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Extreme drought events and the sustainability of fish farming in net cages in reservoirs of the semi-arid northeastern region in Brazil

Eventos extremos de seca e a sustentabilidade da piscicultura em tanques-rede em reservatórios do semiárido brasileiro

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Abstract: Reservoirs play important roles in local socioeconomic development and are particularly relevant in developing countries. The rearing of Nile tilapia (*Oreochromis niloticus*) in cages is one of the fastest growing activities carried out in reservoirs since it is a strategy to sustain the growing demand for food fish. Most reservoirs are in eutrophic or hypereutrophic conditions in the semi-arid northeast region of Brazil and thus, the expansion of aquaculture endangers the ecological functions of the reservoirs by increasing the eutrophication potential. On the other hand, aquaculture contributes to economic development by generating jobs and income for the population and being an important alternative in the production sector for riverine populations. In this context, we present in this article our opinion about the sustainability of fish farming activities in net cages in reservoirs of the Brazilian semiarid, especially when subjected to extreme drought events.

Keywords: Nile tilapia; eutrophication; aquaculture.

Resumo: Os reservatórios desempenham funções importantes no desenvolvimento socioeconômico local, sendo particularmente relevantes em países em desenvolvimento. Entre seus diversos usos a criação de tilápia do Nilo (*Oreochromis niloticus*) em tanques-rede é um dos que mais cresce, principalmente para sustentar a demanda crescente por pescado. No semiárido brasileiro, onde a maioria dos reservatórios está em condições eutróficas ou hipereutróficas, a aquicultura é mais uma pressão de eutrofização, colocando em risco suas funções ecológicas. Por outro lado, as atividades de aquicultura auxiliam no desenvolvimento econômico através da geração de empregos e renda para a população, sendo uma importante alternativa produtiva para as populações ribeirinhas. Neste contexto, apresentamos neste artigo uma avaliação sobre a sustentabilidade das atividades de piscicultura em tanques-rede desenvolvidas em reservatórios do semiárido brasileiro, principalmente quando submetidos a eventos extremos de seca.

Palavras-chave: tilápia do Nilo; eutrofização; aquicultura.

In semi-arid regions, the high relationship between the drainage basin area and the reservoir area, the environmental conditions of prolonged droughts, irregular rainy periods, high evaporation and long water retention times increase the vulnerability of reservoirs to eutrophication (Thornton & Rast, 1993; Jeppesen et al., 2015; Santos et al., 2017). The external nutrient contributions from productive activities such as agriculture and aquaculture, in addition to urban pollution, is one of the most important anthropogenic impacts to increase the eutrophication process of the reservoirs (Khan & Panikkar, 2009; Banerjee et al., 2016; Lopes et al., 2017). In this context, the improper management of the multiple uses of these environments pose a high risk of deterioration and may gradually lose their social importance and ecosystem services.

The reservoirs of the Brazilian semiarid were designed mainly to accumulate water for anthropogenic use (domestic, industrial and agriculture), as well as preserve part of the watersheds in which they are installed. Most of the reservoirs have a long water retention time and a reduced flow, which tend to generate a negative water balance most of the year. These aquatic environments usually concentrate a higher nutrient load due to high evaporation and the consequent reduction of their volume during periods of intense drought. Higher nutrient concentrations, especially phosphates, increase the vulnerability of these environments to eutrophication from increased primary production and the proliferation of cyanobacteria.

There is currently pressure for dams in northeastern Brazil to be used for fish production in net cages, with state and federal governments proposing public policies to promote the growth and expansion of this activity, especially through the rearing of the exotic Nile tilapia. However, this type of fish farming depends on a high amount of inputs since it is an intensive activity and can cause negative impacts, such as artificial eutrophication. Knowledge of these impacts, the characteristics of the aquatic ecosystem in which the activity is carried out and the current legislation (Conama Resolution No. 357, of 2005) (Brasil, 2005), which deals with the classification of water bodies and gives environmental guidelines, should include how production can be increased without compromising the multiple uses of the aquatic system, aiming at the development of sustainable activities.

Among the main impacts of fish farming in dams is the accumulation of organic matter, uneaten feed remains and excretion from farmed animals (Moura et al., 2014). These materials are concentrated near the net tanks and alter the characteristics of the water column and the sediment. Nutrients that accumulate in environments with long retention time, such as in semiarid dams, the impacts may be more intense and extend over a larger area. Furthermore, fish production in net cages can reduce biodiversity (Diniz & Melo-Júnior, 2017; Ramos et al., 2013).

It is estimated that 30% of the feed offered is directly lost to the aquatic environment and up to 14 kg of phosphorus and 45 kg of nitrogen to the aquatic environment are released for each tonne of tilapia production (Montanhini Neto & Ostrensky, 2015). Reports of intensive tilapia culture in cages in semi-arid tropical regions have shown that up to 37% of the commercial diet for fish productions lost to the environment (Molisani et al., 2015). Thus, the decrease in water quality in several reservoirs is mainly related to the amount of organic matter from fish production in cages (Moura et al. 2016; Xia et al., 2016). During dry seasons, the impacts in reservoirs in arid and semi-arid regions can be even greater since the input of nutrients and organic matter from fish farming has a greater potential to deteriorate water quality with a smaller reservoir volume.

Moura (2018) evaluated the carrying capacity of rearing Nile tilapia (*Oreochromis niloticus*) in net cages in the Santa Cruz and Umari reservoirs (Apodi river basin/Mossoró-RN), subjected to a period of intense drought. The carrying capacity was estimated by modeling the phosphorus mass balance and estimating the capacity of the reservoir to assimilate this nutrient. It was assumed that fish farming was only one of the sources of phosphorus for the reservoirs and considered a scenario of increasing total phosphorus concentrations in water of 5 $\mu g.L^{-1}$. The author concluded that fish farms in the Umari and Santa Cruz reservoirs could sustain tilapia production in net cages in the order of 500 and 300 $t.year^{-1}$, respectively, considering a 5 $\mu g.L^{-1}$ increase in phosphorus concentrations in the water column. However, the Santa Cruz reservoir has phosphorus concentrations higher than 30 $\mu g.L^{-1}$ and should not initiate fish farming activities according to current legislation (CONAMA Resolution, 357) (Brasil, 2005).

The model by Dillon & Rigler (1974) used by Moura (2018) to evaluate the phosphorus loading capacity and the carrying capacity of reservoirs for intensive fish farming in net cages assumes that the volume of the reservoir is static. This is certainly

not the case in reservoirs located in the semi-arid northeastern region of Brazil, of which suffer large variations in volume within the same year and between years. Another model that accounted for the phosphorus mass balance coupled to the water balance of the Santa Cruz reservoir estimated that the carrying capacity of this reservoir for intensive fish farming in net-cages ranged from 2.26 to 20.72 tons of tilapia per month, or 27.12 to 248.64 tonnes per year, depending on the volume of the dam and assuming an emission factor of 10 kg of phosphorus per tonne of tilapia produced and an initial total phosphorus concentration in water of 22 ug L^{-1}, equivalent to the annual average of this variable observed in the reservoir for the year 2017 (Attayde et al., 2019). In this study, the carrying capacity of the Umari reservoir for intensive fish farming was not calculated because the reservoir had an average annual concentration of total phosphorus above the maximum limit of 30 μg.L^{-1} as allowed by legislation (CONAMA Resolution 357, 2005) (Brasil, 2005).

Cacho (2017) evaluated the sedimentation of nutrients and particulate matter in the Umari reservoir with the rearing of Nile tilapia in cages and concluded that the activity increased the sedimentation rates of particulate matter and nutrients (nitrogen, phosphorus and carbon), with significant differences shown between the cultivation region in relation to the control region. The author also found that these changes were restricted to the area of fish farming in the Umari reservoir, since the natural sedimentation rates of particulate matter and nutrients in the control region were reduced and stable. Moura et al. (2014) evaluated the sedimentation rates of nutrients and particulate matter in the Santa Cruz reservoir and also found that the sedimentation of nutrients and organic matter was significantly higher near the fish production activities than in the control region 400 meters away from the activities. For example, the sedimentation of total phosphorus was 100 times higher in the area near the fish production when compared to the natural sedimentation of the reservoir

Moura et al. (2016) evaluated the sustainability of aquaculture in net cages carried out in the Santa Cruz reservoir by using a set of 49 environmental, economic and social indicators. The fish production in net cages was economically viable by generating profit and distributing income. In the environmental dimension, the system was dependent on high inputs of the nutrients nitrogen and phosphorus and on energy, and increased nutrient sedimentation in the reservoir. In the social dimension, the activity employed little physical labor. Modeling that includes environmental, economic and social indicators revealed that family-based fish farming in the Santa Cruz reservoir was potentially sustainable. Cacho (2017) used the same indicators of sustainability and found that the Nile tilapia farming in net cages in the Umari reservoir was not economically sustainable, making the activity unfeasible when carried out in a reservoir (business cooperative).

Most reservoirs in the semi-arid northeast region of Brazil present moderate volumes that are subject to wide fluctuations due to prolonged periods of low rainfall (<700 mm/year). Rainfalls in this region have decreased over recent years, having direct impacts on the water quality and other characteristics of the local reservoirs (Leite & Becker, 2019; Oliveira et al., 2018; Rocha-Júnior et al., 2018). At the end of 2016, about 70% of the reservoirs in the state of Rio Grande do Norte with a capacity above 5,000,000 m^3 were essentially dry (<1% of the total volume). The Umari reservoir was only 18% of its total volume at the beginning of 2016 and was reduced to 8.8% by the beginning of 2017.

The accentuated drought conditions led to a cease in fish farming activities. The reservoir was only 18% of its total volume during this period. High fish mortality was recorded on January 19, 2016 due to heavy rains that led to the fall of surface water temperature, favoring the breakdown of thermal stratification in the area of the net-cages (Figure 1). The loss was about 60 tons of Nile tilapia. The possible turbulent vertical circulation favored the mixing of the entire water column and as a consequence, the reduction of dissolved oxygen and eventually fish mortality.

Studies by Tundisi et al. (2004, 2010) and Morais et al. (2010) showed that cold fronts can promote turbulent vertical circulation in reservoirs and lakes, and can even lead to fish mortality. In the semiarid reservoirs, turbulent vertical circulation can be caused by the following events: drop in air temperature during the night, associated with the intensification of wind velocity; summer rains, in which heavy rainfall is preceded by strong winds and sudden drops in temperature; and the transition period between summer and winter, characterized by intense drops in night temperatures and intensified wind speeds. The occurrence of one of these phenomena may result in mortality of fish reared in net-cages (Silva & Melo-Júnior, 2018).

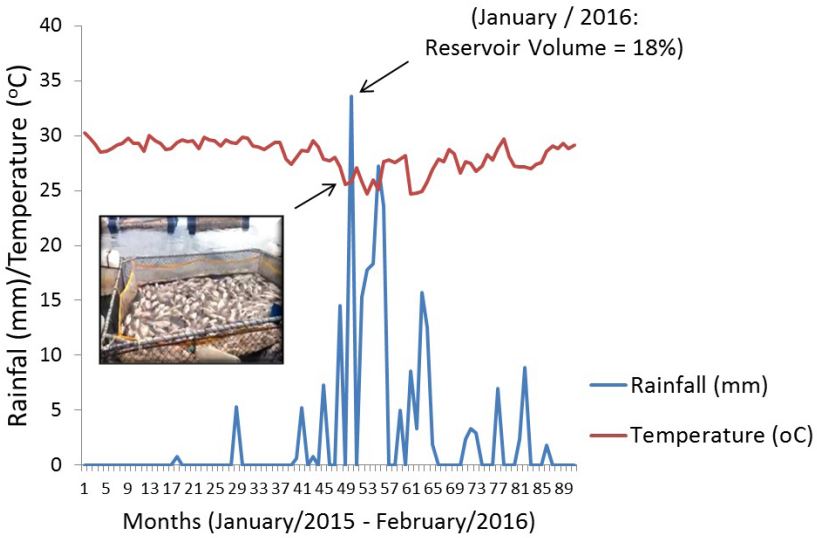

Figure 1. Values of rainfall (mm) and water temperature (°C) in the Umari reservoir (RN) between January of 2015 to February of 2016. Photograph represents the mortality of Nile tilapia in net cages in the Umari reservoir (January 19, 2016).

This seasonality of events is confirmed by the chronology of mass mortalities registered by the Ceará Water Resources Management Company (COGERH, 2016). Given this mechanism of vertical circulation, the sustainability of fish farming in net cages has a strong component in the technological and environmental aspects, which may improve management with investments in the knowledge and structure of monitoring limnological and climate conditions. The successive mortalities also occurred due to the lack of knowledge and monitoring of environmental conditions, as well as the lack of methods to mitigate impacts from this natural phenomenon.

In 2017 and early 2018, turbulent vertical circulation in the Rosário reservoir in the state of Ceará led to the mortality of Nile tilapia cultivated in net cages. The partnership between the fish farmers and researchers from the Limnology and Aquaculture Laboratory of the Regional University of Cariri enabled the adoption of preventive measures and in the next two events of turbulent vertical circulation in 2018, no mortality was observed. The knowledge of the vertical circulation of the reservoir and the change of area where the net cages were installed prevented mortality of the farmed fish. Perhaps, for fish farming in net cages to be carried out in the semiarid northeast region with the turbulent vertical circulation, it is necessary to orient the fish farmers regarding the monitoring of the limnological and meteorological conditions, the possible mitigating strategies, the rotation of the cultivation area to increase resilience, and the use of large fingerlings, which reduces the cultivation time.

Conclusion

The pressure on the reservoirs located in the northeastern semiarid region of Brazil increases further with extreme weather events due to prolonged droughts. Thus, the process of eutrophication of these aquatic environments can be intensified, especially in the reservoirs with intensive fish farming in net cages. The nutrient input from the activity combined with drastic changes in climate conditions may cause inadequate water quality, leading to restrictions related to the multiple uses of these environments. This scenario is problematic because between 2012 and 2017 the semiarid northeast region experienced the worst drought in the last 30 years. The impacts of global warming on reservoirs in these regions can affect the entire ecosystem by altering nutrient concentrations in the water column and causing changes in the structure of aquatic communities. There is a high potential that these environments will gradually become more eutrophic without proper management. In addition to using economic, social and environmental indicators, it is also necessary to evaluate the hydrological characteristics of the reservoirs located in the semi-arid northeast, as variations in the water level of these aquatic environments can drastically reduce the sustainability of fish farming in net-cages.

References

ATTAYDE, J.L., PANOSSO, R.F., BECKER, V. and MEDEIROS, J.D. Capacidade de suporte de seis reservatórios do Rio Grande do Norte para a piscicultura intensiva em tanque-rede. In: *Anais do XIII Congresso Brasileiro de Economia Ecológica*. Campinas: UNICAMP, 2019.

BANERJEE, A., BANERJEE, M., MUKHERJEE, J., RAKSHIT, N. and RAY, S. Trophic relationships and ecosystem functioning of Bakreswar Reservoir, India. *Ecological Informatics*, 2016, 36, 50-60. http://dx.doi.org/10.1016/j.ecoinf.2016.09.006.

BRASIL. Conselho Nacional do Meio Ambiente – CONAMA. Resolução n° 357, de 17 de março de 2005. Dispõe sobre a classificação dos corpos de água e diretrizes ambientais para o seu enquadramento, bem como estabelece as condições e padrões de lançamento de efluentes, e dá outras providências. *Diário Oficial da União [da] República Federativa do Brasil*, Poder Executivo, Brasília, DF, 18 mar. 2005, pp. 1-27 [viewed 20 June 2019]. Available from: http://www.mma. gov.br/port/conama/res/res05/res35705.pdf

CACHO, J.C.S. *O cultivo de tilápia do Nilo (Oreochromis niloticus) em tanques rede em reservatório do semiárido brasileiro é sustentável economicamente, socialmente e ambientalmente?* [Dissertação de Mestrado em Ciência Animal]. Mossoró: Universidade Federal Rural do Semi-Árido, 2017.

COMPANHIA DE GESTÃO DOS RECURSOS HÍDRICOS – COGERH. *Nota técnica 05/2016 GEDOP/DIOPE. Eventos de mortandade de peixe no Estado do Ceará*. Ceará: Secretaria de Recursos Hídricos, 2016.

DILLON, P.J. and RIGLER, F.H. A test of a simple nutrient budget model predicting the phosphorus concentration on lake water. *Journal of the Fisheries Research Board of Canada*, 1974, 31(11), 1771-1778. http://dx.doi.org/10.1139/f74-225.

DINIZ, L.P. and MELO-JÚNIOR, M.D. Can nearby eutrophic reservoirs sustain a differentiated biodiversity of planktonic microcrustaceans in a tropical semiarid basin? *Anais da Academia Brasileira de Ciências*, 2017, 89(4), 2771-2783. http://dx.doi.org/10.1590/0001-3765201720170481. PMid:29267795.

JEPPESEN, E., BRUCET, S., NASELLI-FLORES, L., PAPASTERGIADOU, E., STEFANIDIS, K., NÕGES, T., NÕGES, P., ATTAYDE, J.L., ZOHARY, T., COPPENS, J., BUCAK, T., MENEZES, R.F., FREITAS, F.R.S., KERNAN, M., SONDERGAARD, M. and BEKLIOGLU, M. Ecological impacts of global warming and water abstraction on lakes and reservoirs due to changes in water level and related changes in salinity. *Hydrobiologia*, 2015, 750(1), 201-227. http://dx.doi.org/10.1007/s10750-014-2169-x.

KHAN, M.F. and PANIKKAR, P. Assessment of impacts of invasive fishes on the food web structure and ecosystem properties of a tropical reservoir in India. *Ecological Modelling*, 2009, 220(18), 2281-2290. http://dx.doi.org/10.1016/j.ecolmodel.2009.05.020.

LEITE, J.N.C. and BECKER, V. Impacts of drying and reflooding on water quality of a tropical semi-arid reservoir during an extended drought event. *Acta Limnologica Brasiliensia*, 2019, 31, 10-15. http://dx.doi.org/10.1590/s2179-975x6918.

LOPES, P.F.M., CARVALHO, A.R., VILLASANTE, S. and HENRY-SILVA, G.G. Fisheries or aquaculture? Unravelling key determinants of livelihoods in the Brazilian semi-arid region. *Aquaculture Research*, 2017, 49(1), 232-242. http://dx.doi.org/10.1111/are.13452.

MOLISANI, M.M., DO MONTE, T.M., VASCONCELLOS, G.H., DE SOUZA BARROSO, H., MOREIRA, M.O., BECKER, H., DE REZENDE, C.E., FRANCO, M.A., DE FARIAS, E.G. and DE CAMARGO, P.B.Relative effects of nutrient emission from intensive cage aquaculture on the semiarid reservoir water quality. *Environmental Monitoring and Assessment*, 2015, 187(11), 1-14. http://dx.doi.org/10.1007/s10661-015-4925-4. PMid:26502728.

MONTANHINI NETO, R. and OSTRENSKY, A. Nutrient load estimation in the waste of Nile tilápia *Oreochromis niloticus* (L.) reared in cages in tropical climate conditions. *Aquaculture Research*, 2015, 46(6), 1309-1322. http://dx.doi.org/10.1111/are.12280.

MORAIS, M.A., CASTRO, W.A.C. and TUNDISI, J.G. Climatologia de frentes frias sobre a Região Metropolitana de São Paulo (RMSP), e sua influência na limnologia dos reservatórios de abastecimento de água. *Revista Brasileira de Meteorologia*, 2010, 25(2), 205-217. http://dx.doi.org/10.1590/S0102-77862010000200005.

MOURA, R.S.T. *Modelagem ecossistêmica de reservatórios do semiárido brasileiro e determinação da capacidade suporte da criação de tilápia-do-Nilo em tanques-rede* [Tese de Doutorado em Ciência Animal]. Mossoró: Universidade Federal Rural do Semi-Árido, 2018.

MOURA, R.S.T., LOPES, Y.V.A. and HENRY-SILVA, G.G. Sedimentation of nutrients and particulate matter in a reservoir supporting aquaculture activities in the semi-arid region of Rio Grande do Norte. *Quimica Nova*, 2014, 37(8), 1283-1288.

MOURA, R.S.T., VALENTI, W.C. and HENRY-SILVA, G.G. Sustainability of Nile tilapia net-cage culture in a reservoir in a semi-arid region. *Ecological Indicators*, 2016, 66, 574-582. http://dx.doi.org/10.1016/j.ecolind.2016.01.052.

OLIVEIRA, J.C.D., OLIVEIRA, J.F., REBOUÇAS, L.G.F., NOVAES, J.L. and PERETTI, D. Does the oscillation of the water volume of the reservoir influence in the same way in fish diet? *Acta Limnologica Brasiliensia*, 2018, 30, e104. http://dx.doi.org/10.1590/s2179-975x9216.

RAMOS, I.P., BRANDÃO, H., ZANATTA, A.S., ZICA, É.O.P., SILVA, R.J., REZENDE-AYROZA, D.M.M. and CARVALHO, E.D. Interference of cage fish farm on diet, condition factor and numeric abundance on wild fish in a Neotropical reservoir. *Aquaculture (Amsterdam, Netherlands)*, 2013, 414, 56-62. http://dx.doi.org/10.1016/j.aquaculture.2013.07.013.

ROCHA JUNIOR, C.A.N., COSTA, M.R.A., MENEZES, R.F., ATTAYDE, J.L. and BECKER, V. Water volume reduction increases eutrophication risk in tropical semi-arid reservoirs. *Acta Limnologica Brasiliensia*, 2018, 30, e106.

SANTOS, J.A., MARINS, R.V., AGUIAR, J.O. and CHALLAR, G. Hydrochemistry and trophic state change in a large reservoir in the Brazilian northeast region under intense drought conditions. *Journal of Limnology*, 2017, 76(1), 41-51. http://dx.doi.org/10.4081/jlimnol.2016.1433.

SILVA, M.I.R. and MELO-JÚNIOR, H.N. Circulação vertical e mortalidade de peixes em piscicultura em tanque rede em açude do semiárido cearense. In: *Anais do II Simpósio de Aquicultura e Recursos Pesqueiros* [online]. Recife: UFRPE, 2018 [viewed 3 Dec. 2018]. Available from: https://simpaq.wordpress.com/edicao-atual/

THORNTON, J.A. and RAST, W. A test of hypotheses relating to the comparative limnology and assessment of eutrophication in semi-arid man-made lakes. In: M. STRASKRABA, J.G. TUNDISI and A. DUNCAN, eds. *Comparative reservoir limnology and water quality management*. Dordrecht, The Netherlands: Kluwer Academic Publishers, 1993. http://dx.doi.org/10.1007/978-94-017-1096-1_1.

TUNDISI, J.G., MATSUMURA-TUNDISI, T., ARANTES JUNIOR, J.D., TUNDISI, J.E., MANZINI, N. and DUCROT, R. The response of Carlos Botelho (Lobo, Broa) reservoir to the passage of cold fronts as reflected by physical, chemical, and biological variables. *Brazilian Journal of Biology = Revista Brasileira de Biologia*, 2004, 64(1), 177-186. http://dx.doi.org/10.1590/S1519-69842004000100020. PMid:15195377.

TUNDISI, J.G., MATSUMURA-TUNDISI, T., PEREIRA, K.C., LUZIA, A.P., PASSERINI, M.D., CHIBA, W.A.C., MORAIS, M.A. and SEBASTIEN, N.Y. Cold fronts and reservoir limnology: an integrated approach towards the ecological dynamics of freshwater ecosystems. *Brazilian Journal of Biology = Revista Brasileira de Biologia*, 2010, 70(3), 815-824. http://dx.doi.org/10.1590/S1519-69842010000400012.

XIA, L., FATH, B.D., SCHARLER, U.M. and ZHANG, Y. Spatial variation in the ecological relationships among the components of Beijing's carbon metabolic system. *The Science of the Total Environment*, 2016, 544, 103-113. http://dx.doi.org/10.1016/j.scitotenv.2015.11.110. PMid:26657253.

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