THE LAKES OF MICHOACÁN (MEXICO):
A BRIEF HISTORY AND ALTERNATIVE POINT OF VIEW

FERNANDO BERNAL-BROOKS

(F. W. Bernal-Brooks, Centro Regional de Investigacion Pesquera/Estacion
Limnologica de Pátzcuaro, Calzada Ibarra 28, Colonia Ibarra,
Pátzcuaro, Mich. 61600 Mexico.
[E-mail: bbrooks@jupiter.ccu.umich.mx]

Introduction

In agreement with Limón et al. (1989): "We know very little about the
limnology of the waters of Central America and Mexico. Only two pages in the
Lakes of the Warm Belt, by Serruya & Pollingher (1983), are given to Mexico".
In the absence of a strong theoretical background, fundamental concepts of
limnological science appeared in this country mainly from textbooks and
studies made at temperate northern latitudes, as well as on-site research
performed decades ago. Thus Alcocer-Durand & Escobar-Briones (1991)
describe: "The great impetus acquired by limnology in Europe and America in
the first half of the 20th century stimulated foreign researchers to come and
work in Mexico". From the latter, surprisingly, some out-of-date viewpoints
still remain as an intellectual influence for most Mexican limnologists, even to
the extent of representing undeniable dogmas. This article is intended to open
a discussion about the historical development of lakes Zirahuén, Pátzcuaro and
Cuítzeo in the State of Michoacán (Mexico), and the postulated relationships
between lake ecology and evolution.

The background of limnological concepts in Mexico

Aztec limnology (Deveey 1957), although an outstanding pre-hispanic
achievement contained in codexes concerning the aquatic resources of the
ancient Lake Tenochtitlán, is not related to the main topic of this paper.
Cornerstones traced back in time to explain lake ecology and evolution for the
Michoacán case are identified more recently, as outlined below.

The terms "eutrophic", "mesotrophic" and "oligotrophic" in their German
forms - "nährstoffreiche (eutrope) den mittelreiche (mesotrophe) und zuletzt
nährstoffarme (oligotrophe)" - were introduced into science by Weber (1907),
to describe the general nutrient conditions determined by the chemical nature of
the soil solution in German bogs. The introduction of Weber's terms into
limnology was due primarily to Einar Naumann (1919), who combined an
extraordinary eye for lakes with a passion for succinct, classificatory style of
presentation (Hutchinson 1969).
"Neumann and Thienemann laid the foundation stones of Seetypenlehre, the ecological classification of lakes, just as they jointly initiated the foundation of the International Association of Theoretical and Applied Limnology in 1922" . . . "Contemporarily with Naumann and Thienemann, E. A. Birge and C. Juday collected an unprecedented amount of qualified data from more than 500 Wisconsin lakes. The difference between their lines of action was almost as vast as the ocean that separated the two teams of scientists. On one side, a synthetic attitude and the endeavor to construct, as far as possible, a framework with general applicability; on the other side, an analytical approach and the tedious task of bringing together single bricks for a future structure" (Rodhe 1969).

Drs Yoshiichi Matsui and Toshie Yamashita, both from Japan, were hired as inland fisheries consultants by the Mexican federal government in 1936. Their proposal to the President of Mexico (Gral. Lazaro Cardenas del Rio), for establishing a research facility at the Hacienda de Ibarra beside Lake Patzcuaro, lead to the foundation of the Pátzcuaro Limnological Station in 1938 (Zozaya 1940).

Dr Fernando De Buen, the first man ever dedicated to limnology in Mexico, came to this country late in the 1930s as a refugee from the civil war in Spain. He was adviser at the Estación Limnológica de Pátzcuaro from 1939 to 1944 and wrote outstanding papers dealing with Mexican lakes which, in an elegant style of writing, implicitly bear the influence of European limnology (although formerly in Spain he had been an oceanographer). Some of his papers frequently relate lake ecology and evolution for the Mexican State of Michoacán, as is later explained in detail.

**The lakes of Michoacán**

The region of the so-called Lakes of Michoacán includes the three largest natural lakes, although these are not the only ones. The region is situated (approximately) between 19°15' and 20°00' N, and 101°30' to 102°00' W, ca. 350 km west of Mexico City, within the Mexican Basin. The three lakes have closed watershed (= catchment) basins (Figs 1 and 2); some basic geographical and morphometric data are given in Table 1.

The lake basins lie on volcanic bedrocks formed in the late Tertiary and Quaternary periods. A radiological measurement (K/Ar) for the bedrock of Lake Cuitzeo gives a date of 8.0 ± 0.4 million years BP (CFE 1986). Lake Pátzcuaro is surrounded by late Cenozoic lava flows and volcanic cones that are predominantly basaltic in type (DETENAL 1977), but the region is still volcanically active - the newly-formed (1943) Paricutin volcano lies 50 km west of Pátzcuaro.

The upper catchments contain remnants of natural forest, comprised mainly of pine (*Pinus*), oak (*Quercus*) and fir (*Abies*); lower ground is generally
cultivated. The lakes probably were formed in the late Pliocene or Holocene. In 1973, a core taken at 620 cm depth of water in Lake Pátzcuaro penetrated brown organic muds and occasional layers of volcanic ash until it bottomed at a depth of 2140 cm from the lake surface; the core represents sediments that have accumulated during a period of ca. 44,000 years (Watts & Bradbury 1982).

Morelia, the capital city of Michoacán State, has 428,486 inhabitants, and lies in the catchment of the largest lake, Cuitzeo.

**De Buen's theory on the formation of the lakes**

Important components of the final theory are identified in De Buen's own words [my translation from Spanish] as follows: "The geographical distribution, the altitudes in a stairway fashion and the ichthyological fauna, lead us to assume that lakes Zirahuén, Pátzcuaro and Cuitzeo were part of a tributary to the Lerma River, which became isolated by successive volcanic barriers to form the actual lake basins" (De Buen 1943b). Statements relating lake ecology and evolution for the three lakes are included in a series of papers by De Buen (1943a,b, 1944a,b), although the best explanation integrating the component ideas into a single theory is given by De Buen (1943b): "The lakes of Michoacán are evolving, since their origin, to final demise, changing their original flooded basins for valleys with thick layers of sediments, forming
FIG. 2. Map showing boundaries of the catchments and basins of Lake Zirahuén (Z), Lake Pátzcuaro (P) and Lake Cuitzeo (C, solid areas indicate wetlands). Arrows show the points of maximum lake depths (see Table 1).
THE LAKES OF MICHOACAN (MEXICO) 25

Table 1. Basic lake morphometry [Sources: 1-3], trophic status [Sources: 4-6], surrounding human settlements [Source 7] and land use [Sources: 4, 8, 9] in the watersheds (catchments) of lakes Zirahuén, Pátzcuaro and Cuitzeo. *The population of the Cuitzeo catchment includes the Capital city of Morelia (population 428,486).


<table>
<thead>
<tr>
<th>Variables</th>
<th>Zirahuén</th>
<th>Pátzcuaro</th>
<th>Cuitzeo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altitude (m a.s.l.)</td>
<td>2075</td>
<td>2035</td>
<td>1820</td>
</tr>
<tr>
<td>Catchment area (km²)</td>
<td>260</td>
<td>1096</td>
<td>3757</td>
</tr>
<tr>
<td>Lake area (km²)</td>
<td>10.5</td>
<td>90</td>
<td>420</td>
</tr>
<tr>
<td>Volume (10⁸ m³)</td>
<td>216</td>
<td>500</td>
<td>485</td>
</tr>
<tr>
<td>Mean depth (m)</td>
<td>20.5</td>
<td>4.7</td>
<td>0.9</td>
</tr>
<tr>
<td>Maximum depth (m)</td>
<td>40</td>
<td>12</td>
<td>2.3</td>
</tr>
<tr>
<td>[Sources]</td>
<td>[1]</td>
<td>[2]</td>
<td>[3]</td>
</tr>
<tr>
<td>Conductivity (µS cm⁻¹)†</td>
<td>110</td>
<td>880-980</td>
<td>700-18000‡</td>
</tr>
<tr>
<td>Trophic status</td>
<td>Oligo-</td>
<td>Eutrophic</td>
<td>Hyper-</td>
</tr>
<tr>
<td>mesotrophic</td>
<td></td>
<td></td>
<td>eutrophic</td>
</tr>
<tr>
<td>[Sources]</td>
<td>[4]</td>
<td>[5]</td>
<td>[6]</td>
</tr>
<tr>
<td>Human populations</td>
<td>24516</td>
<td>78455</td>
<td>733511*</td>
</tr>
<tr>
<td>Human settlements</td>
<td>32</td>
<td>100</td>
<td>519</td>
</tr>
<tr>
<td>[Source]</td>
<td>[7]</td>
<td>[7]</td>
<td>[7]</td>
</tr>
<tr>
<td>Major land uses:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agriculture</td>
<td>60%</td>
<td>41%</td>
<td>45%</td>
</tr>
<tr>
<td>Forest</td>
<td>20%</td>
<td>30%</td>
<td>17%</td>
</tr>
<tr>
<td>[Sources]</td>
<td>[4]</td>
<td>[8]</td>
<td>[9]</td>
</tr>
</tbody>
</table>

almost level ground and surrounded by hills that previously belonged to the catchment area. We have in the Michoacán lakes different types of evolution, Zirahuén the youngest, Pátzcuaro already old, Cuitzeo in senescence, and Langunillas is a valley of lacustrine origin".

Barbour (1973) remarked: "Little is known of the geological relationships of the interior basins occupied by the [three] lakes. De Buen (1943) considered them to be successive compartmentalizations of a tributary of the Rio Lerma, formed by lava flows or other volcanic disturbances. He considered Zirahuén, the highest in altitude and the deepest lake, to be the most youthful, Pátzcuaro is mature or old and Cuitzeo is decadent. The presumed fluvial connection extended north from Zirahuén to Pátzcuaro and then north-east through the valley that is currently followed by the Pátzcuaro-Morelia railroad as far as the Rio Grande de Morelia. This river [which exists today] drains into the south side of Lake Cuitzeo which is in turn separated from the basin of the River Lerma by a low rise".
Reviewing the case of Zirahuén, lake evolution and ecology mingles in the statement [my translation]: "Young Zirahuén, with its clear, blue, transparent and deep waters, will undergo rapid ageing; the stages of its geological life-cycle will be shortened by the woodcutter’s axe, with unmerciful deforestation and suicidal destruction of the forest by the action of fire" (De Buen 1943b).

Similarly, for Pátzcuaro, De Buen wrote in the lake ecology-evolutionary sense: "Lake depths decreased, the bottom became smoother, waters became green or yellow because of silting, losing their ancient transparency and blue colour. Pátzcuaro, now with less water, left flat plainland in Chapultepec and Quiroga suitable for agriculture (southeastern portion), so being in a regression stage (shrinking of the water surface by declining water levels) and therefore in plain oldness". These concepts are repeated in the paragraphs under "Lake Origin and Evolution" in the account by De Buen (1944b).

For Lake Cuitzeo, De Buen states that: "In spite of possessing a larger watershed relative to those of lakes Zirahuén and Pátzcuaro, Cuitzeo dried up in the winter of 1941. This process was hastened by the impoundment of the headwaters at Cointzio dam, which cuts off the Grande de Morelia river inputs. Nevertheless, Lake Cuitzeo is in an advanced stage of regression" (a concept that is explained in the previous paragraph).

Further enthusiastic support for De Buen’s ideas has been produced over the last 40 years by Solórzano-Preciado (1955), Deevey (1957), Mendivil et al. (1980), Lopez (1982), Alvarado et al. (1985), Chacon & Muzquiz (1991), Chacon et al. (1991), Chacon (1993a,b) and Cruz (1995).

**Alternative points for consideration**

Limnological studies in Mexico lack continuity of development and have been focused mainly on three large natural lakes (Chapala, Pátzcuaro and Cuitzeo) and the extinct lacustrine basin now occupied by Mexico City (Alcocer et al. 1993). Moreover, apart from the papers by De Buen (1941) and De Buen & Zozaya (1942), research based on observations covering at least one year did not appear again until Ordonez et al. (1982) published work on Lake Zirahuén, including data from 1977-1978. "Unfortunately, part of the limnological tradition that began with Cuesta-Terrón, De Buen, Osorio-Tafall, Rioja and Alvarez, has been lost and there are now only isolated efforts" (Arredondo 1983). As a consequence of the lack of a solid limnological background, the analysis of information relies heavily on relatively old references or on North-American textbooks, even to the point of not questioning general theories in relation to local cases, such as a one-way evolution of lakes from water-filled basins to dry land. Wetzel (1983) actually identified that "the famous successional scheme put forth by Lindeman for Cedar Bog Lake, Minnesota, has been more than once proposed in general ecology texts as the universal
situation (of lake evolution). In this way, the erroneous concept that all lakes become bogs and then land may become widely accepted. While some lakes do progress through this sequence, it is far from the rule”.

Dr Fernando De Buen brought over from Europe the kind of thinking oriented to generalizations, as recognized at that time for European limnology. A similarity was observed by Hutchinson (1969) as follows: "Neumann’s contribution was to provide a theoretical classificatory scheme that enabled a large number of casual observations to be coordinated, although parts of this scheme are probably of limited application". Thus, "generalized ideas may be extremely stimulating, but they do not offer a shortcut to truth if they are based on premature premises" (Rodhe 1969).

Dr Osorio-Tafall (1941) was another Spanish scientist who came to Mexico in the late 1930s. He also studied the biology of fresh waters and claimed that "the lakes of the temperate zone of Europe and North America can be regarded, in general, as a limited number of types with regard to their outstanding features of morphometry, physicochemistry and biology, on the basis of classifications given by Naumann (1929) and Thienemann (1931). But, as long as limnological studies progress and modern methods are applied to the study of lake basins, then disagreements appear with the described types”.

As a counterpart to European limnology, in North America "Birge and Juday achievements . . . rest on the extent, frequency and detail of their observations, which enabled them to arrive at more penetrating and balanced interpretations than more superficial studies would have done. They were not summer-vacation limnologists; their approach was the opposite of dilettante. They were by no means averse to speculation, but first of all they assiduously collected the facts" (Mortimer 1956). Limnological studies in this manner are still urgently required for Mexican lakes and, because of insufficient data and too-rigid theories, modern supporters of De Buen frequently struggle to provide explanations reconciling field evidence with De Buen’s ideas. Some drawbacks and gaps of knowledge in these old concepts are considered below.

Regional geography and fish fauna

At an altitude of 2,080 metres above sea-level, Lake Zirahuén was believed to lie at the top of a "staircase" of waterbodies, close to the headwaters of a hypothetical stream flowing northeast into Lake Pátzcuaro, before finally reaching the Lerma River. However, a lake-to-lake connection between Zirahuén and Pátzcuaro does not fit a modern map (unavailable to De Buen) of the three watersheds (SPP 1982). Bearing in mind that Lake Zirahuén was formed by blockage of "La Palma" stream as a natural impoundment, a close examination of contours and gradients reveals that the "La Palma" flow, interrupted thus on its way downriver, would not go northeastwards to the...
Lerma River but instead it would flow southwards into the Balsas River. Therefore, no geographical pathways can be identified for a straight-forward link to Lake Patzcuaro.

Lake Pátzcuaro was also created by a supposed compartmentalization of an ancient stream through damming by volcanic processes. In this case, the headwaters in the southeastern portion of the watershed (Chapultepec) do not fit a possible connection between Pátzcuaro and Lake Cuitzeo or, at least, a more profound explanation is required since the lake's maximum depth (in the part of the lake basin which resembles a levee-like structure) is in the northern basin of the lake, on the opposite side from that of the headwater. Inspection of a map of the area (SPP 1982) suggests that the logical pathway for a hypothetical stream would be to flow from the south towards the north, and not flow southwards. Actually, Alvarez (1972) provides insights for a more logical relationship with the Zacapu basin 25 km to the northwest.

The fact of a geographical relationship between lakes Pátzcuaro and Zirahuén is based on their very similar ichthyofaunas (De Buen 1943b; Miller & Smith 1986), but past geographical links between both lakes require an alternative explanation to one of a simple lake-to-lake connection. The indices of average faunal resemblance for the two native families of fish in the region (Atherinidae and Goodeidae) are 0.8 for Pátzcuaro-Zirahuen (which have six shared species of fish), 0.25 for Pátzcuaro-Morelia (including Cuitzeo; with three shared species), and 0.24 for Zirahuén-Morelia (including Cuitzeo; with two shared species) (Miller & Smith 1986).

Based on ichthyological elements, Alvarez (1972) proposed an alternative explanation that seems to have been unnoticed by many Mexican limnologists, as a counterpart to De Buen's ideas. "Probably, around Zirahuén and Pátzcuaro there was a river flowing from Uruapan to Zacapu, and thereafter the waters reached the Lerma River. Because of tectonic phenomena, probably basaltic currents, the upper part became isolated from the hypothetical basin, and a small portion of small mountain rivulets then remained towards the Santa Catarina reservoir. Lake Zirahuén was formed by an event that separated it from Pátzcuaro and later the ecological barrier arose between the area of Lake Pátzcuaro . . . and the Zacapu basin marshland. These phenomena separated a wet, poorly drained upper region, and three lentic units with similar ichthyofaunas, barely differentiated at the species or subspecies level. Lake Cuitzeo is a closed basin like Pátzcuaro and Zirahuén, but its separation from the main river-flow seems to be more recent; there are no endemic species and its ichthyofauna is practically the same as that of the Lerma River".

**Paleolimnological evidence**

Watts & Bradbury (1982) and O'hara (1991), quoted by Metcalfe et al. (1994), pointed out that the level of Patzcuaro has fluctuated considerably over both the
long and the short term, but there is no evidence to suggest that the lake has ever desiccated completely or had a clear tendency to dry up in the 44,000 years of its known existence. References to Lake Pátzcuaro paleolimnology also include Deevey (1944), Hutchinson et al. (1956), Saporito (1975), Pollard (1982), Gorenstine & Pollard (1983), Metcalfe et al. (1989, 1994), Street-Perrot et al. (1989), O'hara (1991) and O'hara et al. (1993-1994).

A recent geological study on Lake Cuitzeo concludes that "the initial lacustrine phase was a shallow aquatic environment . . ." (Garduno & Israde 1997). This new standpoint, based on recent field studies, refutes the assumption of an initially deep lake which has been reduced (by sedimentation) to level ground in the course of time.

**Gaps in current knowledge of ecosystem dynamics**

Lake Zirahuen is a warm monomictic waterbody with unique water dynamics amongst the Michoacan lakes. Because it is relatively deep (maximum depth 40 m), seasonal patterns of alternating circulation and thermal stratification develop in the lake, a feature not shared by the other two polymictic shallow lakes, Patzcuaro and Cuitzeo. Furthermore, Zirahuen is an oligo-mesotrophic waterbody, dependent on density currents which continuously maintain aerobic conditions at the bottom of the lake in spite of a regular input of nutrients and organic materials from the watershed (= catchment) (Bernal-Brooks 1988), as occurs in some man-made reservoirs (Lied et al. 1993). This particular feature is also not shared with Patzcuaro and Cuitzeo, preventing Zirahuen from self-fertilization (by recirculating mineral nutrients from the sediments) and so there are no visual effects of eutrophication or "deteriorated appearance".

Lake Cuitzeo's recurrent dessication (the term "regression" was used by De Buen) has been analyzed simply in terms of local effects between atmospheric precipitation and evaporation from the lake, and not in terms of a wider geographical context, the watershed area (De Buen 1943a,b; Mendivil 1980; Alvarado 1985). In this sense the waterbody, at the lowest point in the watershed or catchment, acts as a sump for all surface and groundwater in the region and shows variable fluctuations in water level according to the amount of rainfall. Information obtained at the Chehuayito Station (for water-level registration) indicates that the water surface of the lake reached low points of desiccation in 1942, 1961 and 1982, but also reached the extremes of a water-filled basin in 1958, 1967, 1976, 1988 and 1991.

Traditionally, Mexican limnology has been descriptive, focussing on monitoring physical and chemical components. Recently there has been a gradual change emphasising the integral functional of aquatic systems (Davalos-Lind & Lind 1993), although this new approach has been developed mainly at the Chapala Ecology Station. The opportunity should now be taken to
study the hydrology of catchments and the nutrient loads to lakes, in order to understand the factors involved in lake dynamics and productivity. Future management of Mexican lakes could then be based more firmly on a "functional" background rather than just a "descriptive" framework. Also, research is needed to discern the impacts of cultural eutrophication imposed as an acceleration to the natural process of ageing for the three lake basins of Michoacan.

Finally, an ongoing study by Israde & Garduno (1997) at the University of Michoacan, on the thickness and types of sediments in the lakes - including inorganic and organic horizons - may enhance our knowledge of the geology and paleolimnology of the region.

Acknowledgments

I wish to thank Dr Javier Alcocer-Durand for suggestions relative to this paper, Biol. Gustavo Barajas Mendoza at the computer (Multiservicios en Computacion, Morelia, Mich.), and Dr David Sutcliffe (FBA) for suggestions on improving the manuscript.

References


