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Variation of limnological parameters in a tropical lake used for tilapia cage farming

Graciele P. Venturoti, Alexandra C. Veronez, Rômulo V. Salla, Levy C. Gomes*

Laboratório de Ictiologia Aplicada—Universidade Vila Velha, 29101-770 Vila Velha, ES, Brazil

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ABSTRACT

The aim of this study was to assess the effects of tilapia cage culture on the water quality and sediment of Palminhas Lake during both the dry and rainy seasons. Eight sites within the lake (four in fish farms and four in areas without fish farms) and one site on an affluent stream were sampled monthly from February 2011 to January 2012. Dissolved oxygen and pH were significantly lower at fish farm sites than at locations without farms, while chlorophyll *a* was higher at fish farm sites. Moreover, large seasonal variations were observed, which were not related to the fish farms. The Secchi disc depth and ammonia nitrogen level were significantly higher during the dry season, but temperature, dissolved oxygen, pH, total phosphorus and chlorophyll *a* were significantly higher during the rainy season. The affluent stream contributed substantially to lake eutrophication. Palminhas Lake is mesotrophic and has exhibited a progressive worsening in water quality over the past 20 years. These changes were not caused by fish farming alone but probably by other anthropic activities in the areas surrounding the lake.

1. Introduction

The use of natural and artificial lakes for farming Nile tilapia (*Oreochromis niloticus*) in cages has increased in tropical and subtropical countries (Bueno et al., 2013). Several attributes make tilapia interesting for aquaculture; these fishes exhibit fast growth, tolerance for environmental changes, resistance to stress and disease and acceptance of natural or artificial feeds (El-Sayed, 2006). The development of management techniques, research on nutrition and culture systems, market development and processing advances have all contributed to the rapid expansion of the tilapia industry. In Brazil, Palminhas is a tropical lake that has been used for tilapia culture since 2005. This lake contains four tilapia farms with a volume of 3,280 m^3 and an estimated annual production of 710 t. Fish culture in this lake began without proper management, and changes in water quality, as assessed by water transparency, color, odor and flavor, have been attributed to the presence of tilapia farms.

Tropical lakes are lentic systems with specific thermal stability. Upon the influx of high nutrient loads derived from fish farming cages, these systems can become a favorable environment for increasing the biomass of phytoplankton, which can change limnological variables and trophic states (Guo et al., 2009; Wetzel and Likens, 2000). These alterations used to be attributed to the incorporation of nitrogen and phosphorus, which limits primary productivity in natural aquatic environments (Beveridge, 2008; Wetzel, 2001). Thus, it is necessary to investigate the trophic states of lentic ecosystems that are used for fish farming and the specific effects of fish farming on the limnological parameters of studied lakes. The objective of this paper was to assess the effects of tilapia caged culture on water quality and sediment of a tropical lake during both the dry and rainy seasons.

2. Materials and methods

2.1. Study area

Palminhas Lake (19°25′31″S and 40°14′58″W 01; Fig. 1) is part of the lagoon complex of the lower Doce River, which is composed of more than 60 other lakes and lagoons, within a region characterized by the Barriers formation. The lake comprises approximately 1,100 ha, has a maximum depth of 24 m, and is dendritically shaped, with numerous "fingers" (Esteves et al., 1995). The water is supplied from small tributaries and by rainwater, and the water outlets are composed of channels that flow into the Doce River.

The shoreline of Palminhas Lake is used for commercial, residential and recreational purposes by both individuals and collectives, and a small portion of native forest is still preserved. Commercial activities include grazing, forestry, and rubber tree, coffee and banana plantations. The lake contains four caged fish farms that have produced tilapia since 2005. The volume of the fish farms

* Corresponding author.
E-mail address: levy.gomes@uvv.br (L.C. Gomes).

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Table 1
Environmental parameters, yield and N and P inputs to the environment of four fish farms monitored in Palminhas Lake, Linhares, ES, Brazil. FF—fish farm; TVC—total volume of cages (total useful volume of the cages of each fish farm); FCR—feed conversion rate.

FF	Depth (m) Min–max	Water flux ($m\,s^{-1}$) Min–max	TVC (m^3)	Yield (t/year)	FCR	*N*-input[a] (kg/year)	*P*-input[a] (kg/year)
FF1	7.5–11.8	0–0.16	540	132	1.65	838	180
FF2	15.5–19.2	0–0.57	1,176	288	1.52	1,686	361
FF3	15.4–18.15	0–0.71	900	118	1.60	727	156
FF4	18.0–21.3	0–0.40	664	170	1.55	1,015	218

[a] To calculate *N* and *P* inputs to the environment, the following parameters were assumed: (1) the *N* and *P* content in the feed was 5 and 1%, respectively (manufacturer information) and (2) the *N* and *P* content from feed released into the environment was 77 and 82.5%, respectively (Beveridge, 2008).

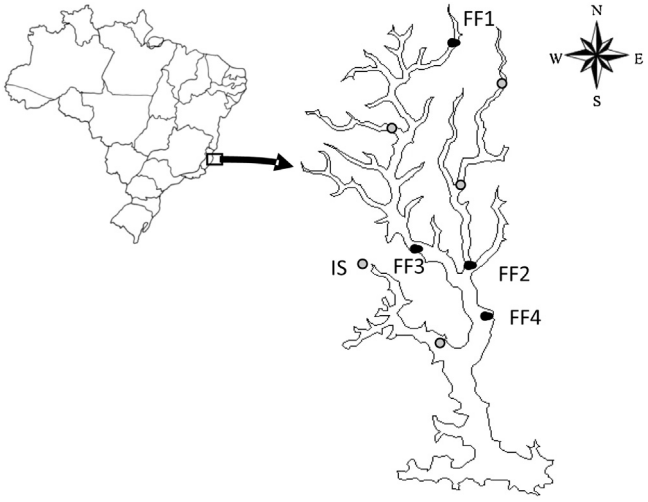

Fig. 1. The study area showing Palminhas Lake, the sampled sites and the Doce River in Linhares, ES (Brazil). The black dots indicate the locations of the monitored fish farms and the gray dots indicate the monitored sites without fish farming. IS = inlet stream.

ranges between 540 and 1,176 m^3, with an estimated annual production of approximately 710 t and a food conversion ratio of approximately 1.6. The maximum depths for the four fish farms during the dry and rainy seasons, their production capacity, the total useful volume of the cages and average feed conversion were measured during the monitoring period (Table 1).

2.2. Sampling

Eight sites within the lake (four in fish farms and four in areas without fish farms) were sampled monthly from February 2011 to January 2012 (Fig. 1). The sites without fish farming were intended to be representative of the entire lake and were chosen based on environmental characteristics, such as the presence of forest, fewer human activities on the shore, water movement, and depth, which were different from the sites with fish farms.

We also sampled a site on a stream that supplies Palminhas Lake. This location was sampled monthly to monitor the incidence of allochthonous nutrient inputs and other parameters, for which the impact of fish farms was measured in limnological variables. Sediment samples were also collected at each monitored site for analysis of organic matter and total phosphorus; samples were taken in triplicate using a Petersen dredge. The material was placed into a pan, mixed and then divided into two samples of approximately 200 mL each, one for the analysis of organic matter and the other for the analysis of total phosphorus.

2.3. Analysis

2.3.1. Limnological parameters

The Secchi disk depth, dissolved oxygen, temperature, hydrogen potential (pH) and electrical conductivity were measured in situ at each sampling site. Electrical conductivity was measured using a multiparametric device (Horiba U52G) at both the surface (to 1 m depth) and the bottom (at 1 m above the sediment). Two samples of surface water were also collected using a 2-L Van Dorn bottle for the analysis of total phosphorus, orthophosphate, ammonia nitrogen, biochemical oxygen demand (BOD_5) and chlorophyll *a*.

The total phosphorus and orthophosphate levels were analyzed using the ascorbic acid method, with previous persulfate digestion treatment in an autoclave for total phosphorus and prefiltered samples for orthophosphate. Chlorophyll *a* was analyzed using the acetone extraction method. The ammonia nitrogen levels were analyzed using the phenate method, and BOD_5 was analyzed by incubation at 20 °C for 5 days. A test was performed using a NIST-traceable standard to assess the accuracy of the total phosphorus results (expected result CV = 8%). The methods for the preparation of glassware for the collection and storage of the water samples are described in section 1060 from APHA (1998). All parameters were analyzed as described in APHA (1998).

2.3.2. Calculation of the trophic state index

The trophic state index (TSI) was calculated as described by Carlson (1977) with modifications for the tropical environments as previously proposed by Toledo Junior et al. (1983). This calculation includes orthophosphate as a parameter and included some calibrations into the calculations to better describe tropical environments. The TSI of each parameter (total phosphorus, orthophosphate, chlorophyll *a* and Secchi transparency) was calculated for each sampling site every month. At the end of the study period, the TSI values were averaged to evaluate the specific conditions for each season. The classification proposed by Toledo Junior et al. (1983) is designated as follows: Ultraoligotrophic TSI < 24; Oligotrophic TSI from 24.1 to 44; Mesotrophic TSI from 44.1 to 54; Eutrophic TSI from 54.1 to 74; and Hypereutrophic TSI > 74.

2.3.3. Mapping the distribution of total phosphorus and chlorophyll a

The annual average total phosphorus and chlorophyll *a* values for the study sites were compiled and processed into a Geographic Information System (GIS), ArcGIS, previously supplied with an image obtained from Ortofotomosaico of Espírito Santo, Brazil, acquired from the State Environment and Water Resources Institute. The Ortofotomosaico image is a digital cartographic product on a scale of 1:15,000 PEC "A" 1, with a spatial resolution of 1 m, drawn from an aerophotogrammetrical survey with a scale of 1:35,000 that was generated in May/June 2008. The image is a composite of approximately 540 blocks of pictures that cover squares of 100 km^2. To produce the maps and to interpolate the functional data, images of the lake were scanned using ArcMap.

2.3.4. Statistical analysis

The months corresponding to each season (rainy and dry) were classified according to the average monthly rainfall between 1976