

Moderate biomanipulation for eutrophication control in reservoirs using fish captured in angling competitions

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ABSTRACT

Key-words:
angling,
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Angling competitions are a popular leisure activity in reservoirs of Southern Portugal. These competitions can gather more than 100 anglers aiming to catch the maximum fish weight. Groundbaiting and catch-and-release angling are two common practices for anglers in competition. In this study, the loads of nutrients from commercial groundbait powders used in angling competitions in the Maranhão reservoir and the possible balance out of those nutrients through a moderate biomanipulation of the fish biomass caught in competitions were analysed. In order to achieve this aim, chemical analyses to groundbait powders most purchased by Portuguese anglers and to fish species most captured in competitions were made. Mass balances on *inputs* and *outputs* of nutrients considering some biomanipulation scenarios were evaluated. Results demonstrated that an effective management on angling competitions implementing a moderate biomanipulation of fish in reservoirs could promote the control of fish fauna and eutrophication, balancing out nutrients from angling.

RÉSUMÉ

Biomanipulation modérée pour le contrôle de l'eutrophisation dans les réservoirs à l'aide de poissons capturés dans les compétitions de pêche à la ligne

Mots-clés :
pêche à la ligne,
biomanipulation,
eutrophisation,
gestion
piscicole,
amorce

Les compétitions de pêche sont une activité de loisir populaire dans les réservoirs du sud du Portugal. Ces compétitions peuvent rassembler plus de 100 pêcheurs visant à attraper le poids maximum de poissons. L'amorçage et la pêche avec capture puis relâché sont deux pratiques communes pour les pêcheurs en compétition. Dans cette étude, les charges de nutriments à partir des poudres d'amorce commerciales utilisées dans ces compétitions de pêche dans le réservoir Maranhão et le solde possible de ces nutriments lors d'une biomanipulation modérée de la biomasse de poissons capturés dans les compétitions ont été analysés. Afin d'atteindre cet objectif, les analyses chimiques des poudres d'amorçage les plus achetées par les pêcheurs portugais destinées à pêcher les espèces les plus capturées dans les compétitions ont été faites. Les bilans massiques sur les entrées et sorties de nutriments suivant certains scénarios de biomanipulation ont été évalués. Les résultats ont démontré qu'une gestion efficace des compétitions de pêche mettant en œuvre une biomanipulation modérée de poisson dans les réservoirs pourrait favoriser le contrôle de la faune piscicole et l'eutrophisation en équilibrant les apports nutritifs de la pêche.

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INTRODUCTION

1 Iberian rivers are highly fragmented and dammed, with rosaries of reservoirs along the river-
2 ine longitudinal dimension (Santos *et al.*, 2006; Alexandre *et al.*, 2013). In Southern Portugal
3 70 large reservoirs are used mainly for agricultural irrigation and human water supply (location
4 of Portuguese dams at <http://www.snirh.pt>), and most of these present eutrophication prob-
5 lems (River Basin Management Plans, <http://www.inag.pt>) related either to the absence of
6 treatment of point sources of pollution (*e.g.* industrial discharges, municipal wastewater, min-
7 ing), or to diffuse pollution sources from crop runoff, particularly of nitrogen and phosphorus
8 (Smith *et al.*, 1999; Carpenter and Lathrop, 2008), frequently associated with the excessive
9 use of fertilizers and other agrochemicals.

10 Fish populations present in southern Portuguese reservoirs are mostly non-native species
11 such as common carp (*Cyprinus carpio* Linnaeus, 1758), goldfish (*Carassius auratus* Linnaeus,
12 1758), largemouth bass (*Micropterus salmoides* Lacepède, 1802), pumpkinseed (*Lepomis*
13 *gibbosus* Linnaeus, 1758), and recently bleak (*Alburnus alburnus* Linnaeus, 1758), along
14 with rheophilic native species, typically barbel (*Luciobarbus bocagei* Steindachner, 1864; and
15 *Luciobarbus comizo* Steindachner, 1864) and Iberian nase (*Pseudochondrostoma polylepis*
16 Steindachner, 1864) (Banha *et al.*, 2015). These native species are able to adapt to the
17 environment of the reservoir displaying regular potamodromous cycles, spawning in trib-
18 utaries and feeding in man-made lentic freshwater habitats (Ferreira and Godinho, 2002;
19 Granado-Lorenço, 2002; Clavero and Hermoso, 2011; Clavero *et al.*, 2013). In these reser-
20 voirs, heavy biomanipulations (see Hanson *et al.*, 1998; Drenner and Hambright, 1999;
21 Kasprzak *et al.*, 2002; Mehner *et al.*, 2002) destined to eradicate non-native species and
22 to provide better conditions for native fish fauna may be difficult to justify and implement due
23 to the special interest that species like common carp and largemouth bass have for anglers
24 and for local economy. However, it would be positive to intervene in the ecosystem in order
25 to maintain well-structured fish populations, and to improve water quality in an expeditious
26 and inexpensive way.

27 Recreational angling is a popular leisure activity in Portugal with nearly 200 000 anglers li-
28 censed for inland waters, as reported by the Institute for the Conservation of Nature and
29 Forests (ICNF), the state agency managing inland fisheries. Most of the angling activity is or-
30 ganized by anglers' associations and takes place in large rivers and especially in reservoirs,
31 gathering over 100 anglers per competition with the aim of catching the maximum fish weight.
32 Groundbaiting is used in these competitions to attract fish to the fishing area. Normally com-
33 mercial groundbait powders are used, composed mainly by flours (*e.g.*, corn, peanut, and
34 wheat), bread crumbs and crackers, aromatics and dyes, in different proportions depending
35 on the target species. Worms, maggots, hemp seeds, corn and other grains are also added
36 by anglers to the groundbait balls which are thrown into the reservoir. Nutrient loads result-
37 ing from groundbaiting may negatively affect water quality and trophic status (Wolos *et al.*,
38 1992; Niesar *et al.*, 2004; Arlinghaus and Niesar, 2005; Lewin *et al.*, 2006; Amaral *et al.*, 2013).
39 Fish captured during the competition time (usually 4 h of angling) are kept in keepnets. At
40 the end of the competition the fish caught are weighed and released back to the reservoir
41 (voluntary catch-and-release angling is practised in general for conservation purposes) thus
42 not allowing the control of fish biomass, especially of nuisance species (Arlinghaus, 2007), or
43 the reduction of nutrients in the system through the removal of fish captured (Wolos *et al.*,
44 1992; Niesar *et al.*, 2004; Lewin *et al.*, 2006).

45 Biomanipulation, even at a moderate level, has been indicated as a possible control tool
46 mainly focused in the communities of benthic-planktonic fish like carp (Wiley and Wydoski,
47 1993; Weber and Brown, 2009), which are considered by several authors as drivers of eu-
48 trophication in reservoirs (Vanni, 2002; Chumchal *et al.*, 2005; Fischer *et al.*, 2013; Nieoczym
49 and Kloskowski, 2013). Truly, the effective management of angling can be envisaged as a
50 benefit to achieve a higher planning of fish fauna and water quality in reservoirs (Cowx and
51 Gerdeaux, 2004; Mehner *et al.*, 2004). Also, fish extraction may be used as a tool to balance
52 the loads of nutrients from groundbaiting. Nevertheless, there is no such experience in Iberian
53 reservoirs.

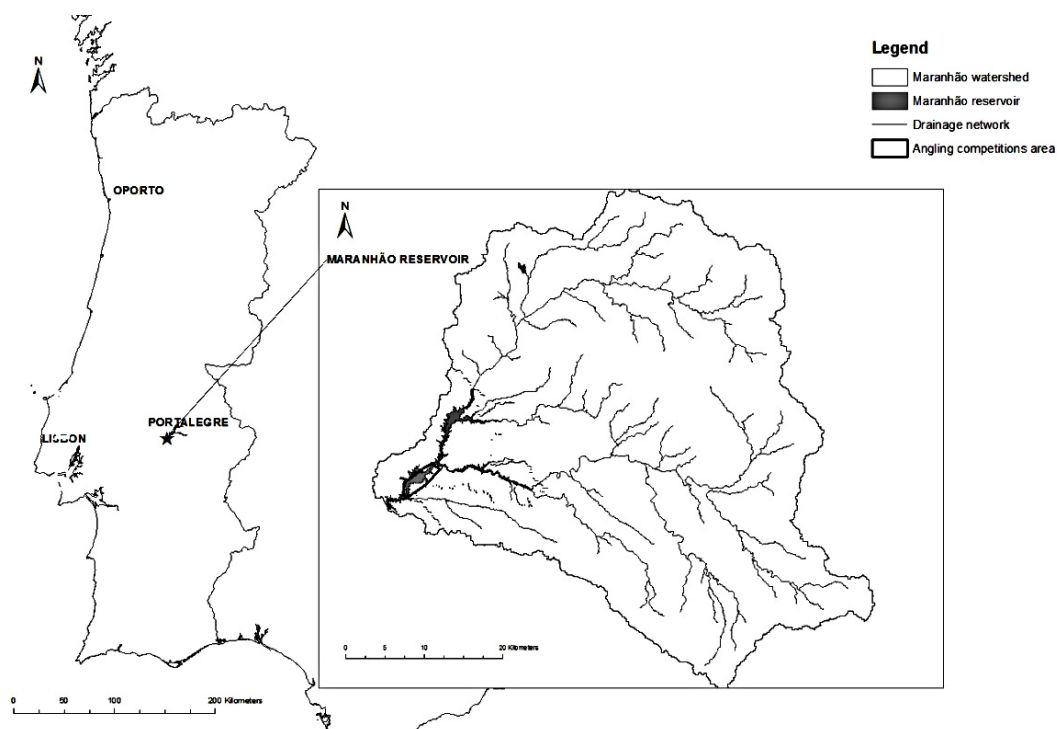


Figure 1

Location of Maranhão reservoir in southeast Portugal, emphasizing the main area where the angling competitions occurred.

This study aims to evaluate whether the nutrient input from the use of commercial groundbait powders in angling completions in Portuguese reservoirs can be balanced out by sacrificing some or all the fish caught in the competitions. Results for some moderate biomanipulation management scenarios (*inputs* of nutrients vs. *outputs* of nutrients) considering the data from angling competitions (number of anglers, commercial groundbait powder used, and fish biomass captured) occurred in Maranhão reservoir are presented. The nutrient budget in the reservoir was determined with: (1) total phosphorus (TP) and total nitrogen (TN) loads entering the waterbody through the use of commercial groundbait powders in competitions (*inputs*), considering different brands; and (2) TP and TN removal from the reservoir through the sacrifice of fish captured (*outputs*) evaluating different scenarios of moderate biomanipulation.

MATERIAL AND METHODS

> STUDY AREA

Maranhão reservoir is a large waterbody in Avis, near the city of Portalegre, with three main tributaries (Figure 1). It was constructed in 1957 and has a total watershed area of 2282 km², with a maximum length of 30 km, a surface area of 19.6 km², an effective storage volume of 181 × 10⁶ m³, and a mean and maximum depth of 12 m and 44 m respectively. The reservoir mean water temperatures vary from 11 °C in autumn-winter to 26 °C in spring-summer. Mean values of transparency (Secchi disk), total suspended solids, chlorophyll *a* and dissolved oxygen (%), for autumn-winter and spring-summer months, range from 1.8 to 1.4 m, 7.5 to 5.7 mg·L⁻¹, 7 to 12 µg·L⁻¹, and 71 to 86%, respectively (values obtained from the national online database of water resources, <http://www.snirh.pt>). The primary use of this reservoir is to supply irrigation to crops on the valleys downstream.

1 Maranhão reservoir is the most popular reservoir in Southern Portugal for angling competi-
 2 tions. In almost three decades of angling data (see Amaral *et al.*, 2013), this reservoir has
 3 hosted 65 154 anglers in 417 angling competitions, with an average angling effort of nearly
 4 40 anglers per hour of competition. The biomass of coarse fish is abundant as a result of
 5 plentiful food sources. Fish fauna is mainly formed by non-native species like common carp,
 6 goldfish, and recently for bleak, but also with native species as barbel and nase.

> INPUTS AND OUTPUTS FROM ANGLING COMPETITIONS

7 The study comprised determining the quantities of TP (as elemental P) and TN (as elemen-
 8 tal N) involved in angling competitions, *i.e.*: (i) the loads into the reservoir resulting from the use
 9 of commercial groundbait powders in those events (TP and TN *inputs*); and (ii) the depletion
 10 of biomass related with fish captured and sacrificed (TP and TN *outputs*).

11 To determine the brands of commercial groundbait powders most purchased by Portuguese
 12 freshwater anglers a telephonic survey questionnaire was applied to 70 fishery shops ran-
 13 domly selected. Typically, the packaging of commercial groundbait does not reveal the com-
 14 position of the product or the quantities of each component used in the formula, and specially
 15 producers do not disclose the values of TP and TN associated with their products.

16 From the 26 different brands referred in the telephonic survey, 10 of the most purchased were
 17 sampled and analysed in order to estimate the most common values of TP and TN present in
 18 the powders. Chemical analyses were performed at the Laboratory of Chemical Analysis of
 19 the Instituto Superior Técnico, accredited by the Portuguese Institute of Accreditation (IPAC;
 20 L0108 trials). To determine the quantity of TP present in each sample, the SMEWW 3120 (In-
 21 ductively Coupled Plasma [ICP]) method was used (APHA *et al.*, 2005), and to quantify TN in
 22 each sample an elemental analysis using the internal method M.M. 8.6 (A.E.) was performed.
 23 This method is based on the complete oxidation of the sample converting all organic sub-
 24 stances into combustion gases that pass through a reduction furnace (quartz tube furnace
 25 at about 1030 °C) and are swept into the chromatographic column, where they are sepa-
 26 rated and detected quantitatively. In the process, excess oxygen is removed by contact with
 27 copper, and nitrogen oxides are reduced to elemental nitrogen.

28 The Portuguese public agency that manages inland fisheries (Institute for the Conservation of
 29 Nature and Forest [ICNF]) requires that for each angling competition the organizers complete
 30 and submit a statistical record. On those records the number of anglers in competition, the
 31 species caught (counting the number and total weight by species), and the duration of the
 32 competition are reported. The records from angling competitions performed in Maranhão
 33 reservoir from January 2001 to December 2009 were compiled to establish the total anglers
 34 per year and the total fish biomass captured by species per year.

35 Fish species recorded as the most captured in these competitions were sampled and chem-
 36 ically analysed to determine the most common values of TP and TN for each species. The
 37 fish species sampled were: common carp, goldfish, barbel, bleak, and pumpkinseed. Since
 38 it was not possible to sample Iberian nase, it was considered for the biomass output cal-
 39 culations that nase have the same contents in TP and TN as bleak. Largemouth bass was
 40 also not sampled because of its low frequency in catches in these competitions. Sampling
 41 was conducted during an angling competition in August 2009 collecting five fish per species.
 42 Chemical analyses were performed at the Laboratory of the Research Institute of Fisheries
 43 and Marine (IPIMAR). Combined samples mixing the five fish of each fish species were made.
 44 To determine the quantity of TP present in each species, the molecular absorption method
 45 was used (APHA *et al.*, 2005), and for quantifying the TN for each species the Dumas method
 46 (Saint-Denis and Goupy, 2004) was performed.

47 The TP and TN inputs into the reservoir from the use of groundbait powders in angling compe-
 48 titions and the outputs resulting from the sacrifice of fish captured by anglers were calculated
 49 per year. Scenarios for different groundbaiting pressures and for biomass manipulation were
 50 studied considering the use of different groundbait brands, quantities of groundbait used per
 51 angler, and the release/sacrifice of biomass captured in angling competitions.

Table 1

Results of chemical analysis performed on the 10 samples of commercial groundbait more purchased by Portuguese freshwater anglers. The elements determined were total phosphorous (TP) and total nitrogen (TN), either in $\text{g}\cdot\text{kg}^{-1}$ of groundbait. All brands analyzed are richer in TN than in TP. Groundbait (+) input values were calculated considering the results of Groundbait # 10 sample powder, and Groundbait (-) input values were calculated from Groundbait # 1 results.

Groundbait samples	TP	TN
Groundbait # 1	1.5	12
Groundbait # 2	1.9	16
Groundbait # 3	2.1	13
Groundbait # 4	2.1	12
Groundbait # 5	2.5	15
Groundbait # 6	3.5	18
Groundbait # 7	3.6	18
Groundbait # 8	3.7	21
Groundbait # 9	5.3	17
Groundbait # 10	6.3	31

Thus, the inputs of TP and TN ($\text{kg}\cdot\text{year}^{-1}$) were calculated from equation (1) considering: (i) the number of anglers in competitions per year; (ii) the quantity of commercial groundbait powders used by anglers; and (iii) the values of TP and TN from groundbait, obtained from the chemical analysis ($\text{TP}_{\text{grdbait}}$ and $\text{TN}_{\text{grdbait}}$; $\text{g}\cdot\text{kg}^{-1}$). For the quantity of groundbait used by anglers, three different pressures were established for the calculations: (1) use of 5 kg of groundbait per angler in competition, (2) use of 3 kg of groundbait per angler, and (3) the use of 1.5 kg of groundbait per angler. Regarding the contents in $\text{TP}_{\text{grdbait}}$ and $\text{TN}_{\text{grdbait}}$, for each biomanipulation scenario the use of groundbait powders with: a) the highest values present in the analysed groundbait samples for calculations of *Groundbait (+)* ($\text{TP} = 6.3 \text{ g}\cdot\text{kg}^{-1}$ and $\text{TN} = 31 \text{ g}\cdot\text{kg}^{-1}$; values from Table 1); and b) the lowest values for calculations of *Groundbait (-)* ($\text{TP} = 1.5 \text{ g}\cdot\text{kg}^{-1}$ and $\text{TN} = 12 \text{ g}\cdot\text{kg}^{-1}$; values from Table 1) was also considered.

$$\text{Groundbait}_{\text{Inputs}} (\text{TP g or TN g}) = \text{anglers} \times \text{grdbait} (\text{kg}) \times \text{TP}_{\text{grdbait}} \text{ or } \text{TN}_{\text{grdbait}} (\text{g}\cdot\text{kg}^{-1}). \quad (1)$$

The outputs of TP and TN ($\text{kg}\cdot\text{year}^{-1}$) from biomass manipulation were calculated from equation (2) taking into account the quantities of fish captured and sacrificed for each species per year (Fish; kg) and the values of TP and TN obtained from the chemical analysis performed for each species (TP_{sp} and TN_{sp} ; $\text{g}\cdot\text{kg}^{-1}$). The quantities of fish captured and sacrificed were determined considering the scenarios: (B0) release of all biomass; (B1) release of barbels, nases, and carps larger than 35 cm (*i.e.* to enhance population of carp's trophy dimension in the reservoir); (B2) release of barbels and nases; and (B3) sacrifice of all biomass captured.

$$\text{Biomass}_{\text{Outputs}} (\text{TP g or TN g}) = \sum_{i=1}^n \text{Fish}(\text{kg}) \times \text{TP}_{\text{sp}} (\text{g}\cdot\text{kg}^{-1}) \text{ or } \text{TN}_{\text{sp}} (\text{g}\cdot\text{kg}^{-1}). \quad (2)$$

The final balance between inputs and outputs of TP and TN was executed from equation (3) pondering the mean annual values of inputs from groundbaiting and the outputs from biomass sacrificed in angling competitions.

$$\text{TP or TN}_{\text{Balance}} (\text{kg}) = \overline{\text{Groundbait}_{\text{inputs}}} - \overline{\text{Biomass}_{\text{outputs}}}. \quad (3)$$

RESULTS

The chemical analyses performed on the 10 samples of commercial groundbait most purchased by anglers revealed that groundbait powders may have very different contents in

Table II

Summary data from angling competitions performed in Maranhão reservoir, from January 2001 to December 2009, including the number of angling competitions performed in the year (competitions), the total angling effort (AE; angler·h⁻¹), the total biomass captured (Biomass; kg), the biomass captured per unit of effort (BPUE; kg·angler⁻¹·h⁻¹), and the main captured species (common names).

Year	Competitions	AE	Biomass	BPUE	Species captured
2001	7	44.51	1952	0.056	Carp; Barbel; Largemouth bass Pumpkinseed
2002	9	32.37	5799	0.097	Carp; Barbel; Goldfish; Nase; Pumpkinseed
2003	5	45.79	2230	0.135	Carp; Barbel; Nase; Pumpkinseed; Largemouth bass
2004	6	28.83	3056	0.126	Carp; Goldfish; Barbel; Nase
2005	13	28.71	5016	0.069	Carp; Barbel; Nase; Pumpkinseed; Goldfish; Largemouth bass
2006	24	21.34	8467	0.046	Carp; Goldfish; Barbel; Nase; Pumpkinseed; Largemouth bass
2007	24	19.57	11897	0.063	Carp; Goldfish; Barbel; Nase; Largemouth bass; Pumpkinseed; Bleak
2008	29	21.06	9957	0.040	Carp; Bleak; Goldfish; Barbel; Pumpkinseed; Largemouth bass
2009	14	21.93	5596	0.084	Carp; Bleak; Goldfish; Barbel; Pumpkinseed; Largemouth bass

1 terms of TN and TP (Table I). In the samples analysed, some were richer in TP and TN with
2 the content of TN varying from 12 to 31 g·kg⁻¹ and the content of TP from 1.5 to 6.3 g·kg⁻¹.
3 The highest and the lowest values of TP and TN were applied in the calculations of ground-
4 baiting inputs and in balances presented forward.

5 Data from angling competitions performed in Maranhão reservoir from January 2001 to De-
6 cember 2009 are summarized in Table II. The year with more angling competition records
7 was 2008 with 29 competitions, although it was a year with a lower angling effort, only
8 21.06 angler·h⁻¹. By contrast, in 2003 fewer competitions were performed, however more
9 anglers gathered in those events registering higher angling effort (45.79 angler·h⁻¹ only
10 in five competitions) and higher quantity of biomass captured per unit of effort (BPUE;
11 0.135 kg·angler⁻¹·h⁻¹). Competitions in 2006, 2007, and 2008 presented the highest values of
12 biomass captured, ranging from 8 to 12 tonnes. However, in 2006 and 2008 values of biomass
13 captured per unit of effort were the lowest (0.046 and 0.040, respectively). The main species
14 captured were common carp, goldfish, barbel, Iberian nase, pumpkinseed, largemouth bass,
15 and bleak (with registers since 2007). Analysing the total biomass captured (%) per species
16 (Figure 2), most of the biomass captured was of carp (84.3%) followed by goldfish (6.4%),
17 barbel (4.2%), and bleak (3.4%); values of biomass captured of pumpkinseed (0.8%), nase
18 (0.6%), and largemouth bass (0.2%) were less representative.

19 Results from chemical analyses performed on the main fish species captured by anglers in
20 competitions revealed that species sampled have relatively similar contents of TP (g·kg⁻¹)
21 and TN (g·kg⁻¹) (Table III). Content in TP varied from 2.0 to 2.9 g·kg⁻¹, and TN varied from 26
22 to 30 g·kg⁻¹. Goldfish was the species with lower contents of TP and TN whereas the bleak
23 had the highest values of these nutrients.

24 According to the balance of inputs and outputs of TP and TN from angling competitions for
25 the biomanipulation scenarios studied, it was possible to determine that the inputs from the
26 use of commercial groundbait powders could be compensated by sacrificing fish captured
27 (Figure 3). Results from the scenarios considering the removal of biomass captured and the
28 use of *Groundbait* (-) in the competitions performed showed that even using 5 kg of ground-
29 bait per angler the balance of TP (graphic A.1) and TN (graphic B.1) is negative, meaning
30 that the outputs from the sacrifice of part (scenarios B1 and B2) or all of the fish captured
31 (scenario B3) were higher than the inputs from groundbaiting. For *Groundbait* (+), the inputs

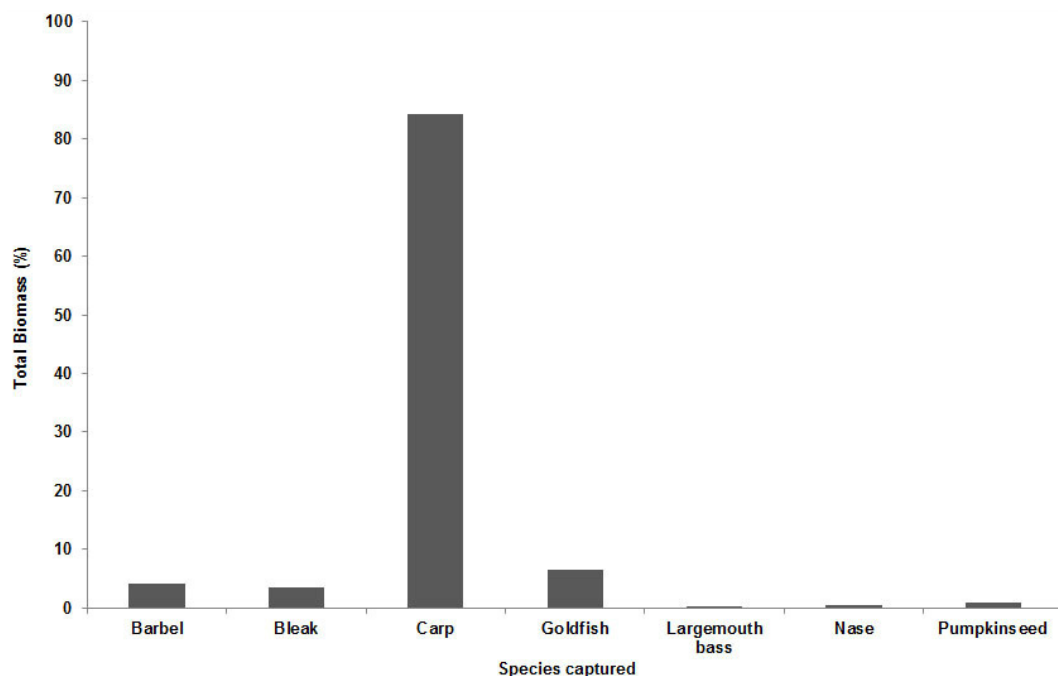


Figure 2

Total biomass (%) of the main species captured in the angling competitions of Maranhão reservoir, from January 2001 to December 2009. Most of the biomass captured was carp (84.3%), followed by goldfish (6.4%), barbel (4.2%), and bleak (3.4%, with the first registers of capture of this species dating from 2007. Bleak is currently the most abundant specie on catches). Pumpkinseed, nase, and largemouth bass represented only 0.8%, 0.6%, and 0.2% of the captures, respectively.

Table III

Results from chemical analyses performed on the main fish species captured by anglers in the competitions carried out in Maranhão reservoir. The elements determined were total phosphorous (TP) and total nitrogen (TN), in $g \cdot kg^{-1}$ of fish.

Species	TP	TN
Barbel	2.2	30
Bleak	2.9	30
Carp	2.2	27
Goldfish	2.0	26
Nase^(*)	2.9 ^(*)	30 ^(*)
Pumpkinseed	2.4	26

*Note: It was not possible to determine the values of TP and TN for nase, so the values defined for bleak were used in calculations. Largemouth bass was not sampled due to his low representation in the catches.

of TP equated the outputs only when it was used 1.5 kg of groundbait per angler and all the biomass captured was sacrificed (graphic A.3, scenario B3). However, in TN balance the inputs from groundbaiting equated the outputs in graphic B.2 considering the use of 3 kg of groundbait per angler and the sacrifice of part of the biomass captured releasing the barbels, the nases, and the carps larger than 35 cm (scenario B1). Evaluating the results from the use of *Groundbait (+)* and *Groundbait (-)* in scenario B0, which set the release of all biomass captured so there were no exits of TP and TN from the reservoir, it is noted that inputs of TP from *Groundbait (+)* were approximately four times higher than the inputs from the use of *Groundbait (-)*, and for TN the inputs from *Groundbait (+)* were nearly three times higher than the inputs from *Groundbait (-)*.

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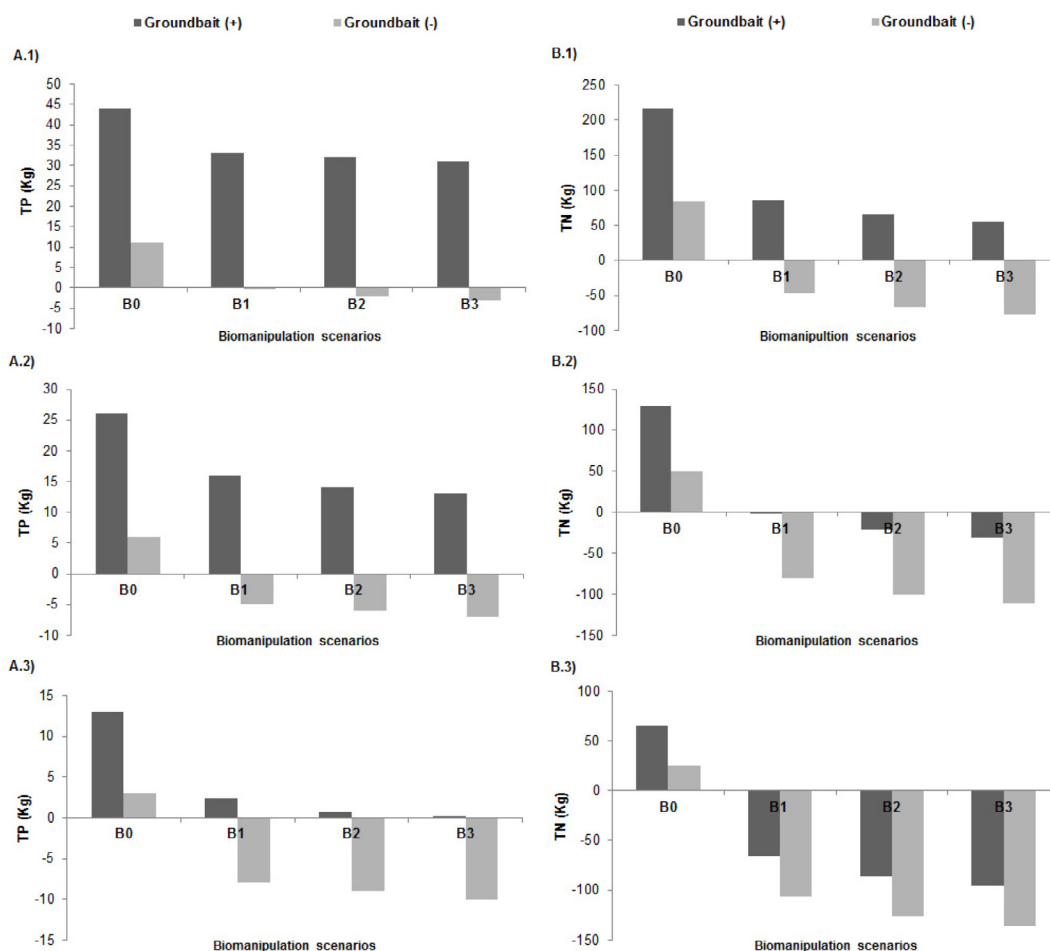


Figure 3

Results of biomanipulation scenarios studied considering the differences of inputs and outputs of TP (A) and TN (B) from angling competitions. Calculations of inputs from groundbaiting were made stipulating the use of: (1) 5 kg of groundbait per angler; (2) 3 kg of groundbait per angler; and (3) 1.5 kg of groundbait per angler. Two groundbait brands were selected having different eutrophication potential: Groundbait (+) favoring higher eutrophication and Groundbait (-) favoring less eutrophication. For the output values, the studied scenarios from biomass manipulation were: (B0) release of all biomass; (B1) release of barbels, nases, and big carps >35 cm; (B2) release of natives, barbels and nases; and (B3) sacrifice of all biomass captured. Graphically, the positive values correspond to loads of TP and TN into the reservoir; the negative values correspond to removal of TP and TN from the reservoir.

DISCUSSION

1 Voluntary catch-and-release angling has been seen by anglers as a conservation ethics and
 2 an ecological attitude (Arlinghaus *et al.*, 2007). However, catch-and-release angling may
 3 induce to overcrowding of fish in reservoirs leading to competition for space and food-
 4 resources (Arlinghaus, 2007) and triggering the fish populations to a small growth. Further-
 5 more, with catch-and-release angling in competitions performed in reservoirs the removal of
 6 nutrients (especially TP and TN) from the waterbody through the sacrifice of fish captured
 7 does not occur, therefore the balance out of nutrients from groundbaiting is not permitted.
 8 Our study highlights that through an effective angling management in reservoirs it is possible
 9 to implement a moderate biomanipulation of the fish populations, that are normally quite
 10 numerous but in most cases poorly structured (Ferreira and Godinho, 2002). Likewise, by
 11 implementing an effective management of fish captured in angling competitions the control
 12 of exotic fish fauna could be promoted and the nutrients inputs from groundbaiting may be
 13 balanced, decreasing the reservoir eutrophication.

Furthermore, the removal of biomass through sacrifice of the fish captured, totally or selecting some fish species and/or dimensions (e.g. removal of carps smaller than 35 cm, as proposed in this study, in order to promote more resources for “trophy carps”), may stimulate more matured and well-adjusted aquatic communities, enriching the angling experiences through the quality of catches (Cowx *et al.*, 2010; Isermann and Paukert, 2010; Arlinghaus *et al.*, 2013). At the same time, through that removed biomass, the load of nutrients in the reservoir from the groundbait powders used in angling competitions could be balanced out, and in some cases the outputs of TP and TN from the reservoir may exceed the inputs of those nutrients from groundbaiting according to the types of groundbaits selected by anglers.

Considering the data from angling competitions performed in Maranhão reservoir and the chemical analyses performed in fish and in commercial groundbait powders selected, by instructing anglers to sacrifice only the biomass captured of the exotic species bleak (reported by Almeida *et al.*, 2014 as responsible for trophic competition and hybridization with endemic Iberian fish fauna), goldfish, and carp smaller than 35 cm, and using a groundbait powder with low eutrophication potential, the inputs of TP and TN from groundbaiting may be compensated. However, when using a groundbait powder richer in TP and TN, with a higher eutrophication potential, it may be needed to sacrifice all fish captured in order to balance those nutrients inputs and anglers should use fewer quantities of those powders.

Some environmental nongovernmental organizations have attempted to ban the use of groundbait in angling invoking that it contributes to eutrophication of reservoirs. As a containment measure, and to limit groundbaiting, Portuguese water managers have implemented the obligation of an authorization to groundbait in angling competitions and the Portuguese Angling Federation also decreased the quantities of groundbait that can be used in their competitions.

Most of all, anglers should be informed of the water quality problems that may arise from the practice of catch-and-release angling and groundbaiting. Anglers must be advised to be more selective in the release of fish captured back to the reservoir and to use smaller quantities of groundbaits as well as choose commercial groundbaits with low eutrophication potential. For that, trademarks of groundbaits should provide more information about the eutrophication potential of their products in order to allow anglers to choose in a more conscious and environmentally friendly manner. Furthermore, that information could be integrated into a more holistic approach to reservoir management. Moreover, as a result of the increasing importance of angling, the pressures resulting from it should be more carefully considered and further studies should be made attending to a more holistic approach of angler-ecosystem relationship.

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