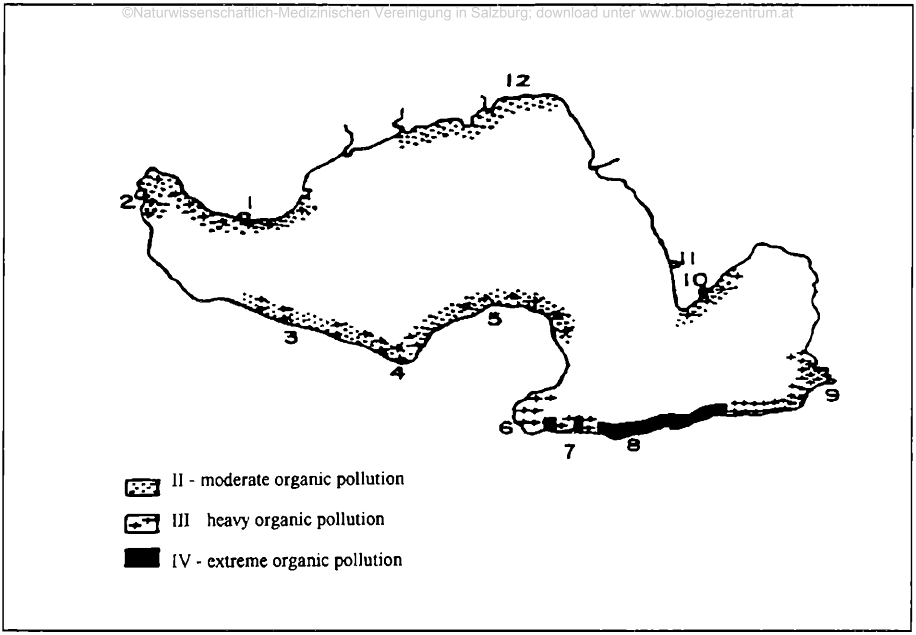

Fig. 4: Water quality in the littoral of Lake Xolotlán

The water quality classification, obtained by the method of ZELINKA and MARVAN (Tab. 3) is lower by one degree than the results according to LANGE-BERTALOT The highest saprobic index with 2,70 to 2.75 was observed in front of Rubén Darío Theatre (8), at Penwalt (7) and Vuelta de Guitarra (6) indicating alpha-mesosaprobic conditions and the lowest one at San Francisco Libre (12), Corpus Christi (5) and San Ramón (11) with 1,60 to 1.65 representing oligo/betamesosaprobic conditions (I/II, very moderately polluted).

The calculated saprobic index according to PANTLE and BUCK ranges from 2.19 at San Francisco Libre to 2.72 at Penwalt indicating a saprobic level between beta- and alpha-mesosaprobic with tendency to beta-mesosaprobic conditions at San Francisco Libre and to alpha-mesosaprobic degree at Penwalt. It is obvious that differences are very little.

Taking into account the physical - chemical and bacteriological data (Tab. 4), indicating a heavy pollution in front of Managua city, the best coincidence was established when using the LANGE-BERTALOT system. The saprobic system was developed exclusively in Central Europe and therefore doesn't work appropiate in a tropical ecosystem. The LANGE-BERTALOT system has a more general approach and leads to better results in the case of Lake Xolotlán.

Table 4: Chemical and bacteriological properties of Lake Xolotlán in the southern and northern basin (according to LACAYO, 1991 and personal communication)

Southern basin- in front of Managua		**Northern basin - near San Francisco Libre**	
Total phosphorus	0.140 - 0.201 mg/l	Total phosphorus	0.090 - 0.110 mg/l
BOD (annual mean)	12.5 mg/l	BOD (annual mean)	5.36 mg/l
Total coliform bacteria	206.614 MPN	Total coliform bacteria	244 MPN
Fecal coliform bacteria	30.000 MPN	Fecal coliform bacteria	170 MPN

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