Acta Limnologica Brasiliensia

Publication of the Brazilian Association of Limnology

Thematic Section: Reservoirs Ecology

*Acta Limnologica Brasiliensia,* 2018, vol. 30, e301
https://doi.org/10.1590/S2179-975X13217
ISSN 2179-975X on-line version

# Reservoir management: an opinion to how the scientific community can contribute

## Gestão de reservatórios: uma opinião sobre como a comunidade científica pode contribuir

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**Cite as:** Bianchini Junior, I. and Cunha-Santino, M.B. Reservoir management: an opinion to how the scientific community can contribute. *Acta Limnologica Brasiliensia*, 2018, vol. 30, e301.

**Abstract: Aim:** To report possible academic experiences as strategic contributions to help manage reservoirs ensuring multipurpose uses. **Methods:** In this opinion article, we point out and discuss academic activities that are usually developed to assess environmental studies in reservoirs. **Results:** Experience shows that various contributions can be highlighted in reservoir management, as well as direct contributions for decision-making of the environmental authorities involved, such as: i) development of experimental procedures to solve specific problems; ii) sampling planning activities; iii) analysis, integration and synthesis of data; iv) qualification of human resources, etc. It is important to mention that all academic activities reported in this article are potentially publishable in scientific journals (knowledge areas: environmental management, limnology, sanitation, public health and aquatic ecology). **Conclusions:** According to the related activities, we identified strong academic orientation (water quality determination, greenhouse gas inventories and water quality simulation using mathematical models, aquatic macrophyte decomposition and growth experiments) for reservoir management.

**Keywords:** reservoir management; environmental studies; limnological indicators.

**Resumo: Objetivo:** Relatar possíveis experiências acadêmicas como contribuições estratégicas para auxiliar a gestão de reservatórios, assegurando, assim, os usos múltiplos. **Métodos:** Nesse artigo de opinião foram pautadas e discutidas as atividades que, usualmente, são desenvolvidas em estudos ambientais em reservatórios. **Resultados:** A experiência acadêmica tem mostrado que além da assessoria direta para a tomada de decisão dos agentes ambientais, várias colaborações podem ser elencadas, como por exemplo: i) desenvolvimento de procedimentos experimentais para solucionar problemas específicos; ii) atividades de planejamento amostral; iii) análise, integração e síntese de dados; iv) qualificação de mão de obra, etc. É importante mencionar que todas as atividades acadêmicas relacionadas nessa publicação são potencialmente publicáveis em revistas científicas (áreas do conhecimento: manejo ambiental, limnologia, saneamento, saúde pública e ecologia aquática). **Conclusões:** Com base nas atividades relacionadas foi possível constatar o grande potencial de contribuição da academia (determinação da qualidade da água, inventários de gases do efeito estufa, simulação da qualidade da água utilizando modelagem matemática e experimentos de crescimento e decomposição de macrófitas aquáticas) para a gestão dos reservatórios.

**Palavras-chave:** gestão de reservatórios; estudos ambientais; indicadores limnológicos.

## 1. Introduction

In order to ensure multipurpose uses of reservoirs, managing these environments is essential to acquire environmental sustainability. Management responsibilities of different environmental stakeholders are often dispersed, showing a continuous need for discussions in order to subsidize with scientific information concerning the decision-making process, e.g. watershed committees (Silva et al., 2017). Due to academic and scientific productivity requirements (publishing papers in national and international periodicals) established for academic members, such as university professors and researchers, participation from the academic community in reservoir management can bring updated information with great added value to discussions and decision-making (Tundisi & Matsumura-Tundisi, 2003; Tundisi, 2013). Among the academic research experiences that can improve reservoir management practices are: (i) studies on the morphometric and hydraulic properties of reservoirs (Henderson-Sellers, 1984, 1993; Marques et al., 2014); (ii) water quality determination; (iii) biota assessment (macrophyte, plankton and ichthyofauna); (iv) field and laboratory experiments designed to describe the effects of driving forces that govern ecosystem processes such as primary production and decomposition (Calijuri & Santos, 2001; Chiba et al., 2015); (v) greenhouse gas (GHG) emission inventories (Marcelino et al., 2015); (vi) using mathematical models to describe reservoir hydrodynamic patterns (e.g. velocity vectors in the central region and sub-segments of reservoirs) and thermal circulation (Andrade et al., 2014); (vii) using mathematical models to support deforestation actions prior to reservoir formation (Bianchini Junior, 1999) and also to identify non-point and point sources that drive eutrophication (Carneiro et al., 2011) and, (viii) evaluating ecosystem services provided by reservoirs (Barbosa et al., 2011).

Currently, the data acquired by academic research are mainly used in environmental diagnosis studies, since this data are frequently available in scientific journals. During the design of the reservoir, or in a particular environmental issue events, specific demands are generated by the regulatory agencies. These demands constitute the so-called *reference terms*. These documents specify the products to be generated, the elements of interest, the sampling frequencies, the duration of the activities, etc. According to the reference terms, those reservoirs managers hire (predominantly) consultancy firms for the acquisition of the requested data (e.g. limnological surveys), or for the development of specific studies (e.g. erosion and sedimentation studies). Such studies are, eventually, carried out by universities and research centers; however, it is usual that the financial criterion overlaps. Another factor to be considered, is that the laboratories of the universities, as a rule, are not accredited, as requested by some environmental agencies that establish the guidelines of the studies. As a rule, academic laboratories and research centers are mostly required when there is a specific issue appears for which there is no consulting professional has the expertise to propose solutions.

Besides the immediate collaboration in the decision-making process in partnership with environmental authorities, it is important to mention that all research activities are potentially publishable in high impact factor scientific journals; this information is easily corroborated by the record of already published articles. Undoubtedly, a great deal of information has a more specific character, which should be dealt with at regional level (e.g. national journals, technical reports, reports). However, regardless of originality, the studies carried by the scientific academy are relevant for training skilled workforce. Particularly in Brazil, numerous scientific studies about reservoir limnology have been published over the last 45 years, such as books (case studies, textbooks and compilations), technical reports, academic publications (thesis, dissertations, internship and scientific initiation reports) and scientific articles. Some of these studies were directly or indirectly financed by the electricity sector (e.g. Santos et al., 1984; Agostinho & Gomes, 1997; Thomaz, 1999; Nakatani et al., 2001; Knie & Lopes, 2004; Santos & Rosa, 2005; Shibatta & Dias, 2006; Pitelli et al., 2012; Brasil, 2014), aiming to carry out environmental studies (mainly before reservoir formation) or to meet specific demands raised by the needs of hydroelectric power plant decision makers.

In addition to external funding (e.g. development agencies), the reservoir management group is also responsible for fostering the necessary conditions so that the academic community´s participation is more focused, useful and committed to ensuring the sustainable development of water resources. In this case, the academy can contribute to solving a specific environmental issue (e.g. occurrence and distribution of aquatic macrophyte, element cycling simulations) and also heading special research and development programs, e.g. Research and Technological Development Program from the Brazilian Electricity Sector (PROP&D ANEEL). Thus, there is a great potential of contributions from academic researchers and universities to reservoir management. In this context, according to our experience with the Brazilian Electricity Sector, this review and opinion article aims to report possible academic experiences as strategic contributions to help manage reservoirs ensuring multipurpose uses.

## 2. Contribution in the Development of a New Hydroelectric Power Plant (Project Phase)

In addition to consulting firms, that predominantly perform activities of this nature, the contributions of the academic community can be made from the time of the Environmental Impact Assessment (EIA), before the reservoir formation (Tundisi et al., 2015). In this case, typical contributions have the following objectives (Paiva & Salles, 1977; Garzon, 1984; Ploskey, 1985): (i) to characterize river basins and areas that would be directly affected (diagnostic phase); (ii) to list and classify environmental impacts due to the filling of reservoirs (prognosis phase); (iii) to promote the development of multiple water usages plans (e.g. water withdrawal, navigability, tourism); (iv) to contribute to developing environmental control programs (e.g. limnological monitoring, aquatic macrophyte surveys, vector control) and mitigate (or even neutralize) environmental impact measures. In this phase, the data sampling period and frequency (usually from 1 to 3 years) of the limnological assessments are established according to the reference term formulated, specifically, for a hydroelectric power plant project. In this project phase, the following activities are typically performed:

(i) limnological monitoring, considering the temporal and spatial variations of water quality in river basins that will be dammed to originate future reservoirs. These limnological inventories are usually quarterly, following the climatic variations (spring, summer, autumn and winter) or the hydrograph of the main river, and in this case sampling is typically done in four periods: flood, rise, ebb and dry seasons. As an example we report a recent study performed in the Teles Pires River, in which the hydrograph criterion was adopted (Vera Cruz/São Manoel Energia, 2017). The subsequent environmental indicators are usually measured while monitoring the phytoplankton (Bicudo et al., 2005), zooplankton (Serafim Junior et al., 2011; Matsumura-Tundisi et al., 2015), benthos (Andrade et al., 2012), ichthyofauna (Fernandez et al., 2007; Arcifa & Esguícero, 2012), aquatic macrophyte (Neiff et al., 2000; Bianchini Junior & Cunha-Santino, 2014), sediments and water samples (Espíndola et al., 2004; Smith et al., 2014). The water quality is characterized by physical (temperature, transparency, turbidity, electrical conductivity, oxy-reduction potential), chemical (dissolved oxygen, total solids, nutrients, metals, chemical oxygen demand, a specific elements of interest) and biological variables (coliforms, biochemical oxygen demand, chlorophyll); as well as the water nutrient status (trophic state index – TSI; Carlson, 1977), the water quality index (WQI; Horton, 1965), and other environmental indicators that can be legislated and often used in this type of monitoring.

(ii) using mathematical models in order to avoid water anoxia or anaerobic conditions by delimiting the area to be cleared before reservoir formation (e.g. Hespanhol, 1984; Ambrose et al., 1993). This activity estimates the deforestation costs according to the predicted clearing strategies. Vegetation suppression activities are an important source of reservoir costs and often entail hazardous and insalubrious work conditions. Therefore, predictions obtained from mathematical model simulations are important from an environmental, financial and labor perspective (Bianchini Junior & Cunha-Santino, 2011).

According to the data obtained by the simulations (Figures 1 and 2; Bianchini Junior & Cunha-Santino, 2015), it can be observed if the total suppression of vegetation is indeed necessary to obtain favorable limnic conditions in recently formed reservoirs (Hespanhol, 1984). According to the results presented in Figure 1, it can be verified that the models consider different scenarios using various combined parameters, in this case, flow and percentage of deforestation of a certain vegetal typology. In this case, it is also possible to change the start date of the reservoir filling and deal with other quantifications of deforestation in other vegetation types (e.g. marshes, pastures, forests). It is important to highlight the possibility of varying different parameters (physical,

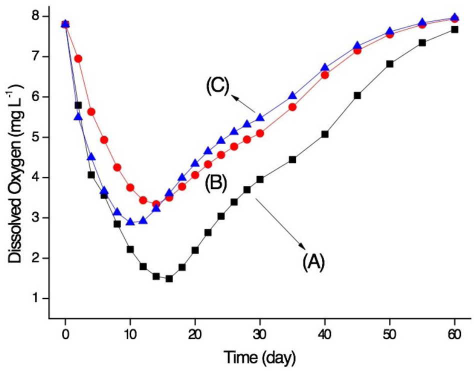


**Figure 1.** Simulations of the dissolved oxygen concentrations during the filling of a new reservoir in 3 hypothetical scenarios. Where: scenario (A) without deforestation and a given constant; scenario (B) deforestation of 68% of the savanna and constant flow; scenario (C) deforestation of 68% of the savanna and variable flow during the filling (according to a given proposal of operative rule). Bianchini Junior & Cunha-Santino (2015).

chemical, biological) to evaluate possible emergent properties of the new aquatic system. Based on the consolidation of the information that occurs during the development of the engineering project (e.g. time of reservoir formation, maximum operating quota), the quantitative deforestation becomes the main variable available for mitigation or neutralization of the impacts of plant resources (and soil carbon) in the water quality of the future reservoir. Figure 2 shows examples of simulations that address filling a reservoir under different percentages of deforestation. It can be observed that the minimum concentrations of dissolved oxygen tend to increase as the effort to remove vegetation increases. On the other hand, the time in which the reservoir water has concentrations < 4 mg $L^{-1}$ decreases, as do the maximum concentrations of biochemical oxygen demand (BOD), N and P. These results can optimize efforts (and costs) of deforestation to comply with current legislation. In addition to improving the water quality of the reservoir (due to the lower consumption of dissolved oxygen and reduction of eutrophication), the cleaning programs of the accumulation basin, subsidized by mathematical modeling, aim at: (i) encouraging the economic exploitation of wood; (ii) directing migration of terrestrial fauna to remaining forest areas; (iii) reducing rates of anaerobic decomposition gas formation (e.g. $CH_4$, $CO_2$ and $H_2S$); (iv) minimizing plant equipment corrosion and its effects on the water quality of the reservoir and; (v) ensuring multiple uses of water in the reservoir and its surroundings.

Depending on the predominant plant typology and amount of soil-labile carbon, it can be predicted if the partial vegetation suppression is sufficient to achieve a desirable water quality or even, if the total cleaning is insufficient to avoid undesirable effects, such as water anoxia or anaerobiosis (Prairie et al., 2018). The effectiveness of vegetation suppression varies according to the conceptual design of each resevoir. Due to the prevalence of refractory compounds in the accumulation basin, with high resistance to degradation such as thick branches, trunks and roots (Swift et al., 1979), the decomposition of these structural plant resources is only completed in the long-term, such as years to decades (Berg & McClaugherty, 2008; Freschet et al., 2012; Mori et al., 2014; Russell et al., 2014). Thus, for example, trees and trunks, totally or partially submerged, were still present in the Marion Millpond Reservoir (Wisconsin, USA), more than 110 years after their formation (Born et al., 1973).

Although there is a legal rule that requires that all vegetation must be suppressed (Law 3,824/60 (11/23/60, DOU 11/24/60), and mathematical modeling studies indicate the reasons for vegetation removal (e.g. decreases in turbidity, color and dissolved oxygen concentrations, attenuation of eutrophication), currently there have been also justification for its maintenance. The importance of subaquatic structures in maintaining species richness and diversity of fish was mainly significant during the initial years after the impoundment. The colonization of these habitats by small invertivorous fish indicates that the non-removal of arboreal vegetation in these reservoirs contributes to the increase of their biogenic capacity. In addition, vegetation provides shelter against predation. Considering the conservation of fishery resources, it has been proposed that pre-removal of tree vegetation in new reservoirs should be allowed only to the extent necessary to maintain acceptable water quality, even considering transient and localized hypoxic processes (Gois et al., 2012). The partial vegetation suppression provides the newly formed reservoir with the development of a complex physical habitat favoring the establishment and maintenance of trophic chains (algae, macrophyte, invertebrates, fish and birds; Brauns et al., 2011) as well as, the maintenance of various ecosystem services such as refuge and habitat for aquatic organisms used in human feeding and medicinal uses; physical barrier

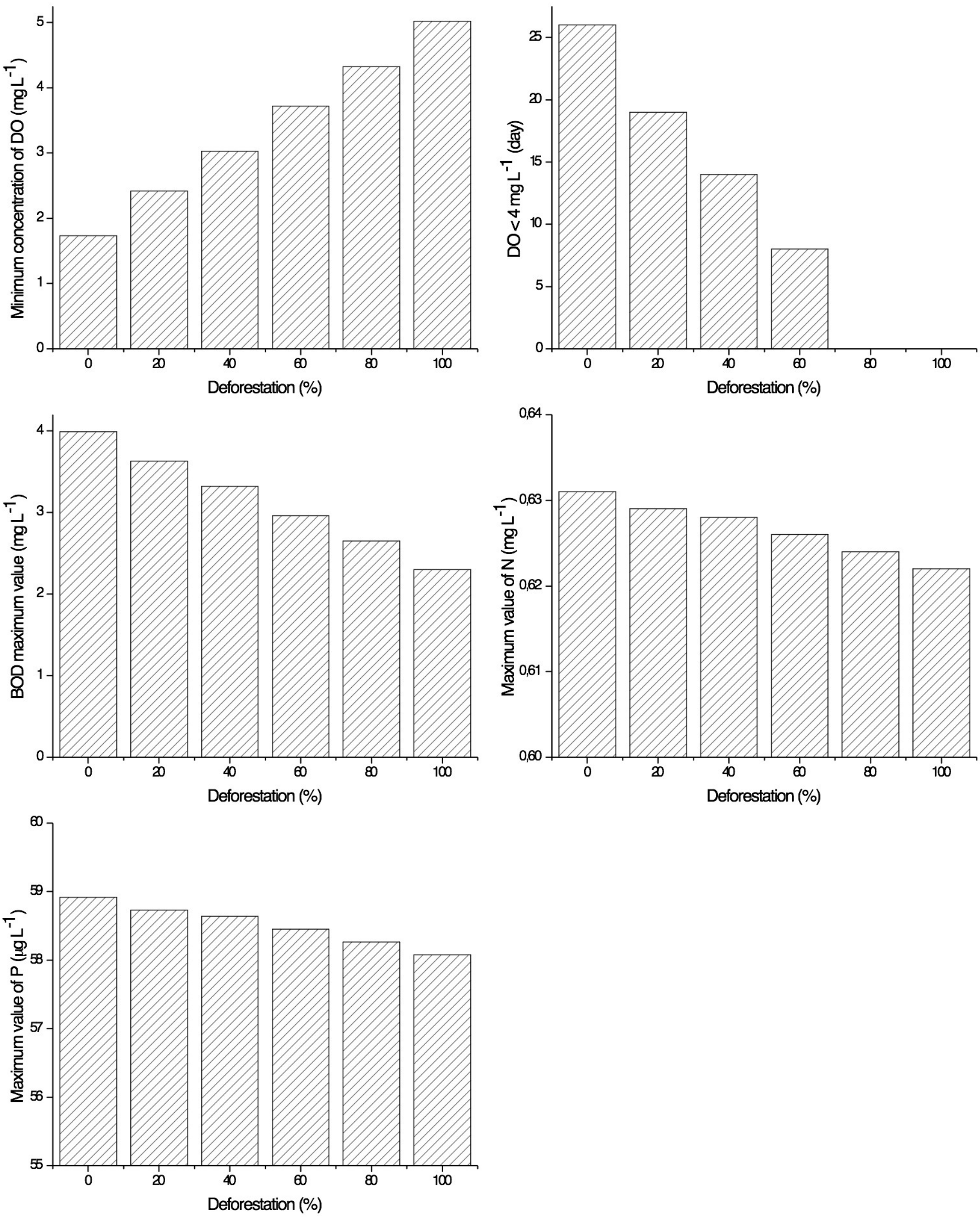


**Figure 2.** The effects of deforestation over: the minimal concentration of dissolved oxygen; the time with dissolved concentration of oxygen less than 4 mg $L^{-1}$; and the maximum concentration of BOD, nitrogen and phosphorous. Bianchini Junior & Cunha-Santino (2015).

to retain macrophytes benefitting navigation, fishing and recreation activities (Czarnecka, 2016).

Considering the cleaning of the accumulation basin, the need to safeguard specific areas is a prerrogative decision of environmental authorities, that evaluate requirements for the protection of fish stock and the assurance of aquaculture. The partial suppression of vegetation in the accumulation basin also tends to delay greenhouse gas emissions ($CO_2$, $CH_4$ and $N_2O$), once decomposition will be processed within the aquatic environemnt and refractory biomass usually decays slowly (Aprile et al., 1999; Bianchini Junior & Cunha-Santino, 2011). Inclusively, the submersion of stems in reservoir water is a current and empirical practice of wood preservation.

In order to perform these simulations, zero order models (μ = f (t)) or first order models (μ = f (t, x) are normally used (*sensu* Jørgensen & Bendoricchio, 2001). The next information is necessary for developing simulations (Hespanhol, 1984): topographic studies (functions: height × area, height × volume), long period flow water regime pattern, vegetation types of the area (forest types, fields, pastures, anthropic fields, wetlands, savanna), biomass inventories of plant resources susceptible to short-term degradation in the accumulation basin (Cunha-Santino et al., 2013) and organic matter of the soil identified by the predominant plant type, element concentration (N, P and C) from the water of tributaries and, parameters of biomass decay (leaves, branches, bark and litter, soil organic matter).

(iii) using mathematical models describing the yield nutrient emissions by non-point and point sources in order to prevent eutrophication of water in the new reservoir. These simulations can investigate possible risks of eutrophication identifying susceptible areas that allow for the development of this process. Moreover, simulations provide the determination of the hydraulic retention times of reservoir segments indicating the specific areas suitable for the growth of aquatic macrophyte. These simulations, which are usually performed with first-order models (μ = f (t, x)) or second order (μ = f (t, x, y)) also indicate the possible effects of urbanization and industries on the water quality of the future reservoir. In order to perform these simulations, the following information is usually necessary (Ambrose et al., 1993; Cole & Wells, 2015): topographic studies (functions: height × area, height × volume), long period water flow regime patterns, vegetation inventory of the area to be impounded, characterization of elements (N, P and C) from the river tributaries, decay parameters of leaves, branches, bark and litter, intensity and locations of deforestation and, population census and identification of the anthropogenic activities in watersheds. In addition, models are useful to investigate complex systems and they can be used to reveal system properties (Jørgensen & Bendoricchio, 2001).

(iv) using mathematical models (first or second order) that describe the thermal regime (stratification patterns) and hydrodynamic patterns of the future reservoir (Huber & Harleman, 1968; Markofsky & Harleman, 1971). To run these models, information related to topographic studies, long-term flow regime, surveys of the region´s meteorology (percentage of clouds, solar radiation (direct and diffuse), wind, temperature, precipitation) and water temperature are essential (Ryan & Harleman, 1971; Harleman, 1982).

(v) using mathematical models (e.g. zero order or first order) that describe carbon (dissolved organic and inorganic carbon), GHG ($CO_2$, $CH_4$, $N_2O$) due to degradation of the remaining submerged biomass in the future reservoir (Thérien & Morrison, 2005; Tremblay et al., 2005). To use these models, basically the following information is needed: densities (g $m^{-2}$) of the phytomass components that will be flooded; percentage of the terrestrial area to be flooded that are occupied by the different types of soil; kinetic parameters for the production of $CO_2$ and $CH_4$ from vegetation decomposition and soil components; influent concentration of dissolved $CO_2$ and $CH_4$; relationship between the terrestrial area flooded by the reservoir zone as a function of the water level; relationship to the surface area (water-air interface) by reservoir zone as a function of the water level; relationship of the volume of water by reservoir zone as a function of the water level; water level in the reservoir as a function of time; influent flow rates as a function of time; water temperature of the reservoir as a function of time (Thérien & Morrison, 2005).

In addition to the previously related activities, it is important to emphasize that the main collaboration of the scientists is generate new knowledge that support-the implementation of the technology desired. The knowledge generated by the development of scientific research on aquatic ecosystems (and their complexities) are almost exclusively products created by scientists. In principle, previously related activities (such as: field inventories and use of mathematical models) may also be performed by scientists, but not exclusively.

## 3. Collaboration from the Academic Community in the Reservoir Operation Phase

Previous to considering the feasible collaborations between the academy and the reservoir managers, it is important to highlight the low proactivity of electrical sector to face the several environmental issues that occur in reservoirs. This feature competes greatly for the low interaction of the electric sector with the academy. Conversely, when this interaction occurs, it is possible to distinguish three management horizons: (i) short-term horizon requiring immediate corrective actions to improve undesirable conditions (corrective management); (ii) medium-term horizon with management aimed at preventing environmental problems (preventive management); (iii) long-term horizon that includes accountability for future generations, i.e. sustainable management (Straškraba & Tundisi, 1999). Thus, after reservoir formations, academic studies can provide: (i) characterization of the trophic state of the reservoir water; (ii) knowledge of the functional (physical, chemical and biological) patterns of the reservoir; (iii) characterization of the river stretch downstream from the dam; (iv) subsidy actions in the management of the reservoir according to the predominant uses in the watershed. In this case, the deadlines and periodicity of the environmental monitoring are determined by the licensing agency. The reference terms that guide these studies include research activities such as:

(i) medium and long-term monitoring (temporal, spatial and depth variations) of the water tributary rivers and within the reservoir zones; in these studies the most common limnological variables recorded are temperature, transparency, turbidity, electrical conductivity, oxy-reduction potential, dissolved oxygen concentration, solids, nutrients, metals, dissolved organic carbon, coliforms, biochemical oxygen demand, chlorophyll-a, and also, the application of indices (TSI, WQI). Measurement or estimation of the amount of water that reaches the reservoir via inflows; it is necessary to determine water levels, possible use of reservoir water and downstream supply potential due to changes in flow result in changes in the water quality. Flow affects pollution levels once increasing flow may lead to dilution and/or flushing of pollutants from the watershed increasing soil erosion (Straškraba & Tundisi, 1999).

(ii) studies approaching the element retention (mass balance). This research refers directly to ecosystem services provided by reservoirs as phosphorus retention (Cunha-Santino et al., 2017) and to multipurposes (e.g. irrigation, navigation, hydroelectric power generation) water management of the reservoir (Tundisi et al., 1999).

(iii) definition of the thermal regime of the reservoir. The establishment of the circulation pattern provides valuable information for understanding the distribution of gases (e.g. dissolved oxygen), retentions and exportation of elements promoted by reservoir hydrodynamic patterns (Henry, 1999, 2014; Andrade et al., 2014). It also establishes the distribution of organisms (and consequently the trophic chains) in the reservoirs´ depths and zones (Wetzel, 2001). In addition to the physical characteristics of the reservoirs (i.e. water outlet heights and of the spillways), the hydrothermal regime determine the predominant characteristics of the water quality of the downstream rivers stretches. This knowledge is essential to the management of the reservoirs outflows, when considering a possible environmental issues (e.g. anoxic medium); Henderson-Sellers (1984); Straškraba & Tundisi (1999).

(iv) mapping, identification and population dynamics of aquatic macrophytes. The interactions of macrophytes in the reservoirs are usually discussed when developing management planning considering water use proposals and the biodiversity associated with these plants (Thomaz & Bini, 1999). Macrophytes may constitute an important resource for several chemical, physical and biological processes within aquatic ecosystems. The metabolic response of these organisms to abiotic factors combined with biological interactions (e.g. competition for light, herbivory, allelopathy) determine the basis of the community diversity and abundance (Lacoul & Freedman, 2006; Bornette & Puijalon, 2009). Thus, the macrophytes are key resources to habitat structuring, and in supporting the trophic chains and several chemical, physical and biological processes within aquatic ecosystems (Thomaz & Cunha, 2010). Billings (1964) pointed out 26 factors (control functions) that directly affect the richness, distribution and abundance of these plants in aquatic environments: nitrogen, phosphorus, macronutrients, salinity, micronutrients, toxins, organic matter (dissolved and particulate) phytoplankton, periphyton, aquatic carnivores, aquatic herbivores, man, morphology of water bodies, light transmission, water level, waves and winds, current, water temperature, air temperature, solar radiation, atmospheric composition, oxygen concentration dissolved, $CO_2$ concentration, pH and sediments. These factors had many interactions; however they influence the photosynthetic characteristics of macrophytes, both on a daily and seasonal scale (Sand-Jensen, 1989).

(v) studies of the dynamics of ichthyofauna populations (Agostinho et al., 2007). Ichthyofauna monitoring is probably the most evident and sensitive activity addressed in reservoir studies, as this information has considerable repercussion considering mortality or any other fact involving fisheries. Riverine populations traditionally use fishing, thus ichthyofauna is always the focal point of reservoir management (Agostinho & Gomes, 2005; Schork & Zaniboni-Filho, 2017).

(vi) monitoring of algal blooms (Aragão-Tavares et al., 2015). Due to the possibility of toxic substance production (neurotoxins and hepatotoxins, Carvalho et al., 2016; Pacheco et al., 2016), monitoring algal blooms is a relatively common activity commissioned by reservoir managers. Managers or regulatory authorities may also require ecotoxicological studies using metal and synthetic compounds (pesticides) and toxicological bioassays (chronic and acute) due to specific environmental problems.

(vii) monitoring of the benthic community, since these organisms constitute a bioindicator to contaminants in chronic doses and sensibility to chemical changes of the environment (Callisto et al., 2005; Molozzi et al., 2013).

(viii) background information to the environmental management of the reservoir (e.g. reservoir managers´ decision making, basin committee and regulatory authorities). According to the conformity of the water quality with the standards established by legislation, data conducted by academic studies can advertise the environmental managers about the specific conditions of the quality. It is really needed to define strategies to control eventual proliferation of undesirable species (fish, phytoplankton and aquatic macrophytes). The consequences of agricultural activity practices on the water quality and the sediments in the reservoir can also be observed.

## 4. Specific Cooperative Programs

A third type of contribution refers to activities developed according to a specific requirement from hydroelectric power plants. In Brazil, these studies are often subsidized by programs, such as PROP&D/ANEEL. This program foresees an amount of financial resources that must be invested in research and development projects in the electricity sector, presenting as a by-product the production of new equipment or improving the services that contribute to the security of the electricity supply, reducing the environmental impact of the sector and technological dependence (ANEEL, 2017).

These types of environmental studies often aim to: (i) investigate and solve a specific problem e.g. excessive growth of aquatic macrophyte and cyanobacteria blooms; (ii) develop a specific procedure such as using fish tanks, controlling algal blooms, model calibration, evaluation of GHG emissions; (iii) investigate a relevant process, such as the effect of residence time on the thermal regime, assessing the carrying capacity of the maintenance of the ichthyofauna. The maximum duration allowed for this type of project is 48 months. An extended deadline of the study must be justified in the final report and should not exceed 60 months. The frequency of activities is determined by the proposers, usually the hydroelectric power plant. Considering the lack of a previous reference term formulated by regulatory authorities, the activities developed under this type of financing present more degrees of freedom showing to be more academic in nature. These studies include, for example, the following activities:

(i) research dealing with the incidence and growth of plankton and aquatic macrophytes associated to the hydraulic attributes and chemical, physical and biological characteristics of reservoir waters and sediments (Ferrareze & Nogueira, 2013a, b; Cunha-Santino et al., 2016).

(ii) inventories addressing the properties of reservoir waters and sediments with the growth of species of medical and sanitary importance (Mustapha, 2008; Silva et al., 2014; Pompêo, 2017).

(iii) inventories that relate the characteristics (chemical, physical and biological) of the waters and sediments to the carrying capacity of the reservoir considering the fisheries and aquaculture activities (Agostinho & Gomes, 2005).

(iv) assessing the occurrence and distribution of macrophytes in order to promote the control of these organisms (control methods, removal equipment specification) effects on different species colonizing the reservoir and negative impact on navigability (Bianchini Junior et al., 2010a).

(v) experiments on the decomposition of plant resources in order to run and calibrate mathematical models that deal with mass balances (Bianchini Junior & Cunha-Santino, 2011). These experiments can also include leachate of macrophytes (e.g. Silva et al., 2011; Bottino et al., 2018), as well the phytoplankton excretion products with high harmful potential, such as toxins and others secondary metabolites, in order to find out the half life of its activities, and its direct or indirect effects on the aquatic organisms (Tessarolli et al., 2018).

(vi) experimentation concerning primary production and growth of phytoplanktonic species that aims to determine the ecological and physiological parameters of species with medical and sanitary interest such as *Microcystis* and *Cylindrospermopsis* (Bouvy et al., 2003).

(vii) macrophyte growth experiments establishing the physiological and ecological parameters ($Q_{10}$, growth rate, carrying capacity, half-saturation constants for light and nutrients) of species with high growth potential (Carr et al., 1997; Bianchini Junior et al., 2010b, 2015).

(viii) hypothesis test of common interest between the hydroelectric power plant and the researcher, such as: eutrophication control, bottom up and top down controls (Glibert, 1998; Jung, 2010).

(ix) calibration and development of mathematical models concerning element cycling simulations (Fonseca et al., 2013, 2016).

(x) identifying ecosystem services: self-purification, vector control, leisure and tourism, maintenance of biological diversity and flood prevention (Cunha-Santino et al., 2017).

(xi) bacterioplankton metabolism and photomineralization inventories (Soumis et al., 2007; Roland et al., 2011), and greenhouse gas emissions in reservoirs of hydroelectric power plants (from pre-filling to operating phases); Santos & Rosa (2005); Rogerio et al. (2013); Brasil (2014).

(xii) identifying the critical environment problems which require further study or follow-up through systematic monitoring (e.g. disruption of crucial environmental systems of the reservoir environment and associated long term effects; Hashimoto et al., 1988).

(xiii) identifying the occurrence and dispersion of invasive exotic species, and its possible control (Havel et al., 2005; Brugnolli et al., 2011; Rocha et al., 2011; Ernandes-Silva et al., 2017).

## 5. Concluding Remarks

Taking the above into account, it was observed that there is a great potential of contributions from the academic community to environmental studies related to artificial reservoirs. In the short term, research and development programs are the practicable way to increase the interaction between these sectors. The direct hiring of academic laboratories should be preferred, especially for the development of activities that consulting firms do not have qualified workforce to solve. The monitoring studies depend on requirements (i.e. accreditation) that are not always met by the academic laboratories. Howsoever, there are different contributions depending on the reservoir age (conceptual phase, filling phase and stable phase); the results generate fundamental subsidies for decision-makers and regulating authorities. Thus, the academic community can contribute to reservoir management from the initial stages in the EIA (developments: diagnoses (inventories), prognostics (models), environmental control plans (e.g. vegetation suppression plan) of the reservoir. After reservoir formation, research activities can be developed by on board periodic monitoring: (i) to determine the water quality at the current quality status; (ii) to verify the conformity of the water and sediment analysis according to the standards established by the legislation; (iii) to identify possible consequences of anthropic activities on the quality of the river water that provide water to the reservoir; (iv) to identify the ecosystem services of the reservoir; (v) to advise decision-makers responsible for watershed management (e.g. basin committees); (vi) to provide input data for mathematical models; (vii) to identify and map areas with phytoplankton blooms and macrophyte development; (viii) to develop conceptual capabilities for decision-making agents (environmental authorities); (ix) to develop corrective solutions and specific interventions and strategies to solve occasional environmental problems and, (x) to provide academic qualifications.

## Acknowledgements

The authors would like to thank the organizing committee of the 7th Symposium on Reservoir Ecology (October 9-11, 2017) for the opportunity to disseminate this work. We would also like to thank the National Scientific and Technological Council (CNPq, process number 305263/2014-5).

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Received: 07 December 2017
Accepted: 09 May 2018