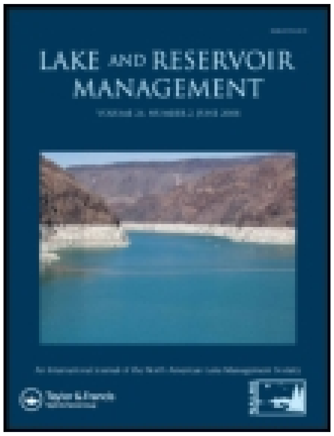

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Modeling water quality in reservoirs used for angling competition: Can groundbait contribute to eutrophication?

Susana D. Amaral [a], David Brito [b], M. Teresa Ferreira [a], Ramiro Neves [b] & Adolfo Franco [c]

[a] Forest Research Centre (CEF), Instituto Superior de Agronomia, Universidade Técnica de Lisboa, Tapada da Ajuda, 1349-017, Lisboa, Portugal

[b] Marine Environment & Technology Center (MARETEC), Instituto Superior Técnico, Universidade Técnica de Lisboa, Av Rovisto Pais, 1049-001, Lisboa, Portugal

[c] Divisão de Gestão dos Recursos Cinegéticos e Aquícolas, Instituto da Conservação da Natureza e das Florestas, Av João Crisóstomo 26-28, 1069-040, Lisboa, Portugal

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Susana D. Amaral,[1,*] David Brito,[2] M. Teresa Ferreira,[1] Ramiro Neves,[2] and Adolfo Franco[3]
[1]Forest Research Centre (CEF), Instituto Superior de Agronomia, Universidade Técnica de Lisboa, Tapada da Ajuda, 1349-017 Lisboa, Portugal
[2]Marine Environment & Technology Center (MARETEC), Instituto Superior Técnico, Universidade Técnica de Lisboa, Av Rovisto Pais, 1049-001 Lisboa, Portugal
[3]Divisão de Gestão dos Recursos Cinegéticos e Aquícolas, Instituto da Conservação da Natureza e das Florestas, Av João Crisóstomo 26–28, 1069-040 Lisboa, Portugal

Abstract

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Inland recreational fishing is a popular leisure activity in Portugal, which has close to 219,000 anglers. This study aimed to determine if the groundbait used to attract fish to the area in angling competitions contributes to eutrophication of reservoirs. We conducted a quantitative and qualitative assessment of commercial groundbait to examine the relationship between eutrophication and groundbaiting in angling competitions performed in Maranhão Reservoir, one of the most important southern Portugal angling reservoirs. Simulations using the CE-QUAL-W2 model were performed from January 2001 to February 2007 considering the number of anglers present in angling competitions and the chemical characteristics of commercial groundbait. The results indicated that the use of 5–10 kg of groundbait per angler (3–20 tons of groundbait per year) did not alter the ecological functioning of Maranhão Reservoir; however, higher angling pressures may lead to a significant increase in nutrient concentrations and consequent increases in primary production in the waterbody. Based on these concerns, we combined modeling with simulations to evaluate the environmental effects of groundbaiting in recreational angling and its relation to reservoir eutrophication. This study represents a contribution to more practical and holistic management of recreational fisheries.

Key words: angling, CE-QUAL-W2, eutrophication, groundbait, Maranhão Reservoir

Recreational fisheries involve millions of people worldwide and contribute substantially to the increase of social and economic benefits, both locally and nationally (Lewin et al. 2006, Cowx et al. 2010). In Portugal, approximately 219,000 recreational anglers are licensed for inland waters, as reported by the National Forest Authority (AFN), the Portuguese state agency managing inland fisheries. The direct and indirect value of the angling activity is estimated at about €4–5 million per year (around US$5.3–6.6 million; Ferreira 2002), and of that amount almost €2 million (US$2.6 million) is related to recreational angling in warmwater reservoirs of southern Portugal (Ribeiro 2003).

*Corresponding author: samaral@isa.utl.pt

Most Portuguese recreational angling occurs during spring and summer (Mar–Sep) in organized competitions aimed at a maximum fish weight. Large rivers and reservoirs are the preferred waterbodies chosen for these competitions, especially reservoirs located in southern Mediterranean areas. Conditions in these reservoirs are suitable for angling competitions because the margins are extensive and relatively homogeneous, with scarce riparian vegetation; in contrast, river margins are usually less accessible and more heterogeneous. Furthermore, in many reservoirs the fish biomass is considerable due to abundant food sources (Navarro et al. 2009), especially for common carp (*Cyprinus carpio*), Iberian barbel (*Luciobarbus* spp.), Iberian nase (*Pseudochondrostoma* spp.), and recently for bleak (*Alburnus alburnus*).

In angling competitions, groundbaiting is an important procedure used to attract fish to the fishing area. Ordinary commercial groundbait is composed mainly of flours (e.g., corn, peanut, wheat), bread crumbs and crackers, aromatics, and dyes, in different proportions depending on the target species. Some studies indicate that the use of groundbait can negatively affect water quality and trophic status, cascading to other ecosystem components such as invertebrates (Wolos et al. 1992, Niesar et al. 2004, Arlinghaus and Niesar 2005, Lewin et al. 2006). Nutrient enrichment of waterbodies and the consequent eutrophication effects are major problems for water quality in reservoirs (Smith et al. 1999, Carpenter and Lathrop 2008). At least 25% of Portuguese reservoirs have poor water quality due to eutrophication (River Basin Management Plans, http://www.inag.pt); therefore, Portuguese environmental nongovernmental organizations and water quality managers have frequently invoked arguments to request groundbaiting bans in reservoirs.

In this study we used simulation modeling to investigate the potential contribution of ordinary commercial groundbait used in angling competitions to reservoir eutrophication. White et al. (2010a, 2010b) concluded that simulation modeling is an effective method to assess biotic and abiotic factors that affect water quality and to test hypotheses in reservoir–watershed systems. Among the several models available, CE-QUAL-W2 is one of the 2D models most used to assess and manage large rivers and reservoir–watershed systems, in conjunction with the Soil and Water Assessment Tool (SWAT) model (Debele et al. 2008). Although some studies have addressed groundbaiting (e.g., Wolos et al. 1992, Niesar et al. 2004, Arlinghaus and Niesar 2005, Lewin et al. 2006), we found no previous research that applied the modeling of reservoir water quality with simulations related to groundbaiting. We integrated SWAT (Neitsch et al. 2002) and CE-QUAL-W2 (v. 3.1; Cole and Wells 2003) models to model and simulate water quality parameters under varying groundbait loading in Maranhão Reservoir.

Study area

Maranhão Reservoir was chosen as the study reservoir because of its popularity for angling competitions in Southern Portugal. Over 3 decades of substantial angling information (Table 1), Maranhão Reservoir has hosted 417 angling competitions and 65,154 anglers, with an average angling effort of nearly 40 anglers per hour of competition.

Maranhão Reservoir, constructed in 1957, is a large waterbody with 3 main tributaries, a maximum length of 30 km, a surface area of 19.6 km^2, an effective storage volume of 181×10^6 m^3, mean and maximum depth of 12 m and 44 m, respectively, and a total watershed area of 2282 km^2. The watershed consists of about 73% arable land and heterogeneous agricultural areas, 7% permanent crops (olive groves), 17% forests, and only 0.3% urban and industrial areas (information from CORINE L and Cover 2000; Fig. 1).

Table 1.-Summary data from angling competitions held in public water reservoirs located in southern Portugal.

Reservoir	N.°/yr with information	Total angling competitions	Total of anglers	Mean angling Competitions/yr	Mean anglers/yr	Mean anglers/ Competition	Angling Effort (angler/h)
Alqueva	8	42	2569	5	321	61	15.29
Alvito	11	19	1522	2	138	80	20.03
Barrocal	6	11	393	2	66	36	8.93
Caia	11	49	4074	5	370	83	20.79
Divor	17	49	2071	3	122	42	10.57
Facho	10	24	1843	2	184	77	19.20
Lucefecit	8	14	1077	2	135	77	19.23
Maranhão	29	417	65154	14	2247	156	39.06
Mercês	11	41	2492	4	227	61	15.20
Montargil	23	79	8434	4	367	107	26.69
Monte Novo	13	25	2029	2	156	81	20.29
Odivelas	20	79	11521	4	576	146	36.46
Pego do Altar	21	55	5382	3	256	98	24.46
Roxo	15	29	3732	2	249	129	32.17
Santa Clara	9	13	383	2	43	30	7.37
Vale do Gaio	29	135	15561	5	537	115	28.82
Vigia	21	86	6507	4	310	76	18.92

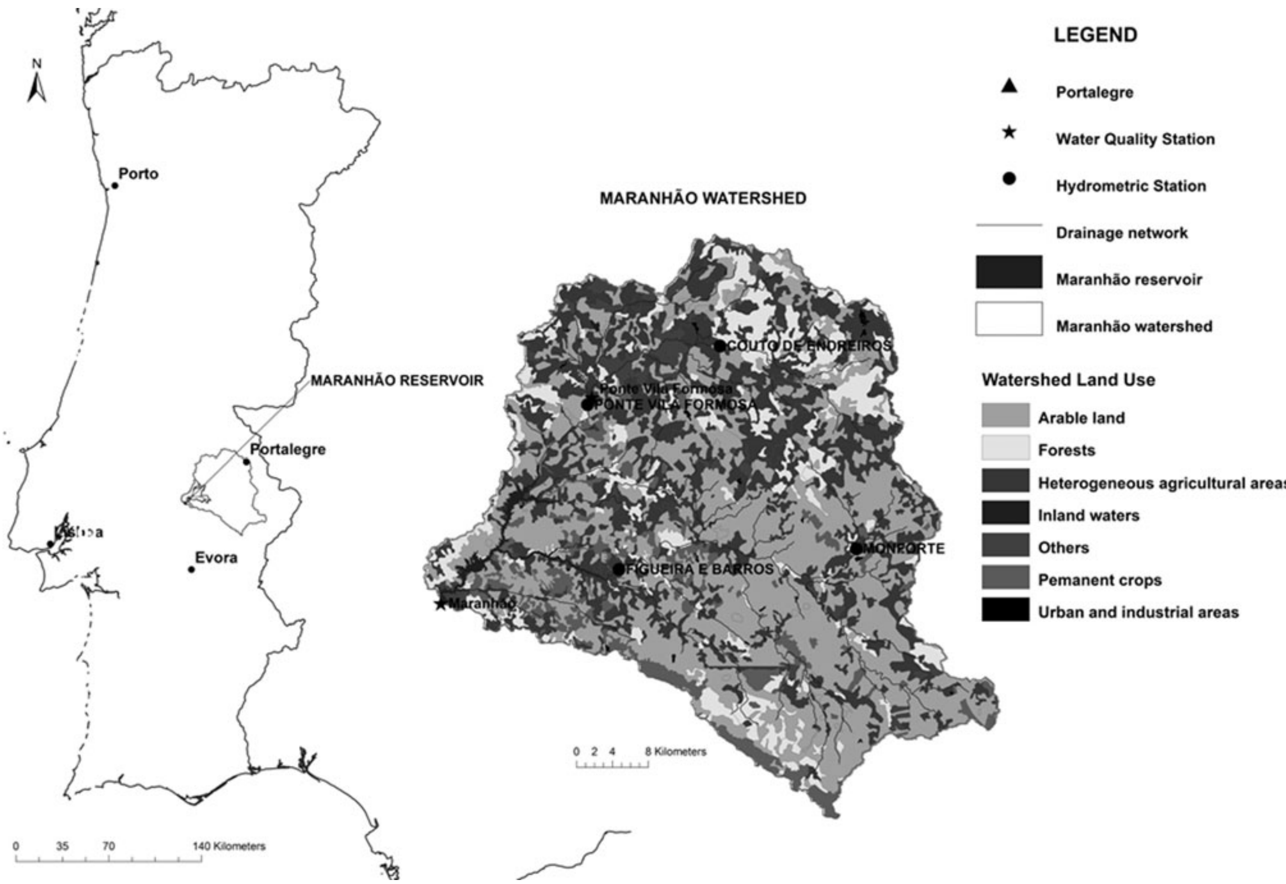

Figure 1.-Location of Maranhão Reservoir, highlighting watershed and land use, and the 2 water quality stations and the 4 hydrometric stations considered in the study.

The primary use of Maranhão Reservoir is to supply crop irrigation to the valleys downstream. A few point sources of pollution related to municipal wastewater treatment facilities from small-sized urban areas (e.g., Portalegre, at the top of the watershed), and nonpoint sources of nutrients from fertilizers and farm drainage, are the primary nutrient sources for the reservoir.

Materials and methods

We used SWAT and CE-QUAL-W2 models as tools for assessing changes in water quality in Maranhão Reservoir related to different groundbait loadings in angling competitions. To depict how the reservoir would respond to variations in groundbait loading, we established (1) a reference scenario representative of the actual condition of the reservoir water quality (established after model calibration against field data), and (2) several model simulations with scenarios of increasing organic matter loadings from commercial groundbaiting (based on angling competitions performed in Maranhão Reservoir data from Jan 2001 to Feb 2007).

Water quality modeling

We defined a boundary condition for the Maranhão Reservoir water quality model from the input tributaries (flow and concentrations). Model calibration was based on hindcast simulations forced by historical data. Because field data for water quality and flow exist in different time spans, the SWAT model was used, after flow calibration with available field data, to compute flow discharged from the watershed into the reservoir for the dates with water quality field data.

The SWAT model was executed using meteorological data from the national grid (http://snirh.pt); a NASA digital terrain model with 90 m resolution (http://earthexplorer.usgs.gov); land use from CORINE Land Cover 2000 (http://dataservice.eea.europa.eu/); and soil texture from the European Union soil database (http://eusoils.jrc.ec.europa.eu). Implementing CE-QUAL-W2

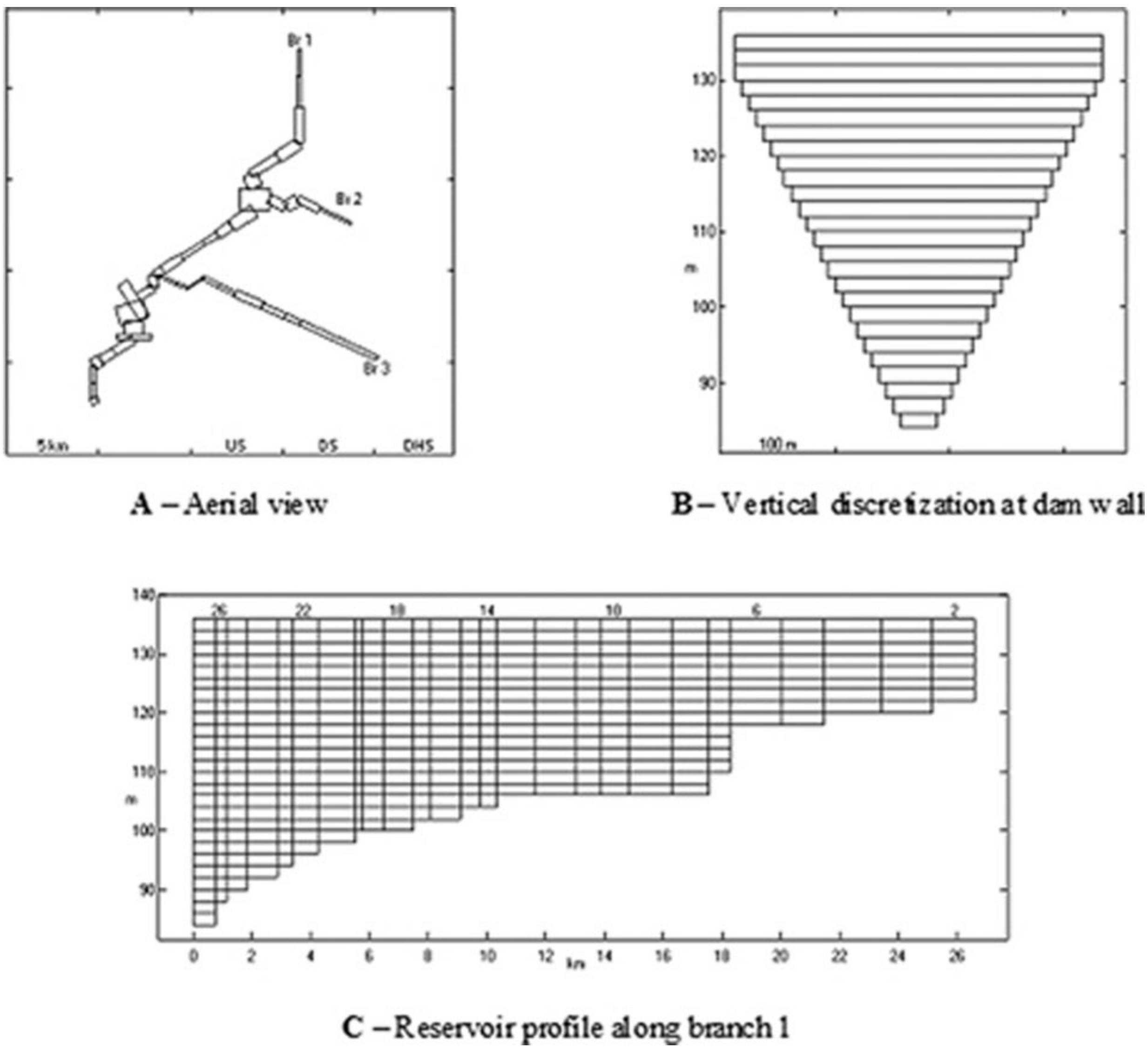

Figure 2.-CE-QUAL-W2 bathymetry for Maranhão Reservoir: (A) aerial view, (B) vertical discretization at dam wall, and (C) reservoir profile along branch 1.

modeling water quality required the bathymetry of Maranhão Reservoir (with cell lengths 375–2000 m and vertical discretization 2 m; Fig. 2) obtained from national cartography (scale 1:25 000; http://www.igeoe.pt); meteorological data; reservoir volumes; and water quality data collected from the Portuguese Water Institute through its long-term monitoring program (SNIRH), which includes monthly data collected by automatic stations at 2 different depths (10–20 m and 30–40 m) and made available to the public on its website (http://snirh.pt). Tributary inflows were simulated by the SWAT model after calibration.

Model validation was based on a graphical and statistical comparison of model estimates against field data (Kim and Kim 2006). The SWAT flow validation was based on field data of flow measured in 4 hydrometric stations (Ponte Vila Formosa, Couto Andreiros, Monforte, and Figueira e Barros; Fig. 1) along the main tributaries. For the CE-QUAL-W2 model validation, we used main tributary and reservoir field data from the automatic sampling stations of Ponte Vila Formosa and Maranhão, sampled monthly from 1999 to 2007 by the Portuguese Water Institute (Fig. 1). Validation accuracy for the water quality models was assessed based on the root mean square error (RMSE; Kim and Kim 2006) to provide an average concentration difference between observed field data and estimated model values in the reservoir, calculated as equation 1 (Ostfeld and Salomons 2005), where N is the number of values evaluated, P is the predicted model value, and O is the observed value in the field. Along with RMSE, the Nash-Sutcliffe efficiency (NSE; equation 2) and the mean absolute percentage error (MAPE; equation 3) were calculated for the SWAT model and CE-QUAL-W2, respectively (Moriasi et al. 2007).

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n} (\mathrm{Pi} - \mathrm{Oi})^2}{N}} \quad (1)$$

$$\mathrm{NSE} = 1 - \left[\frac{\sum_{i=1}^{n} (\mathrm{Oi} - \mathrm{Pi})^2}{\sum_{i=1}^{n} (\mathrm{Oi} - \bar{\mathrm{O}})^2}\right] \quad (2)$$

$$\mathrm{MAPE} = \frac{1}{n} \sum_{i=1}^{n} \left|\frac{\mathrm{Oi} - \mathrm{Pi}}{\mathrm{Oi}}\right| \quad (3)$$

Model simulations with groundbait

We used groundbait data from angling competitions from January 2001 to February 2007 for the CE-QUAL-W2 model simulations. Calculations considered (1) the number and dates of angling competitions performed, (2) the number of anglers present at each event, and (3) the loads of total phosphorus (TP; as elemental P) and total nitrogen (TN; as elemental N) resulting from the use of commercial groundbait in each competition. Data from angling competitions were obtained from the statistical records sent by the organizers of those events to the AFN. Reports included the number of anglers who participated in the competition; the species caught, counting the number and total weight by species; and the duration of the competition (Table 2).

The producers of groundbait powder typically do not reveal the composition of the product or the quantities of each component used in the formula, and, above all, do not disclose the values of TP and TN associated with their products. Therefore, to estimate the typical values of TP and TN present in groundbait required for our study, we performed chemical analyses on 10 samples of ordinary commercial groundbait from different brands purchased by anglers. These analyses were performed at the Laboratory of Chemical Analysis of the Instituto Superior Técnico, accredited by the Portuguese Institute of accreditation (IPAC; L0108 trials), for samples of surface water, drinking water, and wastewater. To determine the amount of TP present in each sample, the SMEWW 3120 (Inductively Coupled Plasma [ICP]) method (SMEWW 2005) was used; to quantify TN in each sample an elemental analysis using the internal method M.M. 8.6 (A.E) was performed.

The TN and TP inputs into the reservoir associated with the use of groundbait for model simulations were calculated from equation 4, considering the values of TP and TN obtained from the chemical analysis and using the highest values present in the analyzed groundbait samples (TP = 6.3 g/kg and TN = 31 g/kg; Table 3).

$$\mathrm{Groundbait}_{\mathrm{input}}(\mathrm{TP_g} \text{ or } \mathrm{TN_g}) = \text{anglers} \times \mathrm{grdbait(kg)} \times \mathrm{TP(g/kg)} \text{ or } \mathrm{TN(g/kg)} \quad (4)$$

The resulting TN and TP inputs were applied in the model on competition dates for segment 16 of branch 1 (Fig. 2), where the largest number of angling competitions were performed, in the form of labile particulate organic matter (LPOM) considering the model parameters ratio for phosphorus, nitrogen, and organic matter. Simulations were conducted from January 2001 to February 2007 using on the following scenarios: (1) C_0: reference scenario (no groundbait inputs added); (2) C_1: anglers × 5 kg groundbait inputs; (3) C_2: anglers × 10 kg groundbait inputs; (4) C_3: anglers ×

Table 2.-Number of angling competitions performed annually, total competition time per year (h), anglers involved per year, and quantity of groundbait used per year (t; metric ton) considering an average use of 5–10 kg/angler, from January 2001 to February 2007.

Year	Angling competitions	Total competition time (h)	Anglers	Groundbait used (t) considering:	
				5 kg/angler	10 kg/angler
2001	7	28	681	3.4	6.8
2002	9	36	1392	7.0	13.9
2003	5	20	870	4.4	8.7
2004	6	24	836	4.2	8.4
2005	13	52	1444	7.2	14.4
2006	24	96	1985	9.9	19.9
2007	—	—	—	—	—

Note: The last row appears with no data because there were no angling competitions until February 2007.

Table 3.-Results of chemical analysis performed on 10 samples of groundbait for the elements: total phosphorus (TP; g/kg), and total nitrogen (TN; g/kg).

Groundbait samples	TP (g/kg)	TN (g/kg)
Sensas – Carpas Natura	1.5	12
Amorim	1.9	16
Barbosa	2.1	13
Kaptura	2.1	12
Timar	2.5	15
Calado	3.5	18
Van den Eynde – Carp	3.6	18
Sorraia	3.7	21
Van den Eynde – Expo	5.3	17
Sensas – 3000 Barbeux	6.3	31

10 kg groundbait inputs × 10; and (5) C_4: anglers × 10 kg groundbait inputs × 100.

The CE-QUAL-W2 simulations with and without groundbait inputs were evaluated by graphically comparing concentrations of TP, orthophosphate (PO_4^{3-}), nitrate (NO_3^-), ammonium (NH_4^+), and chlorophyll *a* (Chl-*a*) from the reference scenario without groundbait inputs (C_0) with the simulations that included commercial groundbait (C_1, C_2, C_3, and C_4).

Results

Chemical analyses performed on 10 samples of groundbait revealed that commercial groundbaits may have notably different eutrophication potentials because trademarks of groundbait have varying nutrient contents, and some are richer in TP and TN. In samples analyzed, the TN content varied from 12 to 31 g/kg and TP content varied from 1.5 to 6.3 g/kg (Table 3).

Comparisons between field data and SWAT-predicted monthly flows based on R^2 and NSE values showed acceptable correlation and high model efficiency, varying from 0.83 to 0.88 and from 0.72 to 0.84, respectively, except for Figueira Barros station which showed high correlation (0.88) but low efficiency (0.04). Figueira Barros station had only 4 years of data from 1986 to 1990, and comparison with model results seemed to indicate that the available data might not be representative; data from this station was therefore not used for validation. RMSE values varied from 0.87 to 4.06 m^3/s, excluding Figueira Barros station due to its low efficiency (Table 4).

Table 4.-Statistical comparison between field data in the main hydrometric stations and SWAT predicted flows (monthly results for daily flow in m3/s). NSE: Nash-Sutcliffe efficiency; RMSE: root mean square error.

Station	R^2	NSE	RMSE (m^3/s)
Couto Andreiros	0.83	0.82	1.64
Ponte Vila Formosa	0.88	0.72	4.06
Monforte	0.86	0.84	0.87
Figueira Barros	0.88	0.04	5.27

Field data and simulated SWAT flow in the 3 hydrometric stations (Couto Andreiros, Ponte Vila Formosa, and Monforte) follow the same trends and peaks (Fig. 3), demonstrating that the SWAT model was a good predictor of the inflow to the reservoir in the simulated period. The CE-QUAL-W2 model adequately represented the main factors influencing water quality in the reservoir, predicting values with an acceptable variation compared to field values (Table 5). This model also provided a coherent representation of the seasonal trends of temperature (temp), dissolved oxygen (DO), NO_3^-, NH_4^+, TP, and Chl-*a* concentration in Maranhão Reservoir (Fig. 4).

Annual external loads of TN and TP into Maranhão Reservoir from the angling competitions in the four simulation scenarios (C_1, C_2, C_3, C_4) were considerably lower when compared with the watershed inputs, especially from scenarios C_1, C_2, and C_3; for scenario C_4 the TN and TP inputs from the angling competitions were higher, corresponding to approximately one-tenth of the inputs from the watershed. Annual reservoir discharges were higher than the loads from groundbaiting but were minor compared with the inputs from the watershed (Table 6).

Graphic representations of the CE-QUAL-W2 simulations (Fig. 5, 6, and 7) verified that for 5–10 kg quantities of groundbait used by anglers in competitions (scenarios C_1 and C_2), evolutions of TP, PO_4^{3-}, NO_3^-, NH_4^+, and Chl-*a* concentrations were identical to C_0. The results of scenarios C_3 and C_4, however, show that with angling pressures 10 times and 100 times higher, changes would likely occur in the concentrations of TP, PO_4^{3-}, NO_3^-, NH_4^+, and Chl-*a* in the reservoir.

Analysis of concentrations of TP and PO_4^{3-} and comparison of values to the reference scenario (C_0) indicated a small change in scenario C_3, verifying small peaks of concentration when the groundbait inputs were introduced in the model as LPOM mass discharges at the date and location closest to the angling competitions. Following the discharge of LPOM related to those events, however, concentrations of TP and PO_4^{3-} again coincided with C_0 values. In scenario C_4, concentrations of TP and PO_4^{3-} were higher

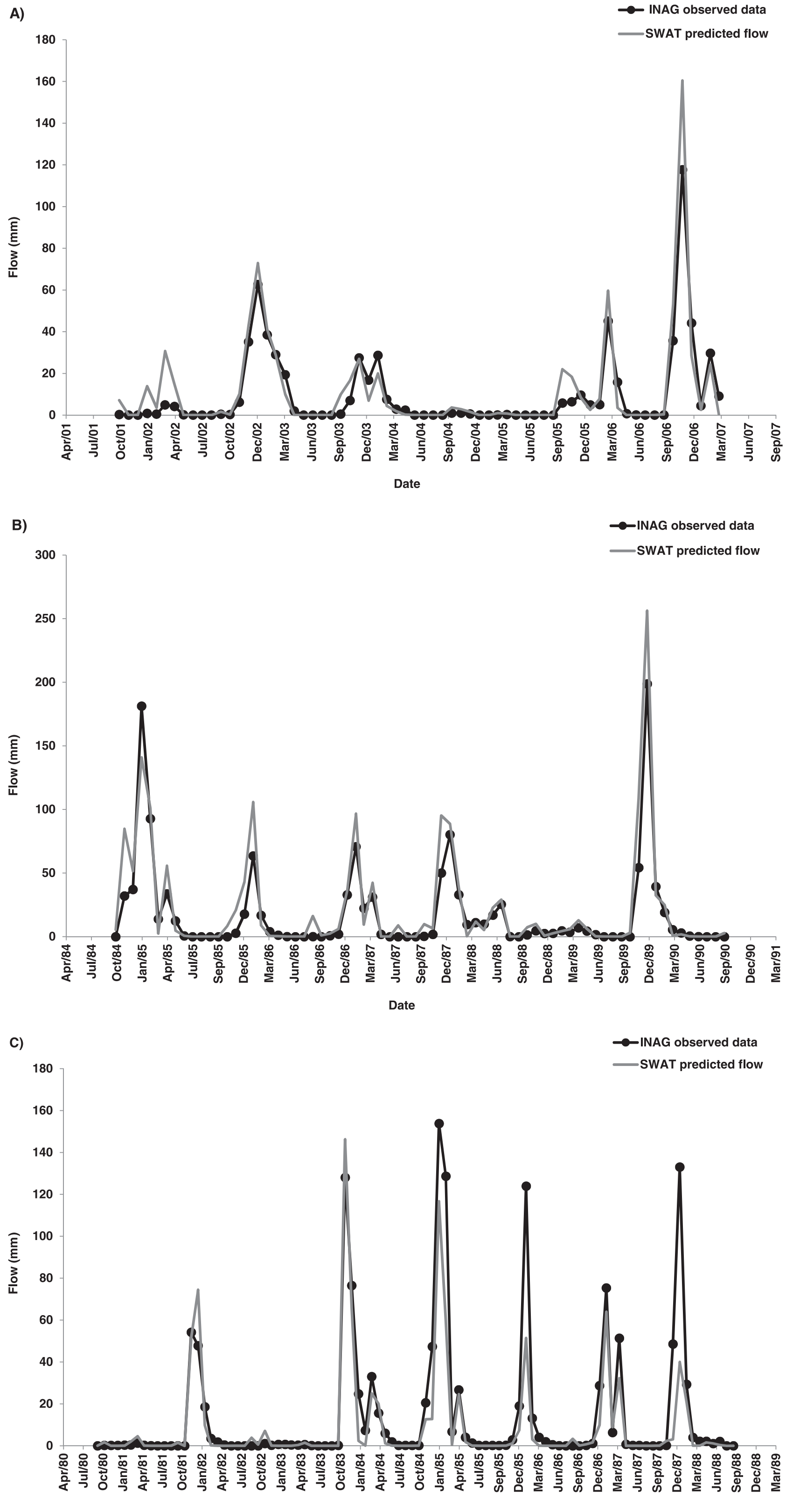

Figure 3.-Graphics of SWAT model flow validation based on field data from 3 hydrometric stations: (A) Couto Andreiros, (B) Ponte Vila Formosa, and (C) Monforte.

Table 5.-Statistical comparisons between field data (first rows), provided by INAG, and predicted values from CE-QUAL-W2 (second rows) for water quality parameters as temperature (temp; C), dissolved oxygen (DO;% saturation), total phosphorus (TP; mg/L), ammonium (NH_4^+; mg/L), nitrate (NO_3^-; mg/L), and chlorophyll *a* (Chl-*a*; μg/L). The columns N, Av, 25%, 75%, MAPE, and RMSE, stand for number of pair of records (measured and modeled), average, 25th percentiles, 75th percentiles, mean absolute percentage error, and root mean square error, respectively.

Water quality parameter	N	Av	25%	75%	MAPE	RMSE
Temp (C)	72	18.77	13.60	23.53	0.04	2.97
		19.03	15.46	22.73		
DO (% sat)	72	73.47	56.83	91.32	0.05	23.36
		66.50	43.45	85.30		
TP (mg/L)	69	0.08	0.04	0.12	0.80	0.11
		0.11	0.03	0.15		
NH_4^+ (mg/L)	54	0.08	0.05	0.10	1.44	0.12
		0.14	0.09	0.17		
NO_3^- (mg/L)	67	0.49	0.09	0.72	1.75	0.39
		0.41	0.28	0.48		
Chl-*a* (μg/L)	67	8.25	2.40	9.19	4.12	10.39
		11.83	8.63	13.15		

than in the reference scenario (C_0) throughout most of the simulation (Fig. 5).

Similar to observations for TP and PO_4^{3-}, small changes in concentrations of NO_3^- and NH_4^+ were detected in scenario C_3 compared to C_0, related to the LPOM mass discharges from the use of groundbait in angling competitions. Changes were especially detected from May to November 2005, returning to concentrations observed at baseline (C_0) following the end of the LPOM discharge. For scenario C4, concentrations of NO_3^- and NH_4^+ were higher than in the reference scenario throughout most of the simulation, in particular for the NO_3^- component (Fig. 6).

Chl-*a* concentrations in scenario C_3 were higher than C_0 from June to October 2005 and July to October 2006, and again coincided with the reference values by the end of the simulation. In scenario C_4, Chl-*a* concentrations diverged more from C_0 and were higher in 2004–2005; however, during some periods concentrations were lower than the reference values (Fig. 7).

Discussion

Modeling water quality in reservoirs can be a difficult task due to simplifications used to describe the complex aquatic ecosystem and the use of nonlinear equations to estimate changes in water movement and nutrient cycling (Cole and Wells 2003, White et al. 2010b). CE-QUAL-W2 (v. 3.1) limitations listed by Cole and Wells (2003), in addition to limitations in monitoring data, may contribute to the observed differences between field data and predicted values. The main goal of this study was to analyze the effect of groundbait inputs into the Maranhão Reservoir, and the key concerns about the modeling were that (1) CE-QUAL-W2 should represent the seasonal trends of nutrients and Chl-*a* in the Maranhão Reservoir, and (2) the model responded to the increasing inputs of groundbait. These conditions were observed, as shown through the graphical validation of the SWAT and CE-QUAL-W2 models, and especially the responses of CE-QUAL-W2 to the simulations performed.

The burden of TN and TP inputs into the Maranhão Reservoir from groundbaiting was low compared with loads from the watershed. Regarding the number of anglers and the chemical characteristics of the commercial groundbait studied, the simulations performed demonstrated that scenarios C_1 and C_2 were similar to the reference scenario C_0; therefore, the current use of 5–10 kg of groundbait per angler (C_1 and C_2), in this case corresponding to inputs of 3–20 tons of groundbait per year, did not alter the ecological functioning of Maranhão Reservoir. As shown in the simulations, however, with angling pressures 10 to 100 times higher (scenario C_3 and C_4, respectively) changes would likely occur in the concentrations of TP, PO_4^{3-}, NO_3^-, NH_4^+, and Chl-*a*, and these loads of nutrients into the reservoir may alter its ecological functioning.

Analyzing the results from scenario C_3, which can be considered a threshold scenario, the higher values recorded in these simulations during summer and fall were probably related to the higher angling effort and, especially in 2005 and 2006, the drier than normal climatic conditions experienced during those months. For scenario C_4, all values were higher than the reference concentrations due to the greater loads of groundbait, except for Chl-*a* concentrations that had lower concentrations than the reference values in some periods of the simulation. This reduced Chl-*a* concentration may be related to shifts in phytoplankton composition toward an algal community dominated by cyanobacteria, thus decreasing Chl-*a* values as a phytoplankton biomass indicator due to cyanobacteria's lower cells contents of Chl-*a* per unit biovolume (Kasprzak et al. 2008, Carvalho et al. 2009).

Nevertheless, the sensitivity of these artificial waterbodies to an additional load of nutrients is strongly related to its geomorphological and hydrographic properties, such as watershed geological conditions, flow, turbidity, depth, temperature, and turbulence of the water system. So, taking into account the precautionary principle, if angling pressure increases greatly, anglers should be alerted to water quality degradation that may arise from groundbaiting and should reduce the use of these products as well as choose commercial groundbait with low eutrophication potential.

Table 6.-Annual external loads of total nitrogen (TN; t) and total phosphorus (TP; t) into Maranhão Reservoir from the angling competitions, considering the 4 simulation scenarios (C1, C2, C3, C4); annual external loads of TN (t) and TP (t) from the watershed; annual reservoir discharges of TN (t) and TP (t); and total average value (Av; t/year), from 2001 to 2006.

Year	Groundbait loads (t) from simulation scenarios								Reservoir loads (t) from the watershed		Reservoir discharge (t)	
	C1		C2		C3		C4					
	TN	TP	TN	TP	TN	TP	TN	TP	TN	TP	TN	TP
2001	0.11	0.02	0.21	0.04	2.11	0.43	21.11	4.29	432	51	190	16
2002	0.22	0.04	0.43	0.09	4.32	0.88	43.15	8.77	1471	135	540	82
2003	0.13	0.03	0.27	0.05	2.70	0.55	26.97	5.48	436	30	179	12
2004	0.13	0.03	0.26	0.05	2.59	0.53	25.92	5.27	165	13	61	3
2005	0.22	0.05	0.45	0.09	4.48	0.91	44.76	9.10	1008	59	230	23
2006	0.31	0.06	0.62	0.13	6.15	1.25	61.54	12.51	1544	83	536	59
Av (t/year)	0.19	0.04	0.37	0.08	3.72	0.76	37.24	7.57	843	62	289	32

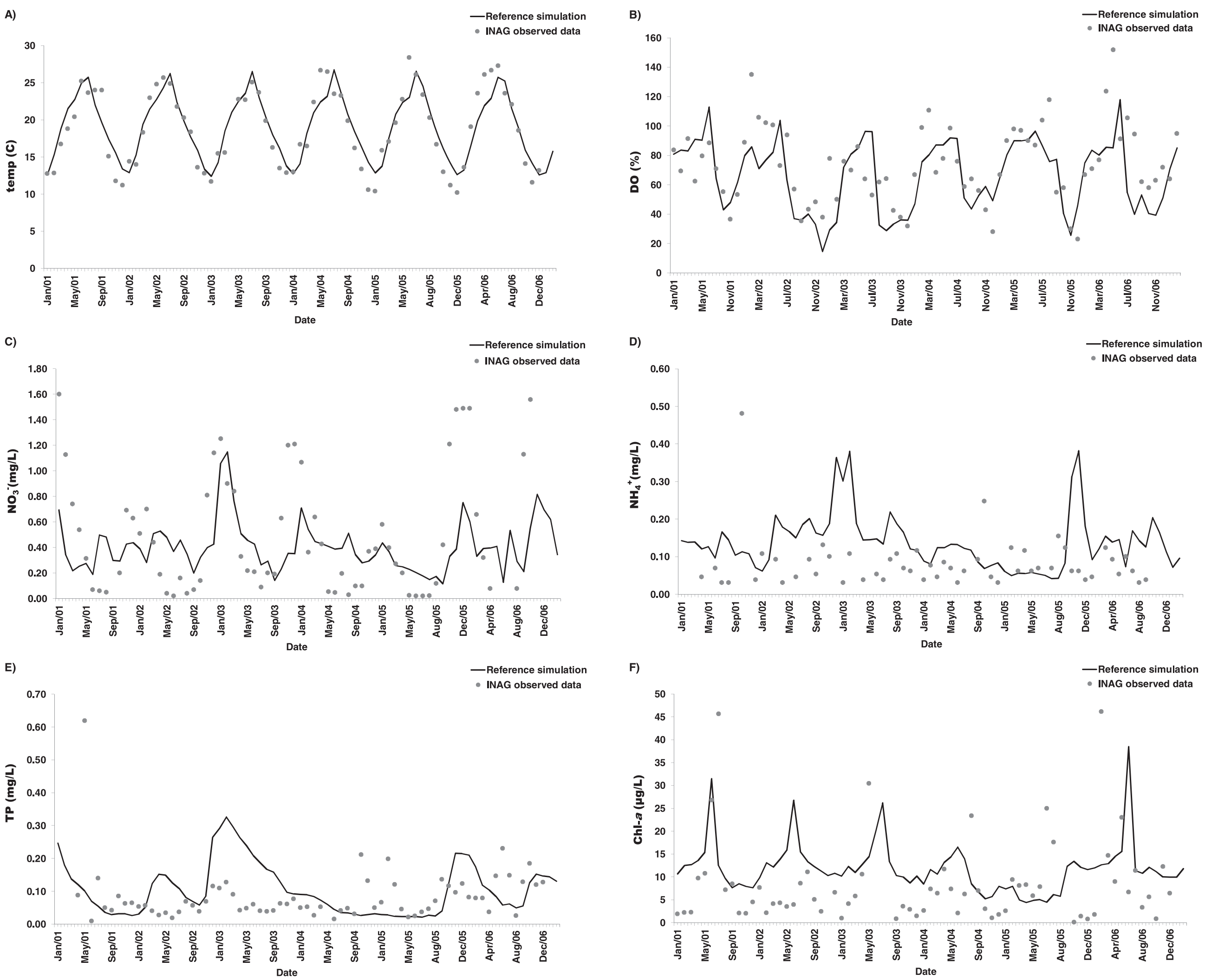

Figure 4.-Graphics of CE-QUAL-W2 model validation based on INAG field data from January 2001 to February 2007, representing: (A) temperature (temp; C), (B) dissolved oxygen (DO;% saturation), (C) nitrate (NO_3^-; mg/L), (D) ammonium (NH_4^+; mg/L), (E) total phosphorus (TP; mg/L), and (F) chlorophyll *a* (Chl-*a*; μg/L).

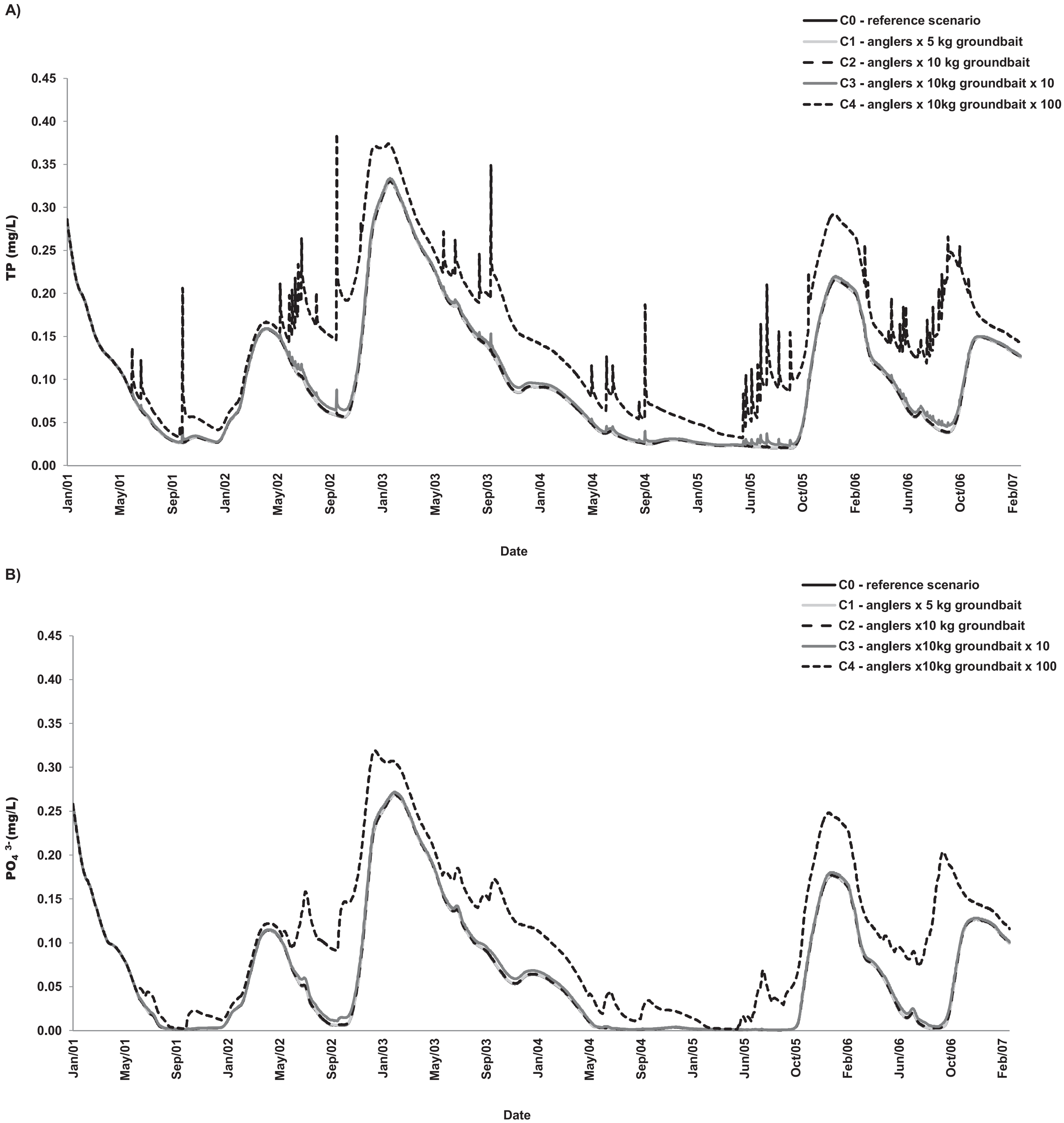

Figure 5.-Results from CE-QUAL-W2 simulations from January 2001 to February 2007 representing changes in concentration over time in Maranhão Reservoir for (A) total phosphorus (TP; mg/L), and (B) orthophosphate (PO_4^{3-}; mg/L).

Trademarks should provide more information about the eutrophication potential of their products to integrate that information into a more holistic approach to reservoir management.

Although inland recreational angling management receives some attention at the local level by a few stakeholders, the effects that this activity can have on fish populations, at waterbody's primary production, and on ecosystems in general are still poorly studied (Jackson et al. 2010). Because anglers are numerous, the pressures resulting from this leisure activity should be more carefully considered and further studied through a holistic angler–ecosystem approach.

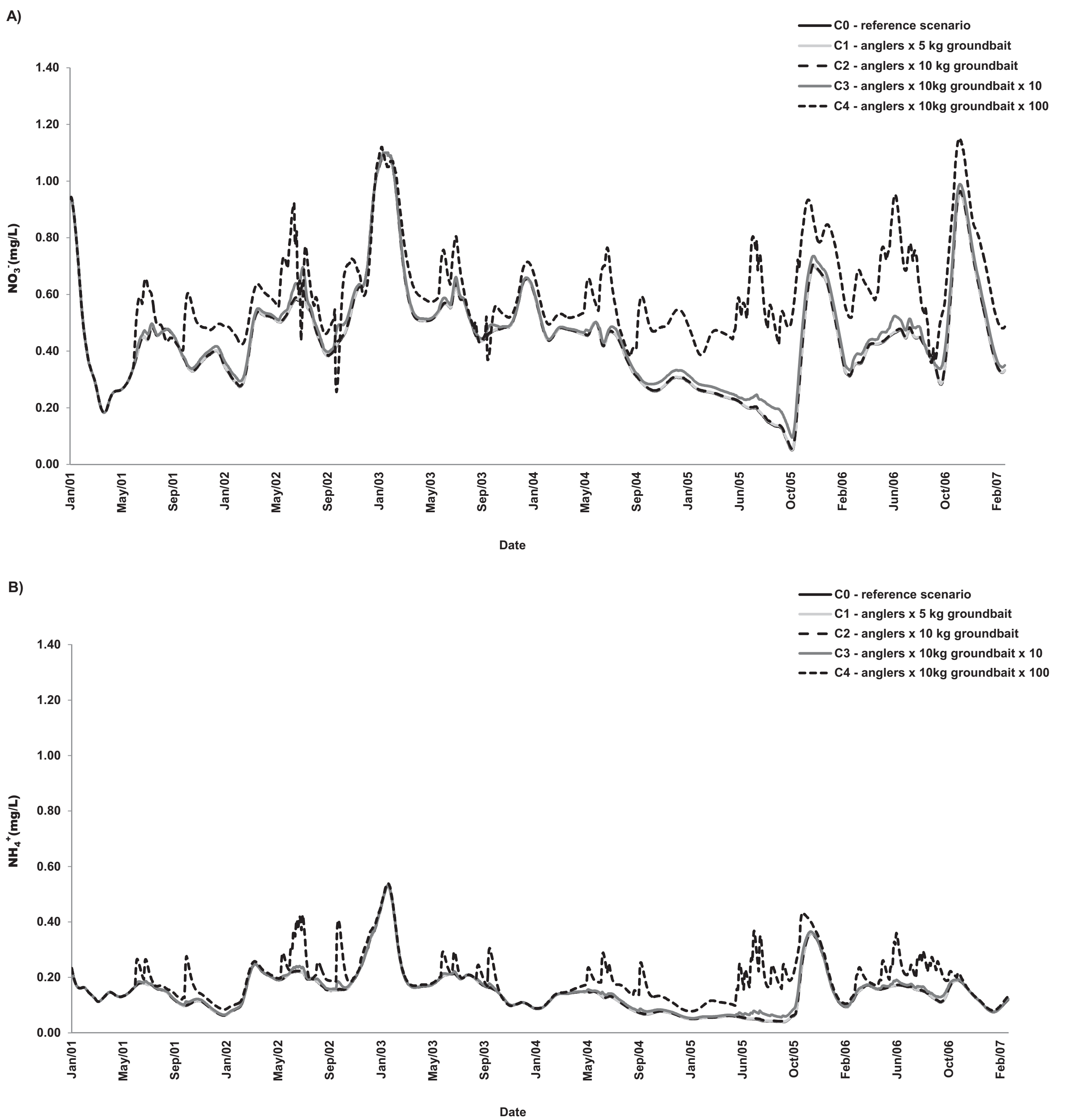

Figure 6.-Results from CE-QUAL-W2 simulations from January 2001 to February 2007 representing changes in concentration overtime in Maranhão Reservoir for (A) nitrate (NO_3^-; mg/L) and, (B) ammonium (NH_4^+; mg/L).

Integrated management of reservoirs is needed, and modeling can be a useful tool for decision making in water resources management. This study has shown the meaningful advantage of combining CE-QUAL-W2 and SWAT models on the study of groundbaiting in recreational fisheries and reservoir eutrophication. Further analysis on external loading rates from the watershed (related to management of watershed uses), phosphorus budgets and eutrophication control, and reservoir water level management could be developed.

To improve recreational angling and eutrophication management we suggest (1) coordinated actions between fisheries management and regional water authorities to address eutrophication, a key element for both; and (2) obligatory information on groundbait nutrient levels and

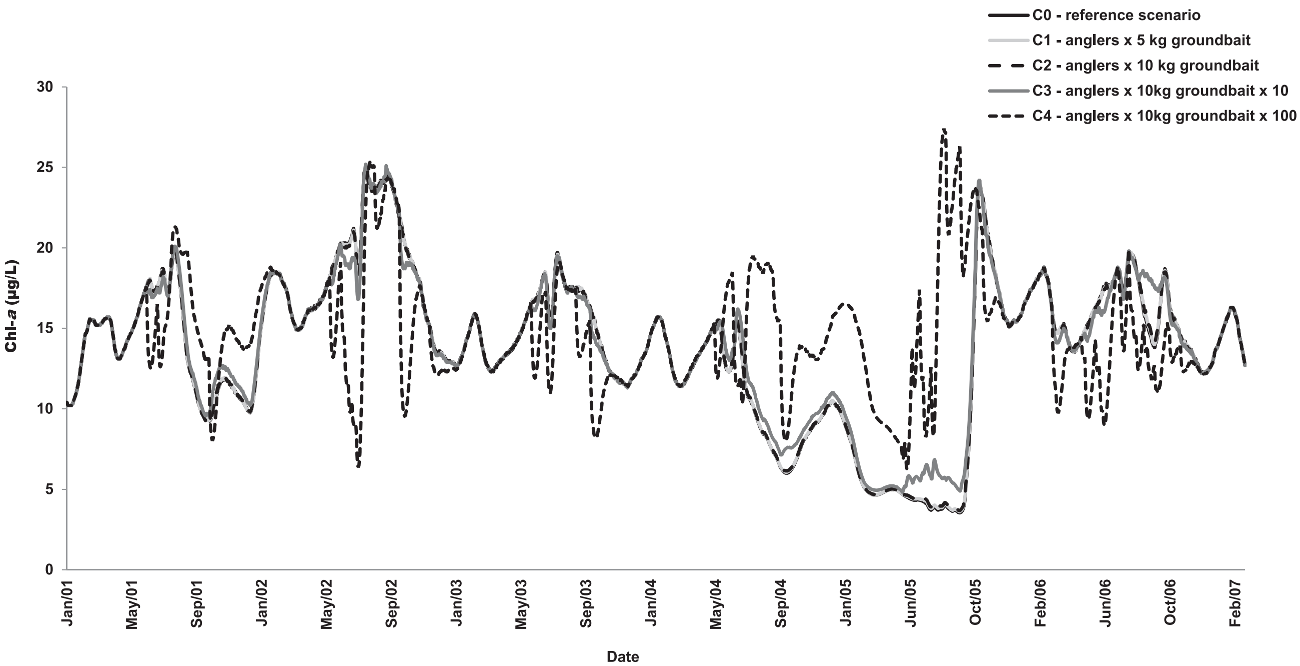

Figure 7.-Results from CE-QUAL-W2 simulations from January 2001 to February 2007 representing changes concentration over time in Maranhão Reservoir for chlorophyll *a* (Chl-*a*; μg/L).

limits for groundbait loads in angling competitions. If these measures are implemented, we see no need to ban the use of groundbait in recreational fisheries in reservoirs. On the contrary, effective improvement of recreational fisheries in reservoirs is needed to maximize the social, economic, and even environmental benefits.

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References

American Public Health Association (APHA), American Water Works Association (AWWA), Water Environment Federation (WEF). 2005. SMEWW - Standart methods for the examination of water and wastewater, 21st ed. Eaton A, Clesceri LS, Rice EW, Greenberg AE (eds). Washington DC, USA.

Arlinghaus R, Niesar M. 2005. Nutrient digestibility of angling baits for carp, *Cyprinus carpio*, with implications for groundbait formulation and eutrophication control. Fisheries Manag Ecol. 12:91–97.

Carpenter SR, Lathrop RC. 2008. Probabilistic estimate of a threshold for eutrophication. Ecosystems. 11:601–613.

Carvalho L, Solimini AG, Phillips G, Pietiläinen O-P, Moe J, Cardoso AC, Solheim AL, Ott I, Søndergaard M, Tartari G, Rekolainen S. 2009. Site-specific chlorophyll reference conditions for lakes in Northern and Western Europe. Hydrobiologia. 633:59–66.

Cole TM, Wells SA. 2003. CE-QUAL-W2: A two-dimensional, laterally averaged, hydrodynamic and water quality model, version 3.1 user's manual. Vicksburg (MS). US Army Engineering and Research Development Center. Instruction Report EL-03–1.

Cowx IG, Arlinghaus R, Cooke SJ. 2010. Harmonizing recreational fisheries and conservation objectives for aquatic biodiversity in inland waters. J Fish Biol. 76:2194–2215.

Debele B, Srinivasan R, Parlange J-Y. 2008. Coupling upland watershed and downstream waterbody hydrodynamic and water quality models (SWAT and CE-QUAL-W2) for better water resources management in complex river basins. Environ Model Assess. 13:135–153.

Ferreira MT. 2002. A pesca em águas continentais [Fisheries in inland waters]. Ambiente 21.. 4:72–75. Portuguese.

Jackson ZJ, Quist MC, Downing JA, Larscheid JG. 2010. Common carp (*Cyprinus carpio*), sport fishes, and water quality: Ecological thresholds in agriculturally eutrophic lakes. Lake Reserv Manage. 26:14–22.

Kasprzak P, Padisák J, Koschel R, Krienitz L, Gervais F. 2008. Chlorophyll a concentration across a trophic gradient of lakes: An estimator of phytoplankton biomass? Limnologica. 38:327–338.

Kim Y, Kim B. 2006. Application of a 2-dimensional water quality model (CE-QUAL-W2) to the turbidity interflow in a deep reservoir (Lake Soyang, Korea). Lake Reserv Manage. 22(3):213–222.

Lewin WC, Arlinghaus R, Mehner T. 2006. Documented and potential biological impacts of recreational fishing: Insights for management and conservation. Rev Fish Sci. 14:305–367.

Moriasi DN, Arnold JG, Van Liew MW, Bingner RL, Harmel RD, Veith TL. 2007. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Am Soc Agric Biolog Eng. 50(3):885–900.

Navarro E, Caputo L, Marcé R. Carol J, Benejam L, Garcia-Berthou E, Armengol J. 2009. Ecological classification of a set of Mediterranean reservoirs applying the EU Water Framework Directive: A reasonable compromise between science and management. Lake Reserv Manage. 25:364–376.

Neitsch SL, Arnold JG, Kiniry JR, Srinivasan R, Williams JR. 2002. Soil and Water Assessment Tool user's manual: Version 2000. College Station (TX): Texas Water Resources Institute. TWRI Report TR-192.

Niesar M, Arlinghaus R, Rennert B, Mehner T. 2004. Coupling insights from a carp, *Cyprinus carpio*, angler survey with feeding experiments to evaluate composition, quality and phosphorus input of groundbait in coarse fishing. Fisheries Manag and Ecol. 11:225–235.

Ostfeld A, Salomons S. 2005. A hybrid genetic-instance based learning algorithm for CE-QUAL-W2 calibration. J Hydrol. 310:122–142.

Ribeiro PF. 2003. Avaliação económica de bens ambientais–Uma aplicação ao caso da pesca desportiva nas albufeiras do Alentejo [Economic assessment of environmental goods–An application to sport fisheries in Alentejo's reservoirs]. Ingenium. 73:64–66.

Smith VH, Tilman GD, Nekola JC. 1999. Eutrophication: impacts of excess nutrient inputs on freshwater, marine, and terrestrial ecosystems. Environ Pollut. 100:179–196.

White JD, Prochnow SJ, Filstrup CT, Byars BW. 2010a. A combined watershed-water quality modeling analysis of the Lake Waco reservoir: II. Watershed and reservoir management options and outcomes. Lake Reserv Manage. 26:159–167.

White JD, Prochnow SJ, Filstrup CT, Scott JT, Byars BW, Zygo-Flynn L. 2010b. A combined watershed-water quality modeling analysis of the Lake Waco reservoir: I. Calibration and confirmation of predicted water quality. Lake Reserv Manage. 26:147–158.

Wolos A, Teodorowicz M, Grabowska K. 1992. Effect of groundbaiting on anglers' catches and nutrient budget of water bodies as exemplified by Polish lakes. Aquacult Fish Manage. 23:499–509.