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A new morphometric study of Carioca Lake, Parque Estadual do Rio Doce (PERD), Minas Gerais State, Brazil

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ABSTRACT. Carioca Lake is located within the limits of the Rio Doce State Park, in the eastern part of the state of Minas Gerais. This park, one of the largest natural reserves of the Atlantic Rain Forest in Brazil, is a hotspot of tropical biodiversity. The purpose of this study was to update existing information on the bathymetry and morphometric features of the lake, using differential GPS (DGPS) technology for data collection, coupled to a digital echo sounder. The bathymetry was based on the acquisition of 1106 points, where the depths as well as the geographic coordinates were obtained. The new study allowed the refinement of existing primary and secondary morphometric data for this lake.

Key words: Carioca Lake, bathymetry, morphometric parameters, mapping.

RESUMO. Novo estudo morfométrico da lagoa Carioca, Parque Estadual do Rio Doce (PERD), Estado de Minas Gerais. A lagoa Carioca está localizada nos limites do Parque Estadual do Rio Doce (PERD), na região leste do Estado de Minas Gerais. Este parque, uma das maiores reservas naturais da Mata Atlântica no Brasil, é um hotspot da biodiversidade. Este trabalho tem por objetivo elaborar um novo mapeamento batimétrico e descrever as características morfométricas deste ambiente utilizando a tecnologia do GPS diferencial (DGPS) para coleta dos dados de localização geográfica em conjunto com uma ecossonda digital, equipamento para coleta das informações de profundidade. O levantamento batimétrico da lagoa Carioca foi baseado num total de 1106 pontos com profundidade e localização conhecidas, obtidas com precisão submétrica. O novo estudo permitiu o refinamento dos dados morfométricos primários e secundários existentes para este lago.

Palavras-chave: lagoa Carioca, batimetria, parâmetros morfométricos, mapeamento.

Introduction

Knowledge of the morphological characteristics of a lake is important because the shape of the aquatic body affects practically all of the physical, chemical, and biological properties of the ecosystem (VON SPERLING, 1999). The morphology of a drainage basin, for example, is often considered as one of the most important characteristics of the lakes within it, since it basically differentiates the properties of one lake from another (e.g., trophic level, retention time, Secchi depth, thermal regime, and oxygen regime) (JOHANSSON et al., 2007). Several studies have shown that the mean depth is the dominant controlling factor of the productivity (HANNA, 1990; FEE et al., 1996; BEZERRA-NETO; PINTO-COELHO, 2002). The shape of a lake also regulates the sedimentation and the oxygen dynamics in the hypolimnion (RESCK et al., 2007).

A bathymetric chart is a tool of great importance for the knowledge of the morphological features of water bodies. The bathymetric analyses enable the construction of a depth map, which provides a sound basis for the process of making correct decisions to address the use and sustainable management of a given water body, and is crucial in the preparation of studies on aquaculture, navigation, dredging, fishing, or leisure activities.

Over the past decade, the technological capacity for bathymetric mapping has developed explosively. These innovations include the use of differential global positioning systems (DGPS) for an accurate determination of the mapping, in combination with echo sounders that export the data to systems of geographic information (SIG) computer software. These modern geographic positioning devices, together with the new sounding technology, generate much more accurate bathymetric maps than were possible in the past.

This study aimed to deliver not only a new bathymetric chart but also to describe the morphometric characteristics of Carioca Lake (PERD, Minas Gerais State). Studies in this environment began

in 1977, and from this date dozens of scientific articles were published (BARBOSA; TUNDISI, 1980; REYNOLDS et al., 1983; BARBOSA; COUTINHO, 1987; MARQUES et al., 1999) addressing physical, chemical, and biological aspects of its limnology. The first bathymetric chart of Carioca Lake and calculations of the main morphometric parameters were published by Tundisi and Musarra (1986). The methodology used in this work was innovative for its time, using the technique of echo sounding to determine the main morphological characteristics of Carioca Lake, plus three more lakes (Dom Helvécio, Barra, and Jacaré) of the middle Rio Doce lake district.

Material and methods

Study area

The Parque Estadual do Rio Doce (Figure 1) is the largest remnant of the Atlantic Rain Forest biome in Minas Gerais, totaling 36,000 ha of forests (5% of the original forested area in the region), surrounded by *Eucalyptus* spp. plantations.

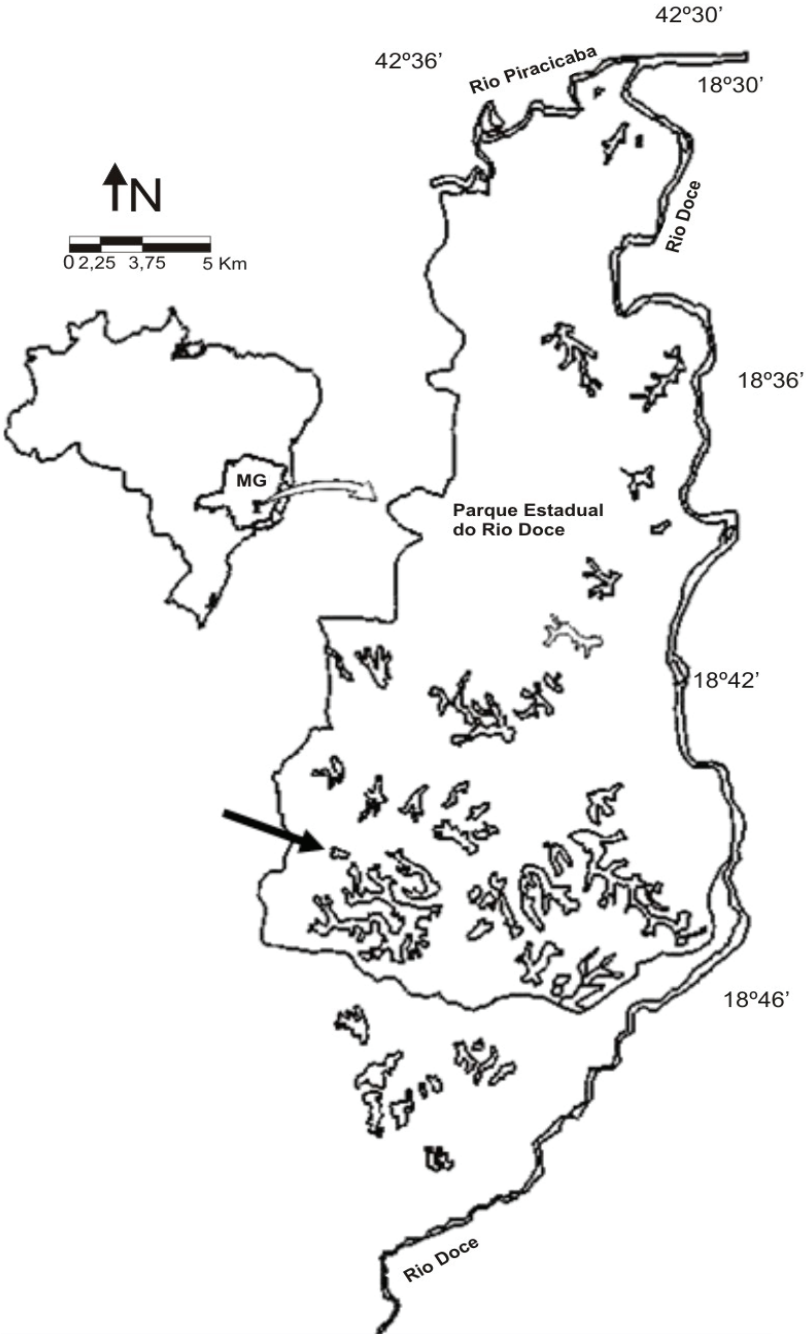

Figure 1. Location of the Parque Estadual do Rio Doce in southern Brazil.The arrow indicates Carioca Lake.

The lakes occupy an area of 3,500 ha, which corresponds to 9.8% of the total area (MÉIS; TUNDISI, 1997). In the southern portion of PERD is Carioca Lake (central point 19º45'S; 42º37'W), the object of this study. Carioca Lake is a natural lake surrounded by the Atlantic Rain Forest. It is mesotrophic and warm-monomictic, with a short circulation period during winter (June to August). The lake is stratified during the rest of the year (HENRY; BARBOSA, 1989).

Data collection

The bathymetric study in Carioca Lake was performed using the high-precision differential GPS (DGPS) technology in order to collect the data for the geographical location, together with state-of-the-art equipment for collecting depth information. A digital Biosonics echo sounder (*Biosonics Inc.*) was used, which collects data through a high-frequency (200 kHz) transducer, traveling attached on board the boat at a depth of 0.50 m of water level, depending on the conditions of the bottom of the lake. The digital echo sounder is coupled with a differential global positioning system (DGPS) AgGPS 132 (*Trimble Co.*). The field data sampling was done on May 13, 2008.

The DGPS had its data corrected *in situ*, through satellite Omnistar subscription. Thus, the data collected by the positioning unit of the boat were corrected in real time, and the positioning error was less than 100 cm. For each GPS position information (every two seconds), X and Y coordinates were recorded along with the value Z (depth) collected by the digital echo sounder. The UTM projection and the WGS84 (*World Geodetic System*) horizontal datum were set as a way of storing positioning data by the system.

The transducer of the echo sounder and the kinematics of the DGPS antenna were fixed at the opposite ends of the stack positioned at midlength of the vessel. The centering of the DGPS antenna in relation to the echo sounder's transducer reduces errors from the positioning tilt of the boat. The boat moved in zigzag lines at an average speed of 8 km h^{-1}. A conventional Garmin GPS 76 (*Garmin Ltd.*) was used to guide the boat's movement in the water.

Production of the bathymetric chart

The first step was the preparation of the contour map of Carioca Lake (bathymetric map) and of the 3D view map. The shoreline of the lake was scanned through the Didger 3.0® program (*Golden Software Inc.*), by georeferenced orthophotos from the lake on a 1:10000 scale acquired from the Energy Company of Minas Gerais (Cemig S/A). These images could be used because there were no significant changes in the shoreline of the lake during the period (comparing with Landsat satellite images).

The bathymetric map was produced using the program Surfer 8.0® (*Golden Software Inc.*). This program uses algorithms of interpolation to create a mesh of equally spaced data. This mesh is required for the preparation of the contour map. In this process, the original data collected in the field (the XYZ file of location and depth) are used to generate values for sites where observations are lacking. The choice between the various interpolators available in the Surfer program (inverse distance, kriging, minimum curvature etc.) in the generation of the data mesh for Carioca Lake was made by visual comparison of maps and by the analysis of residuals (grid/residuals module of the Surfer).

Calculation of the morphometric parameters

The bathymetric survey made possible the calculation of the primary and secondary morphometric parameters. The maximum depth was removed from the original field data. The perimeter (P), the effective length (Le), and the maximum effective width (We) were estimated on the chart by the bathymetric image analyzer program, Scion Image® (*Scion Corporation*). The surface area (A), the bottom area (Ba), and the total volume (V) were calculated from sub-routines of the program *Surfer*. To calculate the volume, this program uses three different algorithms: trapezoidal rule, Simpson's rule, and Simpson's 3/8 rule. The average of the three methods for calculating the volume of Carioca Lake was the one used. Also in the *Surfer* environment, volumes and areas between tier depths, spaced 2 m apart, were calculated.

The formulas for calculating the following morphometric parameters were taken from Von Sperling (1999): mean depth ($\overline{Z}$); relative depth (Z_R); development volume rate (D_V), perimeter development rate (D_P), mean width (L_m), and mean slope (α).

Results and discussion

The bathymetric survey of Carioca Lake was conducted with a total of 1,106 points with known depth and location and with sub-metric accuracy. The interpolator used in the grid generation of data that best represented the behavior of the surface and showed the lowest residual values (mean -0.02 ± 0.07) was kriging, which can act as an exact interpolator in relation to the agreement with the original points of observation. From the selected grid a bathymetric model of the lagoon was generated, with curves every 2 m of depth, and an

elevation of 242 m for the surface of the lake on the day of collection (Figure 2).

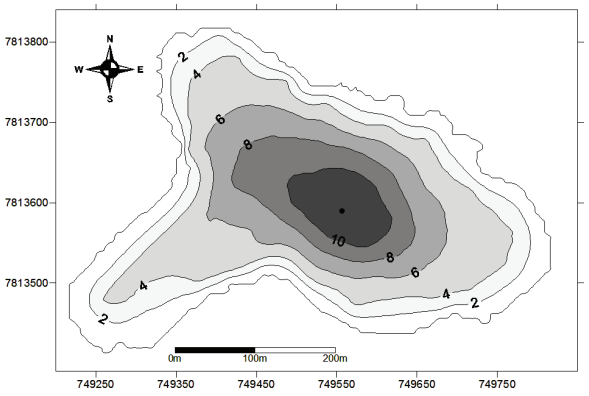

Figure 2. Bathymetric map of Carioca Lake, Parque Estadual do Rio Doce, Minas Gerais State. The dot at the center of the lake indicates the location of maximum depth (11.8 m).

The three-dimensional bathymetric model (Figure 3A) is an important tool for a better visualization of the lake basin, which usually reflects the nature of the drainage basin. From this model, it is possible to see the details of the relief from the bottom of the lake, which is a result of the dense sampling grid. From the bathymetry in the 3D view, it is also possible to compare the relief of the bottom of the lake made by the bathymetric model, with the image of the relief created (in real time) by the *Biosonics* echo sounder during the collection of data. From the echogram shown in Figure 3B, generated from a transect through the lake in the east-west direction, we see that the bottom relief shown by the *Biosonics* echo sounder was satisfactorily reproduced by the 3D bathymetric model. This further indicates that the model chosen for bathymetric mapping adequately represents the real surface.

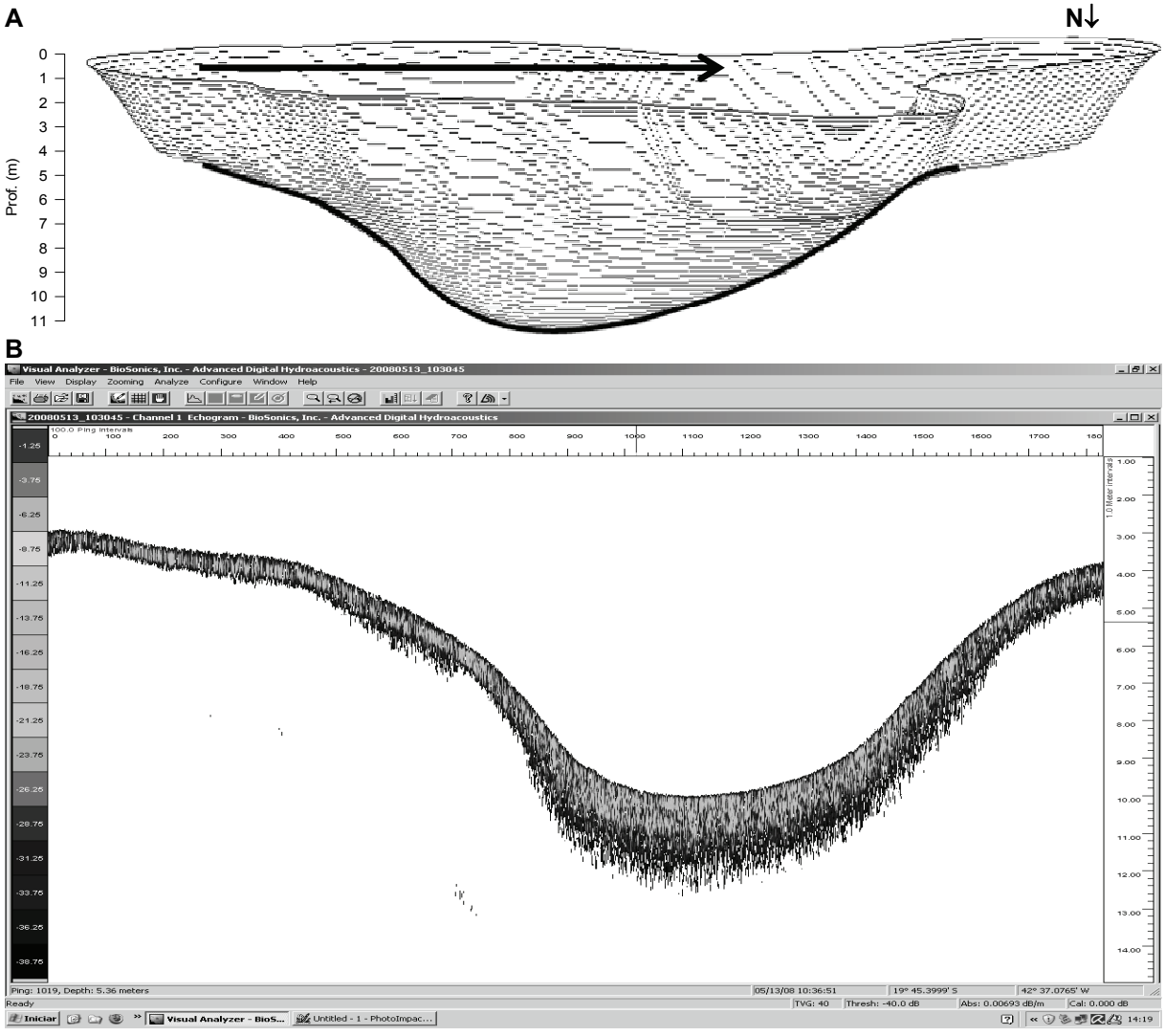

Figure 3. (A) Bathymetric profile in 3D view of Carioca Lake, Parque Estadual do Rio Doce, Minas Gerais (North – South view), with emphasis on the slope of the lake bottom; B) Echogram generated by *Biosonics* echo sounder, showing the profile of the bottom transect in the east-west direction (indicated by the arrow in the figure above), made in June 2008.

The Table 1 summarizes all the morphometric data of Carioca Lake, including the volume and total area of the water surface, calculated from the new bathymetric chart. The total volume of 671.2 x 10^3 m^3 calculated for Carioca Lake in this study represents a difference of 950% less than the value published in the study of Tundisi and Musarra (1986), which was 713.6 x 10^4 m^3. We believe that there may have been an error in the printing of the article, and that probably the authors had calculated the volume as 713.6 x 10^3 m^3, which would represent a difference of 6% higher than the calculation obtained in the present study. This last figure appears in other publications (HENRY, BARBOSA, 1989; HENRY, 1997).

There was only a small difference in the value for surface area between the results of Tundisi and Musarra (1986) and the results presented here. These authors estimated the surface area as 13.5 ha, which is 4.2% less than the area of 14.1 ha estimated in this study.

Table 1. Morphometric characteristics of Carioca Lake, Parque Estadual do Rio Doce, Minas Gerais State, Brazil.

Morphometric Parameters	
Surface area (*A*)	14.1 ha
Volume (*V*)	671.2 x 10^3 m^3
Perimeter (*P*)	1718 m
Maximum effective length (*Le*)	572.8 m
Maximum effective width (*We*)	350,7 m
Maximum depth (Z_{max})	11.8 m
Mean depth ($\overline{Z}$)	4.76 m
Relative Depth (Z_R)	2.78 %
Mean width (L_m)	246.2 m
Volume development rate (D_V)	1.21
Shoreline development rate (D_L)	1.28
Mean slope (α)	5.57 %

The same routine of the Surfer program, used to calculate the total surface area and volume of the lake, was used for the calculation of these parameters, for each 2 m of depth. The details of these data are shown in Table 2. From this table, it is possible to conclude that 65.4% of the total lake volume corresponds to depths less than 4.0 m.

Table 2. Data on area and volume for depth strata of Carioca Lake, Parque Estadual do Rio Doce, Minas Gerais State, Brazil.

Depth (m)	Area (m^2)	% area	Tier	Volume (m^3)	% volume
0	141030.13	100.0	0-2	244129.83	36.37
2	109551.53	77.68	2-4	194886.48	29.03
4	84411.13	59.85	4-6	127955.44	19.06
6	45293.18	32.12	6-8	67280.67	10.02
8	23729.80	16.83	8-10	31095.01	4.63
10	8807.40	8.04	10-11.4	5873.81	0.88
11,8	1.03	0.001	Total	671221.25	100.0

Conclusion

The methodology of automated bathymetry used in this study proved to be a good choice for the rapid estimation of most morphometric parameters in a small lake. The high accuracy of geographic positioning and the precision of depth measurement of the Biosonics echo sounder provided high quality and reliability in the final results obtained in a short period of time. The morphometric parameters in this study, together with the new bathymetric chart of Carioca Lake, are valuable tools to promote better understanding of one of the most-studied natural lakes in Brazil. The present investigation found unexpected (large) differences in several morphometric parameters, when compared to the available literature. These differences clearly justify the effort expended in this new study.

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References

BARBOSA, F. A. R.; TUNDISI, J. G. Primary production of phytoplankton and environmental characteristics of a shallow Quaternary lake at eastern Brazil. **Archiv für Hydrobiologie**, v. 90, n. 2, p. 139-161, 1980.

BARBOSA, F. A. R.; COUTINHO, M. E. Decomposition rates of allochthonous material (litter) in Lake Carioca - Rio Doce Forest Park – MG. **Revista Brasileira de Biologia**, v. 47, n. 1/2, p. 37-45, 1987.

BEZERRA-NETO, J. F.; PINTO-COELHO, R. M. A morfometria e o estado trófico de um reservatório urbano: lagoa do Nado, Belo Horizonte, Estado de Minas Gerais. **Acta Scientarium. Biological Sciences**, v. 24, n. 2, p. 285-290, 2002.

FEE, E. J.; HECKY, R. E.; KASIAN, S. E. M.; CRUIKSHANK, D. R. Effects of lake size, water clarity, and climatic variability, on mixing depths in Canadian Shield lakes. **Limnology and Oceanography**, v. 41, n. 5, p. 912-920, 1996.

HANNA, M. Evaluation of models predicting mixing depth. **Canadian Journal of Fisheries and Aquatic Sciences**, v. 47, n. 5, p. 940–947, 1990.

HENRY, R. A comparative study of thermal structure, heat content and stability of stratification in three lakes. In: TUNDISI, J. G.; SAIJO, Y. (Ed.). **Limnological Studies on the Rio Doce Valley Lakes, Brazil**. Rio de Janeiro: Academia Brasileira de Ciências/USP, 1997. p. 69-77.

HENRY, R.; BARBOSA, F. A. R. Thermal structure, heat content and stability of two lakes in the National Park of Rio Doce Valley (Minas Gerais, Brazil). **Hydrobiologia**, v. 171, n. 3, p. 189-199, 1989.

JOHANSSON, H.; BROLIN, A. A.; HÅKANSON, L. New approaches to the modelling of lake basin morphometry. **Environmental Modeling and Assessment**, v. 12, n. 3, p. 213-228, 2007.

MARQUES, M G. S. M.; FERREIRA, R. L.; BARBOSA, F. A. R. A comunidade de macroinvertebrados aquáticos e características limnológicas das lagoas Carioca e da Barra, Parque Estadual do Rio Doce, MG. **Revista Brasileira de Biologia**, v. 59, n. 2, p. 203-210, 1999.

MÉIS, M. R. M.; TUNDISI, J. G. Geomorphological and Limnological Processes as a Basis for Lake Typology. The Middle Rio Doce Lake System. In: TUNDISI, J. G.; SAIJO, Y. (Ed.**). Limnological Studies on the Rio Doce Valley Lakes, Brazil**. Rio de Janeiro: Academia Brasileira de Ciências/USP, 1997. p. 25-48.

RESCK, R.; BEZERRA-NETO, J. F.; PINTO-COELHO, R. M. Nova batimetria e uma avaliação ecológica de parâmetros morfométricos da Lagoa da Pampulha (Belo Horizonte, Brasil). **Geografias**, v. 3, n. 2, p. 24-37, 2007.

REYNOLDS, C. S.; TUNDISI, J. G.; HINO, K. Observations on a metalimnetic Lyngbya population in a stably stratified tropical lake (Lagoa Carioca, eastern Brazil). **Archiv für Hydrobiologie**, v. 97, n. 1, p. 7-17, 1983.

TUNDISI, J. G.; MUSARRA, M. L. Morphometry of four lakes in the Rio Doce Valley Lakes system and its relationships with primary production of phytoplankton. **Revista Brasileira de Biologia**, v. 46, n. 1, p. 159-171, 1986.

VON SPERLING, E. **Morfometria de lagos e represas**. Belo Horizonte: UFMG, 1999.

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