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Morphometric characteristics of six Mexican coastal-lakes related to productivity

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Abstract: The morphometry of six coastal-lakes of the Guerrero State, SW Mexico, was quantitatively determined, and the morphology of the lakes described. The morphometric parameters involved in lake's productivity (such as mean depth) were used in a new simple ranking technique for calculating the Morphometrically-Conditioned Productivity (MCP). MCP is the potential productivity that a lake may develop based only upon its morphometric characteristics. Five coastal-lake fish catches highly correlated with MCP ($r = 0.947$, $a \leq 0.05$). The sixth (Mitla) does not fit the ranking, probably because of artificial isolation. The original chemical, physical and biological characteristics were modified from saline to freshwater. This technique can be applied to lake groups belonging to a single lake district, with no need to consider non-morphometric variables. The result is valuable short term information about expected productivity.

Key words: morphometry, morphology, productivity, coastal-lakes, Guerrero, Mexico.

Morphology is the study of lake forms and their elements (*e.g.*, area, volume, etc.), their genesis from the geographical and geological points of view and their role in a broader physical limnological perspective. Lake morphometry comprises the estimate and measurement of these forms and the elements of form themselves (Håkanson 1981).

Lake morphometry can affect physical, chemical and biological parameters (Rawson 1955, Ryder 1965 and 1982, Brylinsky and Mann 1973 and 1975, Ryder *et al.* 1974, Kerekes 1975, Richardson 1975, Fee 1979, Straskraba 1980). Morphometric data for both marine and freshwater basins can be considered as basic to the interpretation and understanding of hydrological and ecological processes. The prediction of the direction, and sometimes possible changes in ecological systems, can be greatly improved for scientific and management purposes, when accurate morphometric data are available (Chacón Torres *et al.* 1989).

Morphometric parameters are a mean of expressing form quantitatively. Morphometry and morphology can establish comparisons between lakes (Hutchinson 1957). The morphometric parameters are divided in two groups: a) Descriptive parameters, and b) Productivity-associated morphometric parameters (PAMP).

The first group clusters those parameters merely descriptive of the lake's form, such as maximum depth, maximum width, etc. The second group implies not only a description of lake form, but also the productivity expected from its morphometry. Mean depth has been the parameter most clearly stated to influence the productivity of a lake (Ryder 1965, 1982, Ryder *et al.* 1974).

Although several authors, such as Cole (1979), Hutchinson (1957), Wetzel (1975) have discussed the relationship between the morphometric parameters and the lake's productivity, the term PAMP is first introduced here to name these parameters.

The coastal zone of the state of Guerrero has one of the most important coastal-lake complexes in the Mexican Pacific. The geographic location, the fishery yields and the recent touristic development along the shores identify this zone as a valuable historical, ecological, economical, and cultural area.

The area has been the subject of many geological (Lankford 1974, unpubl. and 1977, Gutiérrez and Carranza 1975, unpubl.), hydrological (Arpi *et al.* 1974, unpubl., Castellanos 1975, unpubl.) and biological studies (Ramírez 1952, Stuardo and Martínez 1975, Licea *et al.* 1975, unpubl., Villarroel 1975, unpubl., Yañez-Arancibia 1975 and 1975, unpubl., Stuardo & Villarroel 1976, Yañez-Arancibia *et al.* 1976). Despite the large number of contributions, a detailed ecological description that enables us to estimate the trophic state and to manage the coastal-lakes remains to be done.

Though in the 70s the Mexican Government carried out different studies on natural resource evaluation through a contract between the Secretary of Agriculture and Hydraulic Resources (SARH) and the National Autonomous University of Mexico (UNAM), much of the basic data emerging from the publications on the coastal-lakes of the State of Guerrero appear contradictory. For example, Yañez-Arancibia (1976) reported mean depths of 1.08, 2.50, 2.94, 1.96 and 1.50m for Chautengo, Coyuca, Mitla, Nuxco and Potosi lakes respectively, while Stuardo and Villarroel (1976) assigned mean depths of 1.69, 4.50, 6.35, 3.18 and 2.73m for the same lakes.

The use of these data for process-oriented research (*e.g.*, fishery yield by Secretary of Industry and Commerce -SIC- 1970) and fisheries assessment (e.g., SARH 1975, unpubl.) can lead to confusion and misinterpretation of data.

The morphometry and productivity of the coastal-lakes in Mexico are both incompletely evaluated and misunderstood, despite the large number of hydrological studies. With the increase of tourism along the shoreline and the exploitation of resources, we repeat that "it is essential that data describing the morphometry of the basins and its catchment areas be collected and distributed among engineers, limnologist and decision makers" (Chacón Torres *et al.* 1989). With exception of the Laguna de Términos, in the southwestern Gulf of Mexico, there is not much information about many Mexican coastal-lakes.

Following accurate bathymetric charts, the derived morphometric parameters obtained allowed a description of the most relevant physical and geomorphologic features of the basins of six coastal-lakes in the coast of the State of Guerrero. By these morphometric data it was also possible to develop a simple prediction technique for forecasting potential productivity.

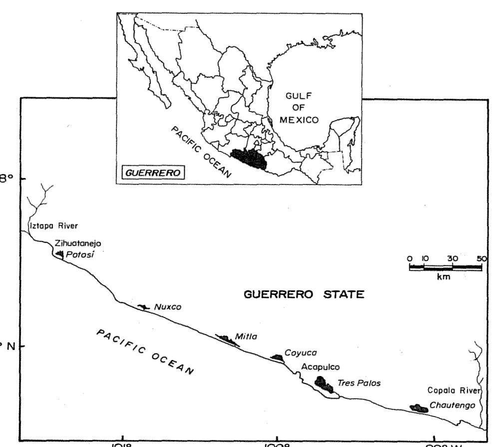

Fig. 1. Location of six studied coastal-lakes in the Mexican Pacific coast.

MATERIAL AND METHODS

Site description: The coastal zone of the State of Guerrero located in the southwestern part of Mexico, extends 490 km. south of the Balsas River to the State of Oaxaca (Fig. 1). Between the Copala and the Ixtapa Rivers, many parts of the shore have coastal-lakes, bordered by narrow coastal plains with low surface relief. A characteristic of this zone is the presence of broad deltas and estuaries (Lankford 1974, unpubl. and 1977).

The climate is tropical subhumid; the temperature ranges from 25 to 30°C with an annual mean of 27.5°C; the prevailing winds blow in a southeastern direction during spring and summer, but show a reverse pattern during the winter. The evaporation rate (1 900 to 2 200mm.) exceeds precipitation (annual mean of 178mm.) that increases the salinity of the coastal-lakes (García 1988).

Six coastal-lakes (Potosi, Nuxco, Mitla, Coyuca, Tres Palos, and Chautengo) were selected for the study; they range in area from 2.66 to 48.36km² (Fig. 1). Permanent rivers discharge into the Tres Palos, Chautengo and Coyuca coastal-lakes and not directly into the Pacific Ocean. Nevertheless, the Mitla, Nuxco and Potosi coastal-lakes are fed only by temporary streams during the rainy season.

According to Mandelli and Vázquez-Botello (1976, unpubl.) Mitla is a freshwater lake (S‰ = 2.67-3.85), whereas Chautengo (S‰ = 14.0-16.25) and Nuxco (S‰ = 19.59-22.34) are saline. Nutrients are high in these three lakes. Total nitrogen, mostly as NH_4, ranges from 3.5 to 18.2, 0.21 to 5.02, and 2.12 to 23.85 µg at.l^{-1} in the Chautengo, Nuxco and Mitla lakes respectively. Total phosphorous ranges from 1.87 to 2.49, 1.6 to 2.4, and 1.13 to 2.47 µg at.l^{-1} for the same lakes. Unfortunately, there is no information concerning Tres Palos, Coyuca or Potosi.

Methods: Morphometric parameters were determined according to the criteria of Håkanson (1981) from the bathymetrical charts prepared by the Program "Uso de la Zona Costera de Michoacán y Guerrero." The Geological Subprogram corresponds to the "Comisión del Río Balsas, SARH y CCML, UNAM" (Lankford 1974, unpubl.). Hutchinson's (1957) symbols were used for referring morphometric parameters throughout the text.

The parameters determined are maximum length (l), maximum width (b), mean width ($\bar{b}$), shoreline (L), development of shoreline (D_L), area (A), volume (V), development of volume (D_V), maximum depth (z_m), mean depth ($\bar{z}$) and relative depth (z_r) (Table 1).

Productivity of the coastal-lakes, in terms of fish catches, was correlated with the morphometrically-conditioned productivity (MCP). MCP is herein defined as the potential productivity that a lake may develop based only upon its morphometric characteristics.

The MCP scores are calculated by considering the productivity-associated morphometric parameters (PAMP). PAMP are morphometric parameters related to aquatic productivity. Some PAMP are directly correlated with productivity (higher parameter values are related to higher productivity rates, *e.g.* l, L, D_L, A and D_V), meanwhile others have an inverse relationship (higher parameter values are related to lower productivity rates, e.g. V and $\bar{z}$).

TABLE 1

Morphometric parameters of six Mexican coastal-lakes

	Lake					
	TP	MI	CH	CO	NU	PO
l (km)	15.85	20.78	10.80	10.94	5.00	2.82
b (km)	5.85	3.40	4.50	4.38	2.50	1.10
$\bar{b}$ (km)	3.05	1.87	3.30	2.87	1.40	0.94
L (km)	45.1	54.0	32.0	30.5	17.1	14.6
D_L	1.83	2.45	1.51	1.54	1.82	2.53
A (km^2)	48.36	38.80	35.64	31.35	7.01	2.66
V (km^3)	0.1661	0.0623	0.0240	0.1890	0.0160	0.0019
D_V	1.47	0.60	0.35	1.01	2.28	0.71
z_m (m)	7.0	8.0	5.7	18.0	3.0	3.0
$\bar{z}$ (m)	3.43	1.61	0.67	6.03	2.28	0.71
z_r (%)	0.09	0.11	0.08	0.28	0.10	0.16

Maximum length (l), maximum width (b), mean width ($\bar{b}$), shoreline (L), development of shoreline (D_L), area (A), volume (V), development of volume (D_V), maximum depth (z_m), mean depth ($\bar{z}$) and relative depth (z_r). Tres Palos, MItla, CHautengo, COyuca, NUxco and POtosi coastal-lakes.

MCP scores (Table 2) are the sum of the values assigned to each PAMP according to their numerical value. For each PAMP the range is determined and divided by K, where K is the number of class intervals calculated according to Dixon and Kronmal's (1965) formula ($K = 10*\log_{10} n$, where n is the data number, eight in our case). For directly correlated PAMP, a value of one is assigned to the first intervale and

TABLE 2

Morphometrically-conditioned productivity (MCP) scores of six Mexican coastal-lakes

	Lake					
PAMP	TP	MI	CH	CO	NU	PO
l	8	8	4	5	1	1
L	7	8	4	4	1	1
D_L	3	8	1	1	3	8
A	8	7	6	6	1	1
V	1	6	8	1	8	8
D_V	5	2	1	3	8	2
$\bar{z}$	4	7	8	1	6	8
SCORE	36	46	32	21	28	29

Maximum length (l), shoreline (L), development of shoreline (D_L), area (A), volume (V), development of volume (D_V) and mean depth ($\bar{z}$). Tres Palos, MItla, CHautengo, COyuca, NUxco and POtosi coastal-lakes. Productivity-Associated Morphometric Parameters.

TABLE 3

Calculation of the development of shoreline as a morphometrically-conditioned productivity (MCP) value

Class	Interval	Coastal lake	Assigned value
I	1.51-1.64	CH &PO	1
II	1.65-1.77	---	2
III	1.78-1.89	TP & NU	3
IV	1.90-2.02	---	4
V	2.03-2.15	---	5
VI	2.16-2.28	---	6
VII	2.29-2.40	---	7
VIII	2.41-2.53	MI & PO	8

Development of shoreline (D_L). Tres Palos, MItla, CHautengo, COyuca, NUxco and POtosi coastal-lakes.

D_L: Minimum Value = 1.51
Maximum Value = 2.53
Range = 1.02

up to K for the last (Table 3). For inverse correlated PAMP, a value equal to K is assigned to the first intervale and down to one for the last (Table 4).

TABLE 4

Calculation of the mean depth as a morphometrically-conditioned productivity (MCP) value

Class	Interval	Coastal lake	Assigned value
I	0.67-1.34	CH & PO	8
II	1.35-2.01	MI	7
III	2.02-2.68	NU	6
IV	2.69-3.35	---	5
V	3.36-4.02	TP	4
VI	4.03-4.69	---	3
VII	4.70-5.36	---	2
VIII	5.37-6.03	CO	1

Mean depth ($\bar{z}$). Tres Palos, MItla, CHautengo, COyuca, NUxco and POtosi coastal-lakes.

$\bar{z}$: Minimum Value = 0.67
Maximum Value = 6.03
Range = 5.36

RESULTS AND DISCUSSION

The morphometric description of the lakes, following Hutchinson's (1957) terminology, is as follows (Table 1).

Tres Palos is a coastal-lake with a subcircular to elliptical form (Fig. 2). Its area and maximum width values are the highest estimated. Tres Palos is a shallow lake with a flat bottom and conical shape. About 80% of the lake volume is achieved at a depth of 3.5m with a reduction of 50% of the area. The isobaths do not follow the shoreline contour.

Mitla lake has a subrectangular elongate shape (Fig. 3). The northwestern portion of the lake has a high sedimentation rate due to its multiple flooding plains. This shallow coastal-lake with a flat bottom is conical in form. It is the longest among the six basins studied. At a depth of 1.5m the area and the volume are reduced to 50%. The isobaths are irregular in shape with two deeper zones located to the north and the southeast.

Chautengo is a shallow coastal-lake, less than 2.0m deep (Fig. 4). It consists of two

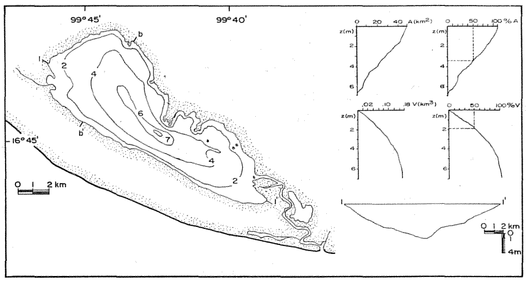

Fig. 2. Bathymetric chart, bathymetric profile along the maximum length, and hypsographic and depth-volume curves of Tres Palos coastal-lake. Isobaths are given in meters. Maximum length (l), maximum width (b), area (A), volume (V), and depth (z).

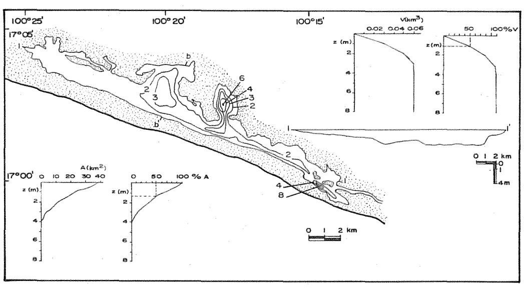

Fig. 3. Bathymetric chart, bathymetric profile along the maximum lenght, and hypsographic and depth-volume curves of Mitla coastal-lake.

basins divided by a shallower zone. The lake has a conical shape with a subcircular surface. About 50% of the total volume is contained at a depth of 0.6m. At 0.8m the area is reduced to 50%. The maximum depth recorded is 5.7m, and is located inside the tidal channel. As to the lake, the maximum depth reaches 2.0m. Isobaths are irregular in shape.

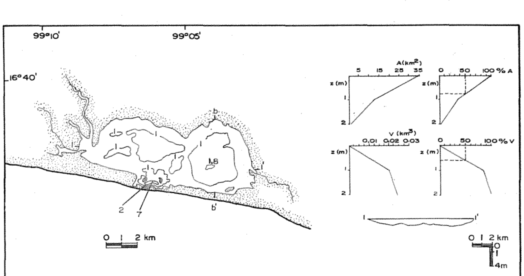

Fig. 4. Bathymetric chart, bathymetric profile along the maximum length, and hypsographic and depth-volume curves of Chautengo coastal-lake.

Coyuca is the deepest of the six coastal-lakes studied and it has the largest mean depth value. It has a subcircular shape with even contours (Fig. 5). In a lake with a volume equal to that of the index of a hypothetical cone, $D_V = 1$, Coyuca closely reaches this value (1.01). About 50% of the volume and area occur at a depth lesser than 4.0m.

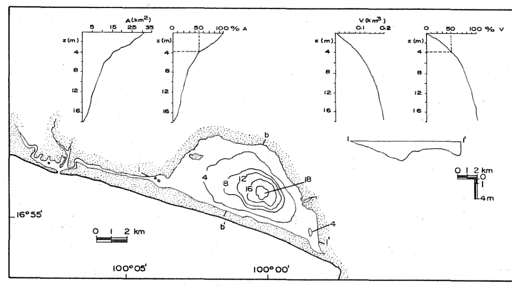

Fig. 5. Bathymetric chart, bathymetric profile along the maximum length, and hypsographic and depth-volume curves of Coyuca coastal-lake.

Nuxco is elliptical in shape, with irregular isobaths along the lake contour (Fig. 6). This lake has the largest development of volume of the six coastal-lakes studied, and develops a truncate conical form. About 50% of its volume is contained at 1.5m and about 50% of the area is reached at 2.5m.

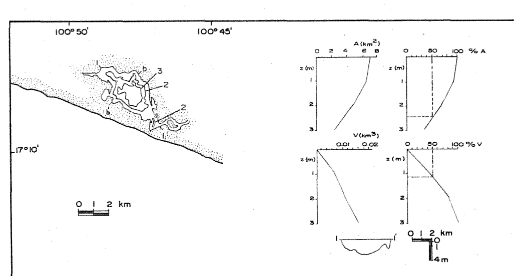

Fig. 6. Bathymetric chart, bathymetric profile along the maximum length, and hypsographic and depth-volume curves of Nuxco coastal-lake.

Potosi is not so deep since it has a maximum depth of 3.0m along the tidal channel in a NNE-SSW direction (Fig. 7). The lake contour is irregular and in a subrectangular elongated shape has the largest development of shoreline value. The basin's form is that of a truncate cone. About 50% of the area and volume occur at a depth of 0.6m.

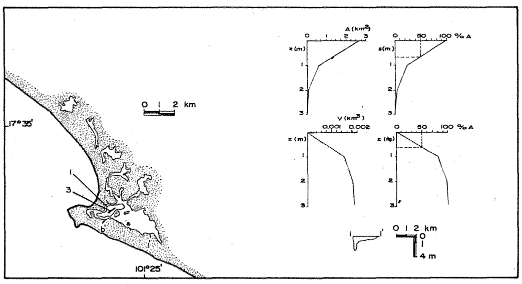

Fig. 7. Bathymetric chart, bathymetric profile along the maximum length, and hypsographic and depth-volume curves of Potosi coastal-lake.

According to Lankford's (1977) classification the six lakes are considered as barred inner shelf coastal-lakes. The bathymetry is typically shallow except the erosional (tidal) channel. The first five lakes belong to type III-A or Gilbert de Beaumont barrier lakes with extended sand barriers (type 66, according to Hutchinson 1957). The sixth lake (Potosi) corresponds to type III-B or cuspate coastal-lake with sand barriers on a triangular orientation, whose apex is closely related to the offshore wave refraction (type 68 according to Hutchinson 1957).

The ordering analysis arranged the lakes in a decreasing scale according to the morphometrically-conditioned productivity (MCP), as follows: Mitla, Tres Palos, Chautengo, Potosi, Nuxco and Coyuca (Table 2). To test if this technique and its application works, the fishery catches (in terms of biomass in $g.WW.m^{-2}$) of the lakes were compared to the morphometric ranking (Table 5). The fishery catches were obtained from Yañez-Arancibia (1978a). The original data (in fish biomass per different surface units) were standardized to fish biomass per one square meter.

TABLE 5

Fish yields of six Mexican coastal-lakes (Yañez-Arancibia 1978a). Morphometrically-Conditioned Productivity. Biomass as grammes wet weight per square meter

Coastal lake	MCP score	Fish biomass
Mitla	46	8.40
Tres Palos	36	42.00
Chautengo	32	38.64
Potosí	29	17.64
Nuxco	28	22.68
Coyuca	21	5.88

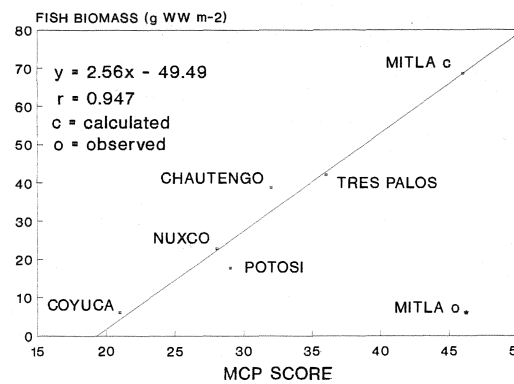

Fig. 8. Correlation between Morphometrically-Conditioned Productivity (MCP) score and fishery yields ($g.WW.m^{-2}$) of the studied Mexican coastal-lakes but Mitla. The observed (o) and calculated (c) fishery yields for Mitla lake are indicated.

The ordering of the lakes in decreasing values of fishery catches was Tres Palos, Chautengo, Nuxco, Potosi, Mitla and Coyuca. A simple regression analysis among the MCP score and the fishery catches (Fig. 8) gave a correlation factor of $r = 0.947$ ($a \leq 0.05$), excluding Mitla lake. This coastal-lake did not fit its MCP ranking. This discrepancy could be explained by the total isolation of the lake since 1967, when an artificial blockage of the sand bar was carried out in a project for improving water quality for agriculture. The original chemical, physical and biological characteristics were modified from a saline to a freshwater environment (Yañez-Arancibia 1976, 1978b, Martínez 1978).

Without an oceanic influence, Mitla developed a hypertrophic status with high primary production rates between 2.64 and 2.87 g $C.m^{-3}.d^{-1}$ (Mee 1987). There is no additional information on primary productivity rates of the other lakes but Chautengo with 0.29 to 0.87 g $C.m^{-3}.d^{-1}$ (Mee 1987). That is why it was not possible to test the method directly on primary production rates.

The Cyanophyceae and Chlorophyceae algae are responsible of the high primary production in Mitla. The number of algae cells per liter reach up to 5 432 million. Blue-green algae *Synechococcus* spp., *Aphanocapsa* spp., *Gomphosphaeria* spp., *Microcystis* sp., and *Spirulina* sp., and the green algae *Ankistrodesmus falcatus* are the dominant components (Licea *et al.* 1975, unpubl.).

In spite of its high primary production Mitla has low secondary production, as can be stated from its reduced zooplankton biomass values (0 to 3.0 $g.WW.m^{-3}$). Few fish larvae larger than 10mm made up almost the entire zooplankton community (Martínez 1978). Several authors (Licea *et al.* 1975, unpubl., Yañez-Arancibia 1975 *in* Licea *et al.* 1975, unpubl., Martínez 1978) found Mitla has developed a short, inefficient trophic food chain mirrored in its low fishery catches (8.4 $g.WW.m^{-2}$). The predicted catch according Mitla's MCP score is 68.44 $g.WW.m^{-2}$.

The values appearing in Table 2 reveal a high similarity between the MCP scores of Tres Palos and Chautengo, thirty-six and thirty-two respectively, also between Nuxco and Potosi with twenty-eight the former and twenty-nine the later lake. These scores also predict similar fishery catches levels for Tres Palos and Chautengo (42 and 39 $g.WW.m^{-2}$), also for Nuxco and Potosi (23 and 18 $g.WW.m^{-2}$).

Morphometric parameters are positively or negatively correlated to the productivity of a lake. A clear example of this is the mean depth-fishery production correlation previously reported by Kerekes (1975), Northcote (1980), Rawson (1952 and 1955), Ryder (1965 and 1982), and Ryder *et al.* (1974). Also Beattie *et al.* (1978) ascribed to the Fresian lakes morphometry the variation of *Chironomus plumosus*. Furthermore, Mc Diffett (1980) found a correlation between chlorophyll a and the development of shoreline (D_L) in south-central Florida lakes.

Though the functional mechanisms by which morphometry exerts control in the production processes of lakes have not been clearly stated (Northcote 1980), the technique herein described may be of some use to predict potential fish catches of lakes occurring in a same district, based on their MCP. This technique could be applied to lake groups belonging to the same lake district, a fact that excludes the use of non-morphometric variables, giving valuable short term information of the expected productivity.

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RESUMEN

Se determinó la batimetría y morfometría de seis lagos costeros del estado de Guerrero, al suroeste de México. Con base en los parámetros morfométricos relacionados con la productividad lacustre, se aplicó una técnica que permite determinar la "Productividad Condicionada Morfométricamente" (MCP). La MCP se define como la productividad que un lago puede desarrollar con base en sus características morfométricas. Con el fin de comprobar el funcionamiento de la mencionada técnica, se compararon los valores de MCP de los lagos con su captura pesquera. En cinco de los lagos la correlación fue elevada ($r = 0.947$, $a \leq 0.05$). El sexto, Mitla, probablemente no se correlacionó debido a que la boca de conexión con el mar fue cerrada para disminuir su salinidad y favorecer el cultivo de cocotales en el área. Con ello se modificaron las características físicas, químicas y biológicas de salino a dulceacuícola. Esta técnica puede ser aplicada a lagos que pertenecen a un mismo distrito lacustre, eliminando la inclusión de variables no morfométricas, lo que permite obtener información valiosa, a corto plazo, de la productividad esperada de un cuerpo acuático.

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