Limnology of the Great Lakes of Nicaragua

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For more than a century, the two largest bodies of water in Nicaragua, Lake Nicaragua and its smaller companion, Managua, have engaged naturalists from several disciplines. Perhaps their appeal has been as curiosities because of the occurrence of fish with marine affinities in the larger lake, especially a dangerous shark. The charm has been in Nicaragua or *Cocibolca*, rather than Managua, properly called *Xolotlán*. Even though the latter is saltier, it has no elasmobranchs or tarpons.

The lakes, and specifically the larger, cover the greatest expanse of any body of water between Lake Titicaca, Bolivia-Perú, and the Laurentian Great Lakes 35° farther north. Despite this, very little limnologic work has been published concerning them.

ORIGIN OF THE LAKES

A widely accepted, but erroneous theory concerning the origin of the two lakes was perpetuated by Cole (1963), following Hayes (1899). It was assumed that a great Pacific bay was isolated by post-Tertiary eruptions and that originally the two lakes were one. This theory also implied a later reversal of hydrographic patterns so that the new lake drained to the distant Caribbean rather than to the nearby Pacific. Geologic theory was influenced a great deal by some biological pronouncements that have not stood the test of time. The Nicaraguan shark was said to resemble Pacific species more than those from the Atlantic (Gill and Bransford, 1877), and it seemed reasonable to postulate a Pacific origin for the newly-formed lake. Because the lakes lie in a region where precipitation substantially exceeds evaporation, and because at least Lake Nicaragua is well-drained, it was easy to accept the theory of sea water becoming diluted and replaced by the fresh waters that fill the basins today.

Zoppis and del Giudice (1958) summarized a different opinion, including that in an unpublished report submitted 16 years earlier by T. C. Wilson and W. F Auer, stating that the lakes occupy low points in a huge graben that never had been connected with the sea. Swain (1961) and Riedel (1972) agreed with the idea that the Nicaraguan Depression was formed by subsidence during the late Tertiary and early Quaternary, and interior runoff alone filled the present lake basins. The theory expressed by Lloyd (1963) that the tectonic depression once connected with the Caribbean was rejected by Swain (1966); his examinations of sediment cores from the two lakes revealed no marine material.

MORPHOLOGY AND MORPHOMETRY

There are conflicting data concerning the dimensions of the two big lakes of Nicaragua. There have been no careful bathymetric surveys that permit the plotting of subsurface contours for Managua, but Swain (1966) was able to sound enough to construct a bathymetric chart for Lake Nicaragua on which Figure 1 is based. A new map (INFONAC, 1974) recently became available, but too late to be used in this report. It shows depth contours from 1.5 to 20 *brazas* (fathoms).

Riedel (1964) showed data from soundings along three transects in Lake Managua. Despite the inadequacy of Riedel's survey, I estimated and extrapolated to make a chart of the lake from which crude approximations of its morphology could be made (Table 1).

Surprisingly, there are great discrepancies based on maps that show simply the surface outlines of the lakes. The area of Lake Nicaragua has been stated as: 8,120 km² (Lin, 1961); 8,264 km², based on U.S. Army Corps of Engineers work in 1961 (Hagberg, 1968) and USCE work of 1966 (INFONAC, 1971); 7,700 km² (Swain, 1966); and 7,740 km² (Riedel, 1964). The principal islands, Ometepe, Zapatera, and the Solentiname group occupy 341 km². From my Figure 1, based on Swain (1966, Fig. 1), I considered the area of Lake Nicaragua to be approximately 7,585 km², half of which lies above the 12-m contour.

Similarly, Lake Managua is assigned an area of 1,228 km² by Lin (1961), 1,050 km² by Riedel (1964) and 1,295 km² by Swain (1966). From the map presented by Riedel, I estimate the lake covers about 1,053 km².

Some data on some smaller, volcanic lakes that pertain to the problem of conflicting morphometrics are shown by Riedel (1964, p. 15). He states incredible shoreline distances and areas for lakes Tiscapa, Nejapa, and Apoyeque, calculations from them showing they have perimeters less than those bounding circles with the same areas as the lakes!

Some tentative morphologic and morphometric data are shown for the two lakes in Table 1. From them some unusual facts about the lakes come to light.

TABLE 1. Tentative morphometric data for Lakes Nicaragua and Managua.

Parameter	Nicaragua	Managua
Area, A, km²	7,584.27	1,052.7
Volume, V, km³	94.16	8.99
Maximum depth, z_m, m	43	28
Mean depth, $\bar{z}$,m	12.4	8.6
Relative depth, z_r, %	0.044	0.076
Length, l, km	166	58.4
Breadth, b, km	73.7	32.7
Mean breadth, $\bar{b}$, km	46	18
Shoreline, L. km	403	200
Shoreline development, D_L	1.31	1.74
Volume development, D_V	0.87	0.92
Mean slope, %	0.087	0.076

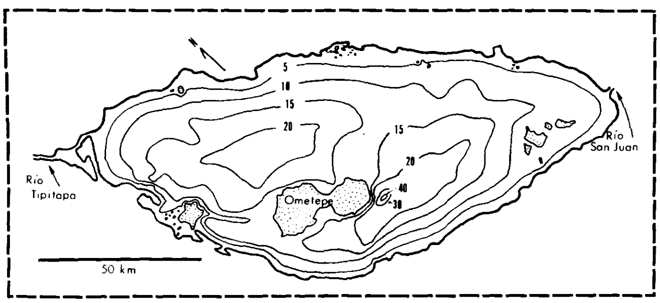

FIG 1. Bathymetric map of Lake Nicaragua. Modified from Swain, 1966. Contours in meters.

Usually the first lacustrine datum people inquire after is the maximum depth (z_m), and they are prone to accept fantastic tales of that dimension. I have accepted 43 m and 28 m from Swain (1961) for Nicaragua and Managua, respectively. It is quite possible that 50 m might be a nice round figure for the larger lake, but other existing estimates, up to 80 or 90 m, imply most unusual configurations. As it is, the deepest spot is in a tiny area southeast of the island of Ometepe. This anomalous subsurface topography has been explained by Swain (1966) as coinciding with the strike of a fault zone. The deep hole, then, may be in a rift. On the other hand, it might lie in an explosion crater. Morphometric calculations are altered very little by substituting 50 m, as z_m, for 43 m. The maximum depth of Lake Managua is 28 m, a figure which does not seem anomalous.

Whatever the case, the noteworthy features of the two lakes is their extreme shallowness and their gently sloping basins, averaging about 0°3′.

Hutchinson (1957, Table 2) listed 12 lakes with areas greater than 15,000 km², all having at least twice the area of Lake Nicaragua. Most of these are deep lakes also, but three of them, Winnipeg, Balkhash and Chad, have maximum depths less than that of Nicaragua. They are probably the only large lakes shallower than Nicaragua. Similarly, their low relative depths 0.011%, 0.018% and 0.008% are less than those of the Nicaraguan basins (Table 1).

Figure 2 shows the results of superimposing Nicaragua and Managua on a graph presented by Hayes (1957), which was based on the study of dimensions from 500 of the world's lakes. The plot of mean depth against area shows that, in general, the greater the area the deeper the lake.

TABLE 2. Some chemical data from Lakes Nicaragua and Managua. Major ions in meq/liter.

Ion	Lake Nicaragua*		Lake Managua**
Total Alkalinity	1.25	1.35	8.7
CO_3^{--}	--	--	1.0
HCO_3^-	1.25	1.35	7.7
SO_4^{--}	0.437	0.19	0.63
Cl^-	0.549	0.45	3.75
Ca^{++}	0.694	0.95	0.47
Mg^{++}	0.518	0.29	1.82
Na^+	0.914	0.77	10.04
K^+	0.118	0.10	0.92
TDS, ppm	127.3	151	747

*Left column, mean of surface and deep water (Swain, 1961). Right column, surface samples (Lin, 1961).

**From surface water only (Lin, 1961).

The Nicaraguan lakes fall far off Hayes' curve; they are too shallow. Nicaragua, to be typical, should have a mean depth of about 40 m and Managua should be, perhaps, 25 m on the average.

Hayes also showed that, when data were available, the mean volume development (D_V) was 1.27. Koshinsky (1970) found 68 glacial lakes in Saskatchewan had a mean D_V of 1.23. Neumann (1959) used dimensions given by Hutchinson (1957) for 107 lakes to compute a mean D_V of 1.40, and was convinced that the ideal or typical lake is an elliptic sinusoid. Such a model, its base (lake area) an ellipse, and its surface (the bottom contour) a sinusoid, would have a D_V of 1.39. Anderson (1961) found the elliptic sinusoid model applied well to the Great Lakes except for shallow Lake Erie, and Lake Superior, which has a very irregular basin. Without altering the maximum depth of either lake, the mean depth of Nicaragua would have to be 20 m and that of Managua 13 m to fit the elliptic sinusoid model. The change in $\bar{z}$ would be greater for Nicaragua, which may owe its slightly lower D_V index (0.87) to the small, aberrant depression south of Ometepe.

PHYSICAL FACTORS

Light penetration is low in the two lakes, the result of wind action on the sediments, plankton growth, and turbidity derived from influent streams (INFONAC, 1974). Secchi disc transparencies range from 0.5 to 2.0 m in Managua and 0.3 to 1.2 m in Nicaragua. At shallow stations in the latter, ranging from 2 to 6 m, Hagberg (1968) reported Secchi disc values from 0.4 to 0.9 m. In the survey reported by INFONAC (1974) transparencies from 0.30 to 0.65 m were found in the same lake. The *coefficient of vertical light attenuation* can be approximated as 3.4 to 0.8 in Managua and from 5.7 to 1.4 in Lake Nicaragua. These figures came from using the empirical equation of Poole and Atkins (1929), where the coefficient is found by dividing 1.7 by the Secchi disc transparency in meters. Holmes (1970) has

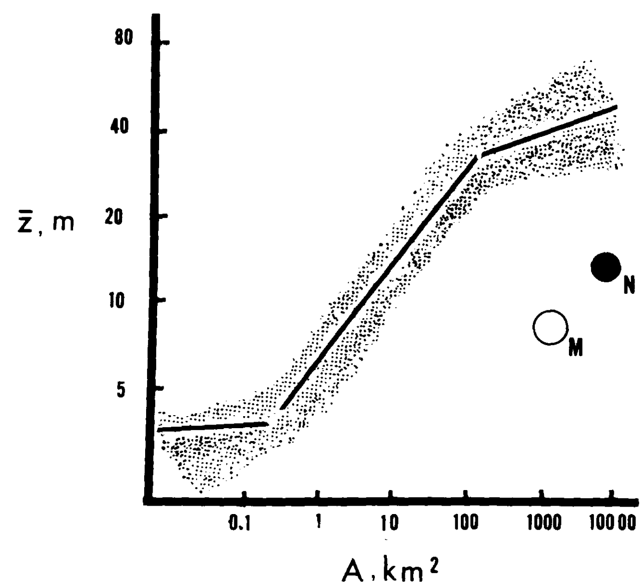

FIG. 2. Mean depth in m plotted against area in km² for about 500 of the world's lakes (modified from Hayes, 1957) with the positions of Lake Managua (M, open circle) and Lake Nicaragua (N, closed circle) shown.

proposed alternatives to the Poole-Atkins equation, but his data agree fairly closely with theirs. Continuing further, the transmittance expressed as percentage per m would range from a low of 0.3 in Nicaragua to 42.7 in Managua. The euphotic zone, bounded by the surface and the depth where 1% of ambient radiation remains, ranges from 1.3 m to 5.4 m in Managua and from 0.8 to 3.2 in Lake Nicaragua.

The opacity of the water contributes, in part, to the near lack of littoral macrophytes in the two lakes. There are a few stands of *Scirpus* and *Typha* in the shallows of less than 2 m, but they are sparse. In protected regions over muddy substrates between depths of 2 and 2.7 m floating plants occur (INFONAC, 1974). They are species of *Eichornia, Pistia* and *Salvinia*.

As might be expected, puzzling contradictions occur in the optic data from the lakes. Swain (1966) states that, of the two, Lake Managua "—is much more turbid." No Secchi disc values or other data support this.

Temperature data are scarce for the two bodies of water. Most evidence points to daily mixing of Managua, although a warm upper stratum exists, attaining at least 31^c in the morning hours. Afternoon winds destroy the incipient stability. The lake is categorized clumsily as a tropical, third-class lake with perhaps need for a warm polymixis appellation. Riedel (1965) classified both lakes as polymictic.

The Lake Nicaragua data obtained by Swain (1966) showed surface temperatures of 28^c, and bottom temperatures of 24°C during the month of March. The density contrast due to temperature alone surpasses what would be found in a temperate lake ranging from 4^c to 16^c in vertical profile. This does not take into account the effects of stratified dissolved and suspended material. Prolonged thermal stratification does not occur according to Swain (1966), but there is some chemical evidence that even short-term stratification proves effective.

Mean monthly temperatures at the city of Managua range from the low in December, 25.8^c, to the April high of 29.5°C. If lake temperatures follow the annual ambient air temperatures, the annual heat budgets would be about 4,265 g. cal/cm^2 and 3,160 g. cal/cm^2 in the lakes Nicaragua and Managua, respectively. Gorham (1964) discussed annual heat budgets in *temperate* lakes and presented some formulae relating them to morphologic data. According to Gorham's formulae the Nicaraguan lakes have heat budgets 10 times too low for their areas and volumes, but this is explained by their not being temperate lakes. The theoretical gains of heat, however, are well in agreement with tropical lakes in general. Large negative winter budgets, of course, typify them (Hutchinson, 1957, Table 53).

Chemical Factors

Figure 3 is a triangular-coordinate plot of the major ions in the two lakes. Probably the Nicaraguan water can be considered the initial type and Managua shows the effects of concentration (Table 2). The former lake is well drained, while the latter occupies a closed basin much of the time when the effluent Río Tipitapa is dry.

Usually, Ca^{++}, Na^{+}, Mg^{++}, and K^{+} are present in Nicaragua's water in that order based on percentage meq per liter. The Ca/Mg ratio is 1.3 to 3.3, and the Ca/Na ratio is 0.73 to 1.2. The anions are dominated by carbonate with substantial Cl^{-} and SO_4^{--}. There is less relative calcium and more sodium than in the "standard" bicarbonate lake waters proposed by Rodhe (1949) and shown by Hutchinson (1957, Table 69). The anion proportions are not much different from the "standard."

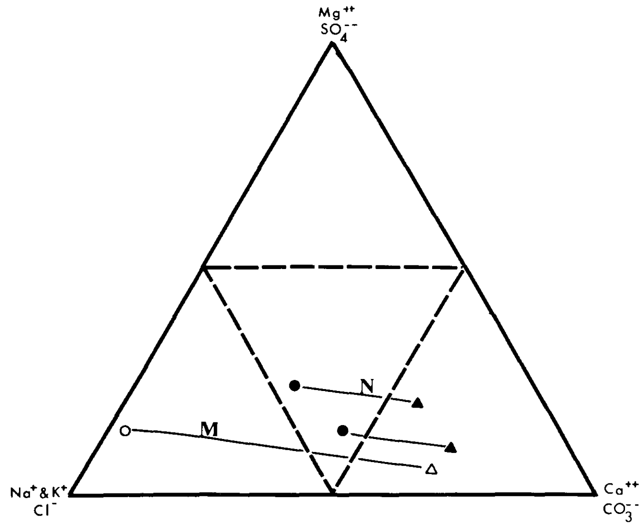

FIG. 3. Triangular coordinate plot of the relative percentages, based on meq/liter, of the major ions in Lake Managua (open symbols) and Lake Nicaragua (closed symbols). Cations indicated by circles; anions shown by triangles. Uppermost connected symbols for Lake Nicaragua based on the mean from surface and bottom water (Swain, 1961); lower Nicaraguan symbols and Managua symbols from surface samples (Lin, 1961).

The chemistry of Managua water, compared with Nicaragua, is marked by: a concentration of five times on a weight basis and more than six times in terms of milliequivalents; a decline in the Ca/Mg ratio to 0.26; and similarly, a decrease in the Ca/Na proportion to 0.47. Accompanying this is a drop in relative SO_4^{--} levels. Perhaps some gypsum has been precipitated to change the water to a sodium carbonate type.

The hydrogen ion concentrations recorded from Lake Managua are usually lower than those from Lake Nicaragua, a phenomenon to be expected on the basis of their different water chemistries. Swain (1966) found pH ranging up to 9.3 in Managua, while the highest value from Nicaragua was 8.9, in surface waters during March. The few data from Lin (1961), Riedel (1964) and Hagberg (1968) showed Nicaragua's pH from 7.0–7.7, whereas Managua's was from 7.6–8.7. The later survey of Nicaragua (INFONAC, 1974) included mention of a pH of 9.6 in shallow surface waters.

Oxygen values are available from the surface waters of Lake Nicaragua (Swain, 1966). They reveal saturations from 74 to 173%, implying intense photosynthesis. Riedel (1964) and Hagberg (1968) described the color of the lake as green to blue-green and green-yellow, fluctuating through the year and attributable to planktonic algae.

The minor chemical elements and nutrients (Table 3) have a bearing on whether or not Lake Nicaragua stratifies. Swain's 1961 data show comparisons between surface water and *"agua del fondo"* (bottom water). The surpassing of surface values by the deep water concentrations are: 4.8 fold for total P; 4.4 for Kjeldahl total N; 5.4 for NO_2; and 10 for total iron. These data imply reducing conditions in the deeps with either intensity or time, or both, adequate for conversion of ferric to the soluble ferrous iron. Swain (1961, 1964, 1966) and Swain and Gilby (1964) present some redox data compared to a standard calomel electrode. Conversions of these data to E_7 referred to a hydrogen

TABLE 3. Minor elements and nutrients from Lakes Nicaragua and Managua. Expressed in ppm.

Element or nutrient	Lake Nicaragua*			Lake Managua**
	A	*B*	*C*	
Total P	0.072	0.344	--	--
Total Kjeldahl N	1.32	5.86	--	--
NO_2	0.01	0.054	--	--
NO_3	--	--	--	tr
Fe, total	0.04	0.4	--	--
F	--	--	0.04	0.05
Boron	--	--	0.08	1.31
SiO_2	--	--	16	7

*Column A surface water; column B deep water (Swain, 1961); column C surface water (Lin, 1961).
**Surface water (Lin, 1961).

electrode shows that the upper 5 cm of sediments are commonly below 0.3 volt, where one would expect the reduction of iron to occur. The lowest E_7 values, down to 0.196, in Nicaragua are south of Ometepe Island, although such low voltages are common in Managua sediments. The sediments are reducing even in the shallows of Lake Nicaragua, 0.284 v at 0.5 m, for example. For this reason, and because Swain (1966) on two occasions found reducing conditions in surface water, it is assumed that sub-surface volcanic gases and the reducing environment of H_2S, reported by Swain (1961, 1964) could be responsible for the low redox potentials, rather than intense decomposition beneath prolonged thermal stratification, but this is not unequivocal. The differences between top- and bottom-water iron that Swain found could have been destroyed by the afternoon winds within hours after he sampled the water. The release of iron and other substances from the sediments may be occurring constantly, but it is obvious only during short-term stratification.

Lin (1961) gave some specific conductance values for the two lakes that can be compared to their total dissolved solids. The relationships can be set down as Williams (1966) did for Australian waters, kC=T, where C is the conductivity in micromhos/cm, and T is total dissolved solids. The factor k, at 25°C, is 0.6 and 0.75 for Managua and Nicaragua, respectively, falling nicely within the limits, 0.5–1.0 (Williams, 1966) and 0.55–0.9 (APHA, 1971; Golterman, 1969).

PHYTOPLANKTON

De Ridder (1966) examined some plankton samples that had been collected by Riedel from Lake Managua. Riedel was unable to work on the larger lake while he was with the F.A.O. Another list of blue-green and green algae was supplied by INFONAC (1974) for Lake Nicaragua. The two lists share some species and are presented in Table 4. The algae are typical of rich and perhaps slightly alkaline waters; they are freshwater types. The appearance of some desmids in the lakes is in agreement with Brook (1965), who listed the genera *Closterium* and *Staurastrum*, with a few species characteristic of eutrophic waters, despite the common notion that the entire family characterizes oligotrophy.

Swain (1966) listed nine genera of diatoms from Lake Nicaragua, one of which may be *Melosira sulcata* Kützing, noted as an estuarine species. In addition, Swain and Gilby (1964) remark on the occurrence of an alga referable to *Elaeophyton*, a genus described and named by Thiessen (1925) as the source of boghead coal. Because Thiessen found the alga in salt lakes and lagoons of South Australia,

TABLE 4. Algae, other than diatoms, reported from Lakes Nicaragua and Managua. Lake Managua data from De Ridder (1966); Lake Nicaragua data from INFONAC (1974).

Lake Nicaragua	*Lake Managua*
Blue-greens	Blue-greens
Oscillatoria sp.	*Anabaena* sp.
Nostoc (?)	*Arthrospira* sp.
	Chroococcus limneticus
Greens	Greens
Microspora (?)	*Gonium* sp.
Pediastrum sp.	*Mougeotia* sp.
Protococcus sp.	*Pediastrum duplex*
Spirogyra sp.	*Pleurococcus viridis*
Ulothrix (?)	(= *Protococcus*)
Desmids	*Scenedesmus quadricauda*
Closterium sp.	Desmids
Desmidium sp.	*Staurastrum gracile*

Swain and Gilby (1964) suggested that its occurrence in both Nicaraguan lakes added to what they termed the lakes' "quasi-marine character." Thiessen's description, in my opinion, is referable to *Botryococcus*, a common planktonic alga in many freshwater environments.

ZOOPLANKTON AND OTHER INVERTEBRATES

Of the two taxa perhaps most characteristic of fresh water, the Cladocera have hardly been studied and there is only one report on the rotifers. Swain and Gilby (1964) report what may have been an ephippium of *Moina* from Lake Nicaragua, and Riedel (1964) speaks of *Bosmina* in fish stomachs from Managua.

De Ridder (1966) published the only paper to date on Nicaraguan rotifers, Riedel having sent seven collections from that nation including three from Lake Managua; Lake Nicaragua was not represented. The samples from Managua contained five species, two being typically American. These were, firstly, *Brachionus havanensis* Rousselet var. *trahea*, which De Ridder considers a distinct species, *B. trahea* Murray, and which is from Mexico to Argentina. With the discovery of typical *B. havanensis* in samples from the crater Lake Masaya, De Ridder concluded that the two species overlap from Mexico to Nicaragua. The second American form was *Keratella americana* Carlin which was very common in all collections. The Nicaraguan example filled a previous distributional gap between North and South America for the last species.

Brachionus caudatus Barrois and Daday occurs on at least four continents. It was represented sparsely in an early April sample, and is referable to the form *provectus* Ahlstrom, known previously only from Mexico. *Lecane bulla* (Gosse) may be an adventitious plankter, and it was rare in the Managua collections. It is a cosmopolitan freshwater species. The fifth rotifer, referable to *Lepadella*, was new to science and was described by De Ridder as *L. riedeli*.

Ostracods were studied by Hartmann (1959) who named five new species, and Swain and Gilby (1964) who described two more species new to science, making a total of nine species from Nicaragua. Two or three species are typical of brackish water environments, but most living species and those represented by remains in the sediments point to a freshwater history for the lake.

The copepods of the larger Nicaraguan lake were listed by Herbst (1960), who found nine cyclopoids, two diaptomids, and one harpacticoid. Two cyclopoids, *Macrocyclops albidus* and *Paracyclops fimbriatus*, are widespread in freshwater environments. One diaptomid, *Diaptomus colombiensis*, is common in Central American plankton assemblages, and the harpacticoid, *Cletocamptus deitersi*, a form with probable marine ancestry, is distributed disjunctly in the Western Hemisphere. Other plankton samples were sent to the Dept. of Biology, University of the South, Sewanee, Tennessee by INFONAC (1974). These were examined by Dr. H. C. Yeatman. The resultant list of copepod fauna consisted of *Thermocyclops inversus, Microcyclops varicans, Eucyclops ensifer, Diaptomus dorsalis,* and *Mesocyclops edax. Thermocyclops inversus* was the most abundant species, yet there is no good evidence that Herbst found it. *Eucyclops ensifer* had been identified earlier by Herbst. Herbst also described a new species of *Diaptomus, D.alter*, from the lake; this is probably *D. dorsalis.* Furthermore, *Mesocyclops nicaraguensis*, a new species described by Herbst (1960), and his determination of *M. brasilianus* are, in my opinion, referable to *M. edax*. Thus, there may be less endemism and unusual features of the copepod fauna than Herbst suggested.

The six nematodes from Lake Nicaragua reported by Hartmann (1959) include four species he considered to have marine affinities which, therefore, implied to him a former connection of the Nicaraguan lowland lakes with the sea.

Commercial Fish Production

From mimeographed reports by Schuster and by Lin, reported by Cole (1963, p. 402), from Lin (1961), and from *Boletin Informativo de Pesca* (INFONAC, 1971) one can obtain figures on the commercial harvest of fish on the two lakes. The best data seem to be 4.8 kg/ha per year for Lake Managua and 0.5 kg/ha per year for Nicaragua. It has been stated that primitive methods account for a production that is only a fraction of the potential. The problems on the great Lake Nicaragua may be such that without modern gear all efforts go poorly rewarded, but in Managua the yearly harvest is relatively good.

Rawson (1955) showed that a plot of fish harvest against mean depth $\bar{z}$ reveals a curve with two arms. At about 20 m there is a break, with high productivity in those lakes having a mean depth less than 20 m and low annual harvest for the deeper lakes. This curve is shown in Figure 4 with the estimated position of the two Nicaraguan lakes added. Managua seems to be producing enough fish to compete with the mainly temperate lakes that Rawson presented. Nicaragua, on the other hand, falls far out of line. For such a shallow lake, it is yielding much less than it should.

Rawson (1955) also presented a formula to show the relation between mean depth and annual fish yield (p):

$$\log (p - 0.56) = 1.1677 - 0.7029 \log \bar{z}$$

Substituting 4.8 kg/ha, Managua's annual yield for p, and solving for $\bar{z}$ gives a value of about 5.7 m. As seen from the curve, Managua, with a mean depth of about 8.6 m, is producing more fish than expected. Nicaragua, however, can hardly be treated in this manner. To make for easier calculation assume it produces 0.57 kg/ha each year. Rawson's formula suggests its mean depth to be 32 km!

From Larkin (1964), Rawson (1955) and Beeton (1969) more data were gathered to show annual fish production in terms of total dissolved solids. A semi-log plot (Fig. 5) shows that either Managua is in line with a steady fish increase related to filtrable residue, and Lake Erie and Winnipeg (Fig. 5, E. and W., respectively) are unusually productive, or the last two are normal and the resources of Managua are being harvested inefficiently. Whatever the case, Lake Nicaragua is producing fewer fish than it should. Or, to be more nearly accurate, Nicaragua is yielding far less to fishermen than one would expect.

Summary

Two great bodies of water covering 9000 km^2, Lake Managua and Lake Nicaragua, have received surprisingly little study despite their appeal to naturalists. Although there has been some dispute, modern opinion supports a tectonic rather than volcanic genesis for the two. They occupy depressions in the tremendous graben known as the Nicaraguan Depression, and very little evidence points to their having been cut off from the sea by volcanic damming. Lake Managua lies 7–8 m above Nicaragua, occasionally draining into it by an intermittent stream.

Detailed bathymetric surveys are wanting, although some useful data from Nicaragua permit estimates of its morphology. The lakes are remarkably shallow, with bottoms gently sloping at an average of less than one per cent. When

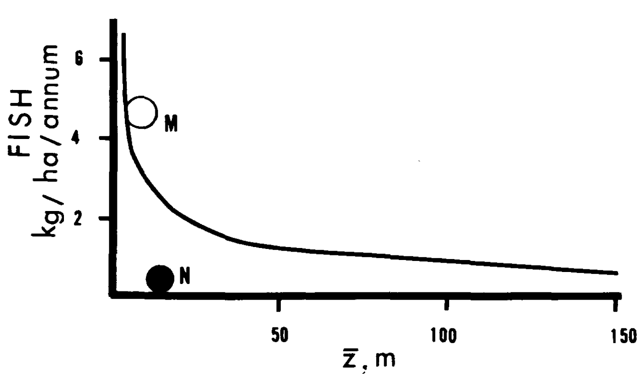

FIG. 4. Commercial fish harvest in kg/ha in relation to mean depth ($\bar{z}$) in large lakes. Smooth line from Rawson, 1955. Managua. (open circle, M) and Nicaragua (closed circle, N) added to the plot on the basis of estimates of annual fish harvest and mean depth.

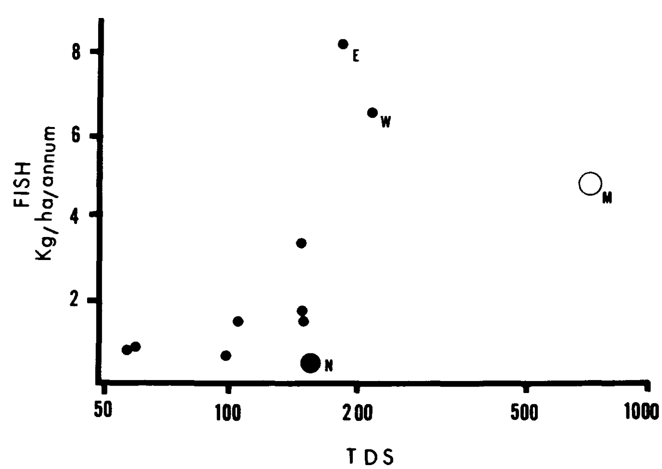

FIG. 5. Relation of annual fish harvest in kg/ha to total dissolved solids (ppm) in large lakes, from various authors. E, Lake Erie, U.S.A.–Canada; W, Lake Winnipeg, Manitoba. Open circle (M), Lake Managua; closed circle (N), Lake Nicaragua. Note semi-log plot.

their large areas are taken into account one might expect mean depths of 30 to 40 m. Probably, however, the mean depths are near 12.4 m. for Nicaragua and an estimated 8.6 m for Managua. Maximum depths are not known exactly, but perhaps only three of the World's great lakes have smaller relative depths than these, which are in the neighborhood of 0.05%. The volume development of Lake Nicaragua is less than 1.0 because of a small, deep hole near the island of Ometepe.

Each lake is turbid because of the wind's effectiveness in stirring the sediments. Light penetration as measured by Secchi disc transparencies (0.3–2 m) implies coefficients of vertical attenuation from 0.8 to 5.7 and lower limits of the euphotic zone from 0.8 to 5.4 m. Turbidity limits the macrophytes to sparse stands of emergents, but oxygen concentrations up to 175% saturation in the upper waters of Lake Nicaragua suggest intensive phytoplanktonic photosynthesis.

No prolonged temperature stratification has been reported, but the contrast between Fe, P and N amounts in surface and bottom waters of Nicaragua suggests effective short-term density barriers. Lower redox and pH values near the sediments may reflect H_2S from subsurface vulcanism and perhaps intense decomposition at temperatures presumably never colder than 24°C.

Because the water of Managua occupies a closed basin much of the time, its dissolved solids surpass those of Nicaragua almost five times. Moreover, its Ca:Mg ratio is six times less, its Ca:Na ratio is 26 times smaller and its Na:K ratio and pH are greater. By contrast, Lake Nicaragua is continually drained.

The invertebrate and algal biota, although little studied, are composed of mostly freshwater types, although some species may have estuarine affinity. The more dilute Lake Nicaragua contains several species of marine fishes, none of which occur in the more saline Managua.

The reported take via commercial fishery in Lake Nicaragua is far below that from temperate lakes of similar mean depth and salinity. This may be a function of inefficient methodology. Managua, on the other hand, yields a harvest commensurate with most lakes of similar dimensions and dissolved solids.

Resumen

Los lagos de Managua y Nicaragua, dos grandes masas de agua que cubren 9,000 km², han sido objeto de relativamente poco estudio, a pesar de su atracción a los naturalistas.

Aunque existe cierta disputa, hoy dia se cree que estos lagos tuvieron origen tectónico, no volcánico. Ambos ocupan depresiones en el tremendo "graben" conocido como "Depresión Nicaragüense", y hay muy poca evidencia de que fueron separados del mar por una barrera volcánica. El Lago de Managua está a 7–8 m sobre el de Nicaragua, en el cual ocasionalmente desagua por medio de un riachuelo intermitente.

Aunque hacen falta estudios batimétricos detallados, ciertos datos permiten estimar su morfología. Los lagos son de poca profundidad, de un fondo con un declive leve, a un promedio menor que el uno por ciento. Tomando cuenta su extensión, uno esperaría profundidades promedio de 30 a 40 m. Probablemente, sin embargo, las profundidades promedio son 12.4 m en el Lago de Nicaragua y unos 8.6 m en el de Managua. Las profundidades máximas no se conocen con exactitud, pero tal vez solo tres de los mayores lagos del mundo tengan profundidades relativas menores que éstas, que se aproximan a 0.05%. El desarrollo de volumen del Lago de Nicaragua es menor que 1.0, debido a una pequeña pero profunda fosa cerca de la Isla de Ometepe.

Los lagos son turbios debido a la eficacia del viento, que revuelve los sedimentos. La penetración de la luz, medida con el Disco de Secchi (0.3–2 m), implica coeficientes de atenuación vertical de 0.8 a 5.7, y límites de la zona eufótica de 0.8 a 5.4 m. La turbidez limita las macrofitas a ser elementos emergentes y más bien dispersos, pero las concentraciones de O_2 hasta un 175% de saturación, en las aguas superiores del Lago de Nicaragua, sugieren una actividad fotosintética intensa en el fitoplancton.

No se ha registrado una estratificación térmica prolongada, pero el contraste entre las concentraciones de Fe, P y N en las aguas superficiales y profundas del Lago de Nicaragua sugieren la existencia de barreras de densidad breves pero eficaces. Los bajos valores de pH y redox cerca de los sedimentos, pueden deberse a H_2S proveniente de vulcanismo subterráneo y tal vez a intensa descomposición, en temperaturas que posiblemente nunca son menores de 24°C.

Debido a que el Lago de Managua ocupa una cuenca cerrada la mayor parte del tiempo, los sólidos disueltos en sus aguas exceden casi cinco veces los del Lago de Nicaragua. Mas aún: las proporciones de Ca:Mg y de Ca:Na son seis y 26 veces menores, respectivamente, y la proporción de Na:K y el pH son mayores. Por el contrario, el Lago de Nicaragua tiene un desagüe continuo.

La biota de algas e invertebrados, aunque poco estudiada, está principalmente compuesta de tipos dulceacuícolas, aunque algunas especies tienen afinidades estuarinas. El Lago de Nicaragua, de aguas más diluidas, tiene varias especies de peces marinos, ninguna de las cuales se encuentra en el Lago de Managua, que es más salino.

La pesca comercial registrada en el Lago de Nicaragua está muy por debajo de la de lagos templados con profundidad media y salinidad semejante. Esto puede deberse al uso de métodos ineficaces. El Lago de Managua, por el contrario, produce una cosecha comparable a la de la mayoría de lagos con dimensiones y solutos semejantes.

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