Science of the Total Environment 761 (2021) 143296

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Ecological impacts of an invasive top predator fish across South America

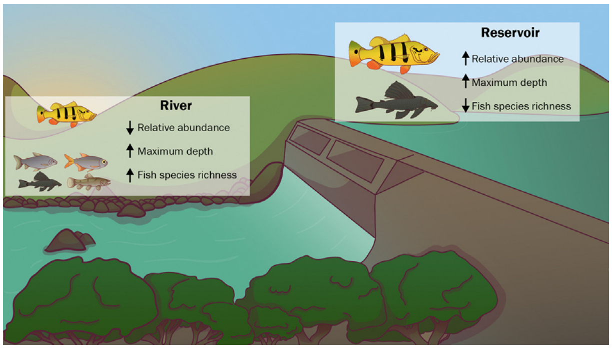
Ana Clara Sampaio Franco [a,*], Emili García-Berthou [a,b], Luciano Neves dos Santos [a]

[a] *Graduate Course in Neotropical Biodiversity, Federal University of Rio de Janeiro State, Av. Pasteur, 458 – R506A, 22290-240 Rio de Janeiro, RJ, Brazil*
[b] *GRECO, Institute of Aquatic Ecology, University of Girona, 17003 Girona, Catalonia, Spain*

HIGHLIGHTS

- Fish species richness decreases with greater invader abundance in reservoirs.
- Greater abundance of the top predator is found in human-modified systems.
- Maximum depth, population status and ecosystem type were the best predictors.
- Introduction year showed invasion pathways not related to geographical proximity.
- Older introductions in reservoirs had less native and more introduced species.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 18 July 2020
Received in revised form 11 September 2020
Accepted 18 October 2020
Available online 4 November 2020

Editor: Sergi Sabater

Keywords:
Peacock bass
Cichla ocellaris
Random forest
Residence time
Amazon basin
Invasibility

ABSTRACT

Peacock bass *Cichla ocellaris* is a piscivorous cichlid native from the Amazon and Orinoco river basins, which has been broadly introduced into tropical areas worldwide, leading to several adverse local effects. However, predictors of its invasibility and assessments of its ecological impacts over large spatial scales are still lacking. The importance of different environmental factors in explaining the relative abundance of peacock bass in 62 sites across South America (30 native and 32 invaded systems) was investigated. The impacts of peacock bass on fish assemblages were appraised, using years since introduction as a proxy of its cumulative impacts and modern statistical techniques, such as random forests, and negative binomial regression models. Random forests highlighted maximum depth, introduced status, and ecosystem type as the best predictors of the peacock bass relative abundance, which ranged 0.01–26.0%, increased with maximum depth, was highest in invaded reservoirs but decreased with depth in native riverine populations. Other factors such as climate or limnological features were less important in explaining *C. ocellaris* abundance, which did not vary markedly with years since introduction. Introduction year was not related to latitude but varied among hydrographic regions, indicating invasion pathways not linked to geographical proximity. Variation partitioning of different fish assemblage metrics showed that hydrographic region followed by limnological and reservoir features accounted for most explained variation, indicating a strong historical and local influence. Introduction time accounted for 5–8% of variation in species composition and diversity, independently of limnological features. Our results suggest that the ecological effects of introduced *C. ocellaris* on native fish fauna are likely but small compared to large geographical and environmental gradients. Although experiments and before-after designs are probably more sensitive in detecting the ecological impacts of invasive species, large-scale compilations of available data are more feasible and can provide invaluable information, especially for large-sized invaders that are often illegally introduced.

---

[*] Corresponding author.
E-mail address: ana.franco@unirio.br (A.C.S. Franco).

https://doi.org/10.1016/j.scitotenv.2020.143296
0048-9697/

1. Introduction

Invasive alien species continue to impact ecosystems and biodiversity despite of worldwide commitments (such as the Aichi biodiversity targets) and legislation to prevent and mitigate these threats (Dick et al., 2013a, 2017; Ricciardi et al., 2012). There has been much progress in describing species characteristics related to invasiveness (Kolar and Lodge, 2001; van Kleunen et al., 2010; Howeth et al., 2015) and also in determining the invasibility of a community or habitat (Ilhéu et al., 2014; Ellender et al., 2015; Franco et al., 2018). However, few effective strategies are still applied to controlling invasive species in aquatic systems, especially in large and species-rich Neotropical environments.

Determining whether single or multiple environmental factors shape the distribution and ecological impacts of invasive alien species is crucial for risk assessment and also for developing control and eradication strategies, especially when these invaders are top predators (Salo et al., 2007; Dick et al., 2013b; Sharpe et al., 2017). Introduced predators are considered as one of the leading causes of declines and extirpations of species worldwide, with adverse effects cascading on food webs and scaling up to entire ecosystems (Pinto-Coelho et al., 2008; Bezerra et al., 2017). These predators often induce changes in the composition and structure of invaded systems, with consequences on both native biodiversity and provision of ecosystem services (Zaret and Paine, 1973; Latini and Petrere, 2004; Salo et al., 2007; Pelicice and Agostinho, 2009).

Impacts of invasive species are more conclusive through both laboratory or field experiments, but this is often not feasible when dealing with large ecosystems or scales and large species, such as the cases for instance of the temperate largemouth bass (*Micropterus salmoides*, Pereira and Vitule, 2019) or the tropical peacock basses (*Cichla* spp.), top predators widely introduced worldwide for sport fisheries (Carol et al., 2009; Garcia et al., 2014; Espínola et al., 2015). The recreational and economic interests lead some sport fishermen to often, albeit illegally, introduce target and bait species throughout systems, probably increasing their chances of establishment through high and constant propagule pressures (Simberloff, 2009; Britton and Orsí, 2012). Long-term assessments might also be used to follow an introduction from its beginning and compare the temporal dynamics with control sites or before-introduction periods, but such large temporal databases are generally unavailable, especially for tropical freshwater systems (Parker et al., 1999; Agostinho et al., 2007). The most available and feasible approach for large freshwater ecosystems arguably is to compare sites with different times since introduction, attempting to account for other environmental gradients with robust modelling (Lodge et al., 1998; Brändle et al., 2008; Carol et al., 2009). Time since introduction (referred to residence time for species introduced into a region but not necessarily in the wild, Pyšek and Jarošík, 2005) has been shown to predict the ranges (Pyšek and Jarošík, 2005; Williamson et al., 2009), abundance (Bennett et al., 2013), severity of impacts (Carol et al., 2009) or degree of enemy release (Hawkes, 2007) of invasive species, although the evidence mostly comes from terrestrial plants.

In the Neotropics, the mediating factors of species invasive ability are still barely known, even with the increasing threat posed by non-native fish species, which is especially alarming, since this region holds ~30% of the world's fish diversity (Reis et al., 2003; Lévêque et al., 2008). Many non-native fish species are continuously introduced throughout the Neotropical region, despite the several impacts described at local levels, especially peacock basses *Cichla* sp., and the tilapia *Oreochromis niloticus* (Figueiredo and Giani, 2005, Pelicice et al., 2015). Peacock basses (*Cichla* spp.) comprise 15 species of cichlids native from the Amazon and Orinoco river basins (Kullander and Ferreira, 2006) that have been widely introduced into several reservoirs throughout the Americas, but especially in south and southeastern Brazil (Espínola et al., 2010; Marques et al., 2016). Within the genus *Cichla*, the group commonly known as yellow peacock basses (*Cichla ocellaris* Bloch and Schneider 1801, *C. monoculus* Spix and Agassiz 1831, and *C. kelberi* Kullander and Ferreira, 2006) is the most widespread, being also introduced in northeastern Brazil (Dourado and Davies, 1978), Panamá (Zaret and Paine, 1973), Florida, US (Shafland, 1996), and more recently Africa and Asia (Concepcion and Nelson, 1999; Hickley et al., 2008; Yeo and Chia, 2010; Rahim et al., 2013; Guerrero, 2014; Golani et al., 2019). They are voracious diurnal piscivores often causing adverse local effects on native fishes when introduced (Zaret and Paine, 1973; Pinto-Coelho et al., 2008; Pelicice and Agostinho, 2009; Sharpe et al., 2017). However, we are not aware of any study addressing how spatial, limnological and reservoir features, and fish species composition of the native and invaded ecosystems interact to explain the abundances of peacock basses through large spatial scales. Besides, the apparent local and regional ecological impacts attributed to peacock basses were not assessed or even supported at broader spatial scales before. Therefore, the aims of our study were: i) to assess the importance of different factors in explaining the relative abundance of *Cichla ocellaris* across South America (the region that harbours most of the studies on this group, Franco et al. in prep.); and ii) to assess the variation of fish assemblages with time since peacock bass introduction, relative to environmental factors, as proxies of ecological impacts of *Cichla ocellaris* at large geographical scales. Here, the molecular-based classification of Willis et al. (2012) was followed, and thus the five phenotypes of yellow peacock basses showing high levels of introgressive hybridization were regarded as a single species, namely *Cichla ocellaris* sensu lato. In addition to sharing many morphological, functional and ecological similarities, the five phenotypes of *Cichla ocellaris* sensu lato (*C. kelberi, C. monoculus, C. nigromaculata, C. ocellaris,* and *C. pleiozona*) comprise the most frequently introduced peacock basses, representing thus the most widespread biological entity of this genus. We hypothesized that peacock bass abundances would be related to some environmental and fish community attributes, but this relationship would be different regarding the ecosystem type (lentic versus lotic) and distribution status (native versus introduced). We expected greater impacts of *Cichla ocellaris* in lentic systems where this species has been introduced, especially those with warmer and more transparent waters, in accordance to previous studies for both native *Cichla intermedia, C. orinocensis,* and *C. temensis* populations (Winemiller, 2001) and introduced *C. kelberi* populations (Espínola et al., 2010).

2. Methods

The online databases of Web of Science, Scopus and Google Scholar were searched until July 2016 using "*Cichla*" AND "fish assemblage" OR "community" OR "native" OR "invasive" OR "alien" OR "introduced" OR "non-native" as keywords. We retained studies with abundance (raw or percentage) data of fish species, in which the yellow peacock basses - *Cichla ocellaris* sensu lato (*C. ocellaris, C. monoculus, C. kelberi, C. pleiozona,* and *C. nigromaculata*) following Willis et al. (2012; see also Espínola et al., 2015) was present, either as a native or alien species. A further search was performed to compile abiotic variables (when they were not already available from the references previously obtained), using as keywords: the name of the system; AND limnology OR hydrography OR water quality; and often the referred variable (e.g. water temperature). Studies for which limnological data were not available were discarded, leading to 62 study populations (30 native and 32 introduced), mostly in Brazil but also in Guyana, Peru, Bolivia and Paraguay (Fig. 1). The following information was finally compiled from the retained studies: relative abundance of all fish species, features from the study system (e.g. hydrographic region, coordinates, reservoir age, residence time, maximum depth, and altitude), some limnological variables (e.g. temperature, pH, total phosphorus and dissolved oxygen concentrations, transparency, and conductivity), year of *Cichla ocellaris* introduction (if applicable), and sampling year. Gillnets were used in most (~90%) of the retained studies, but other fishing gears (i.e. seines, cast nets, long-lines) were also used and gillnet dimension and effort were variable among studies. Therefore, relative abundance (percent proportion of the total fish abundance) of peacock basses and the

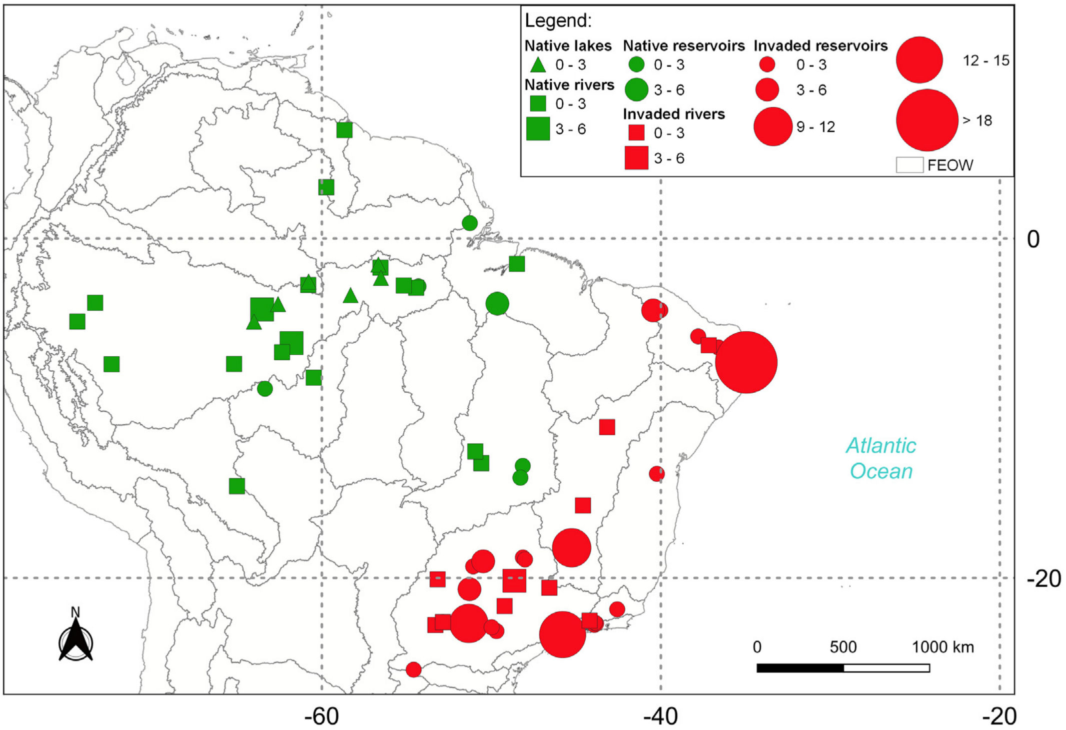


Fig. 1. Map showing the location of the studied lakes, reservoirs and rivers across South America. Symbol size is proportional to the relative abundance of peacock bass. Green symbols are located in the native distribution of peacock bass, while red symbols are at the invaded range.

other fish species were calculated and used in our analyses instead of raw abundances. Although such standardisation might potentially attenuate the responses among fish species and abiotic conditions within a given ecosystem, we expected that relative abundance was robust enough to be used as a proxy for comparisons among systems and to detect peacock bass effects over native assemblages and the relationship of this invader with environmental variables. As in some previous studies (e.g. Carol et al., 2009; Franco et al., 2018), because for most aquatic invasive species data before introductions are seldom available, we used time since introduction as a proxy of the accumulated potential impacts of peacock bass, assuming that the effects on native assemblages (e.g. species declines or extirpations) are not yet fully realized in recent introductions and increase with time. The compiled data are given in the Supplementary information (Tables S1 and S2).

2.1. Data analyses

We used Random forests (RF) to evaluate the importance of predictors of relative abundance of peacock bass, both in the native and introduced areas. Random forest (RF) is a machine-learning technique increasingly used in many scientific areas due to their high accuracy and ability to characterize complex interactions among predictors (Breiman, 2001; Strobl et al., 2008). RF have many advantages over other more conventional statistical techniques: run efficiently on large databases with many correlated predictors, give estimates of what variables are the most important, allow missing data, and handle particularly well nonlinearities and interactions (Prasad et al., 2006; Cutler et al., 2007). We used the 'cforest' function in the 'party' package (Hothorn et al., 2006) of the R software (R Core Team, 2016) to estimate what are the most important variables to explain the relative abundance of peacock bass. Conditional variable importance was assessed through the 'varimp' function, available in the 'party' package (Hothorn et al., 2006), which adjusts for correlations between predictor variables (Strobl et al., 2008). We used as predictors: hydrographic region, latitude, ecosystem type, area, maximum water depth, altitude, transparency, conductivity, precipitation, pH, dissolved oxygen, phosphate, and mean and minimum water temperatures. We used the 'party' rather than the more widely used 'randomForest' R package (Liaw and Wiener, 2002) to avoid the biased variable selection and variable importance for predictor variables when they are of different types (e.g. scales, categories) or in the case of correlated predictors (Strobl et al., 2007, 2008, 2009). We used 1000 trees to build the RF because increasing this number did not substantially change the results of variable importance or explained variation (Strobl et al., 2008). As the number of variables randomly sampled as candidates at each split, we used the recommended default of the square root of number of predictors (Liaw and Wiener, 2002). Note that the out-of-bag estimate of variance used in RF is as accurate as using a test set of the same size as the training set and thus removes the need for a set aside test set in standard applications (Breiman, 2001; Prasad et al., 2006). Moreover, our aim was not to develop a predictive model but to rank the importance of variables and understand their effects. RF partial dependence plots (Friedman, 2001) were obtained for the most important predictors. These plots give a graphical depiction of the marginal effect of a predictor on the response variable, after partialing out the effects of the other predictors in the model (see Tuulaikhuu et al., 2017 for similar analyses). The relationship of relative abundance of *C. ocellaris* with maximum depth by ecosystem type and native/introduced status, and time since introduction in rivers and reservoirs was illustrated through generalized additive models (GAM) with the beta regression family.

For introduced populations, we used variation partitioning (Borcard et al., 1992) to quantify the relative importance of different descriptor sets and years since *Cichla's* introduction (as a proxy of the cumulative impacts of peacock bass) in explaining fish assemblage metrics. Variation partitioning (VP) computes the adjusted R^2 based on linear regression (or redundancy analyses for multiple response variables) to estimate the unique and joint fractions explained by a set of explanatory variables (Borcard et al., 2011). We performed four different VP analyses, using as responses: the matrix of relative abundances (286 species × 32 sites) with Hellinger transformation (Legendre and Gallagher, 2001), the Shannon's index of diversity, observed native fish richness, and Pielou's evenness. We used four predictors sets for each of the VP analyses: 1) limnological and reservoir features (minimum and mean temperatures, pH, absolute value of latitude, and log-transformations of elevation, maximum depth, oxygen, transparency and oxygen and total phosphorous concentrations); 2) ecosystem type (10 rivers vs. 22 reservoirs); 3) years since introduction of peacock bass at the study time; and 4) hydrographic region (five regions as dummy variables). VPs were obtained using function "varpart" in the "vegan" package (Oksanen et al., 2016) of the R statistical software. The different unique and overall fractions in VP were tested with permutation tests (10,000 permutations), using function "anova.cca".

We further used negative binomial (generalized linear) models (NBM) to test for effects of hydrographic region, ecosystem type (reservoir, lake or river) and time since the introduction of *C. ocellaris* (predictors) on species richness, because this response variable is less well modelled with the linear models used in VP. We used the function "glm.nb"as available in the package "MASS" (Ripley et al., 2017) of R statistical software and scripts modified from Magellan and García-Berthou (2015). NBMs are an extension of GLMs which account for overdispersion, which is frequent in ecological data and was also present in our study, with an extra parameter "theta". We compared NBMs with an information theoretical framework (Burnham and Anderson, 1998), i.e. Akaike information criteria (AIC), to compare four models with the abovementioned three predictors: a null model without predictors and models with and without time since the introduction both with additive and multiplicative effects of hydrographic region and ecosystem type. The Akaike's Information Criterion (AICc) combines goodness-of-fit with parsimony (number of parameters) of models, with the best fitting model having the lowest AICc. The relative plausibility of each candidate model was assessed by calculating Akaike weights (w_i), which range from 0 to 1 and are interpreted as the probability that the model is the best among those evaluated given the data.

3. Results

3.1. Relative abundance of *Cichla ocellaris*

The relative abundance (RA) of *C. ocellaris* ranged 0.01–26.0% in the studies considered (mean = 2.1%; Fig. 1) with higher mean values in invaded (3.3%) than in native areas (0.8%). Random forest analyses explained 20.4% of this response variable and suggested that maximum depth of the system, native vs. introduced status, and ecosystem type (rivers, lakes, and reservoirs) were the best predictors of RA (Fig. 2). Other factors such as climate (temperatures and latitude) or physical and chemical water features (transparency, oxygen and phosphate concentrations, pH, and conductivity) were less important predictors. *Cichla ocellaris* increases in abundance with the maximum depth of the system, although mainly in reservoirs in the introduced area (Fig. 3A). The smooth terms of GAM models of RA and maximum depth were significant for reservoirs in the introduced area and rivers in the native area ($P < 0.001$) but followed opposing trends (i.e. positive for introduced reservoirs, negative for native rivers). Higher RA was recorded in native rivers (1%) than in native reservoirs (0.3%) and lakes (0.4%); by contrast, the opposite pattern was found for invaded systems, with 1% in rivers, and reservoirs reaching the highest RA (4.3%) (Figs. 1 and 3).

Among introduced populations, GAM models suggested no relationship (smooth term) between RA and years since introduction (introduction age) in either rivers or reservoirs, despite the higher abundance in the latter (Fig. 3B); therefore, RA of peacock bass did not increase markedly in older introductions. Year of introduction, which was highly correlated with introduction age ($r = -0.96$, $n = 32$, $P < 0.001$), was not related to latitude of the study system ($r = 0.19$, $P = 0.30$) but varied significantly among hydrographic regions (ANOVA, $P = 0.005$) because introductions started earlier in the more populated states of southeastern Brazil (SE Atlantic, e.g. Rio de Janeiro State) and are more recent in the Paraná river basin (Fig. S1).

3.2. Effects of introduction age on fish assemblages

Variation partitioning of fish assemblage characteristics (Fig. 4) showed that: i) except for fish species evenness, hydrographic region followed by physical and chemical water features had higher percentages of explained variation; ii) the differences between reservoirs and rivers were in general less important although its unique effects were significant for species diversity (permutation test, $P = 0.042$); iii) the unique effects of hydrographic region were significant for species composition and richness (permutation tests, $P < 0.05$) and marginally significant for species diversity ($P = 0.083$); iv) the unexplained variation was higher for fish species evenness, in which none of the four predictor sets had significant unique or overall effects ($P \geq 0.095$).

Except for fish species evenness, the overall effects of years since introduction of peacock bass explained 5–8% of the variation (Fig. 4) and were significant for species composition ($P = 0.005$) and marginally significant for species richness ($P = 0.087$). However, the unique effects of introduction age were never significant ($P > 0.05$) because most of its variation was jointly explained with hydrographic region (Fig. 4) given

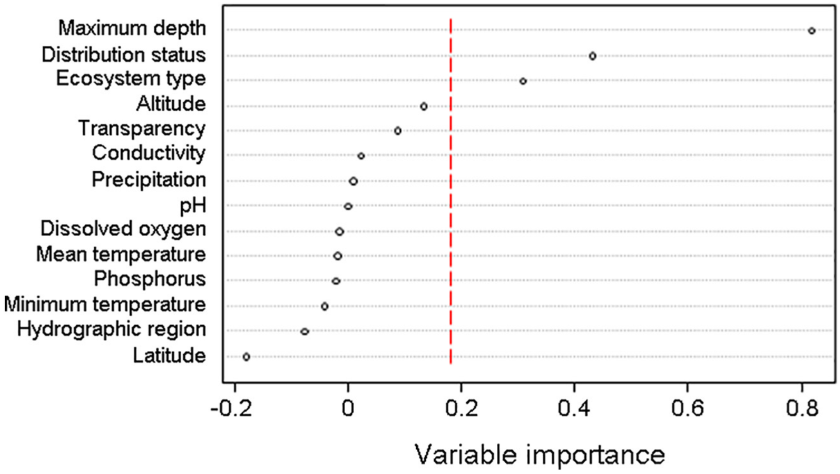


Fig. 2. Variable importance of predictors of relative abundance of peacock bass according to the random forest technique (explained variation = 20.4%). Predictors with variable importance to the left of the dashed red line can be considered uninformative.

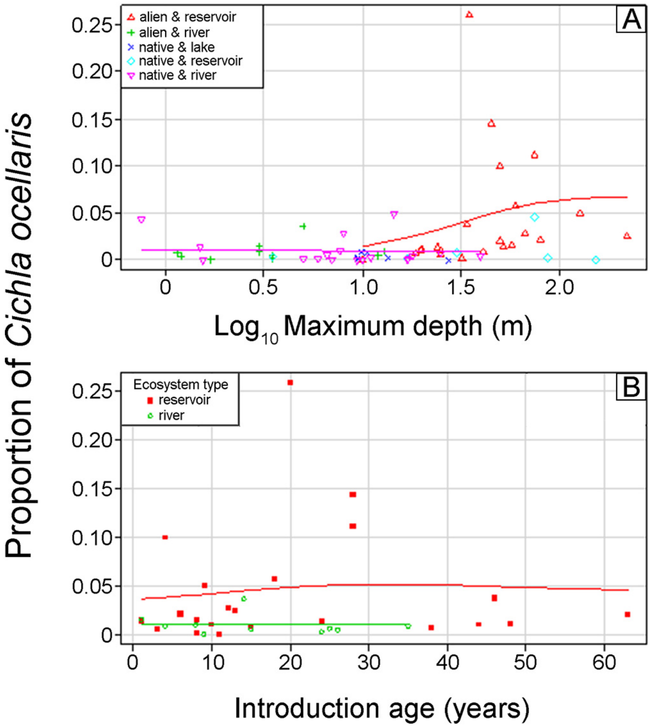


Fig. 3. Relationship of relative abundance of *Cichla ocellaris* with maximum depth by ecosystem type and native/introduced status (top) and time since introduction in rivers and reservoirs (bottom). A generalized additive model with the beta regression family is shown.

the marked differences in introduction year or age among hydrographic regions (Fig. 5). Fish species richness in reservoirs decreased with years since peacock bass introduction (Fig. 5A) and the same pattern is independently observed in three hydrographic regions (Fig. 5B). Information criteria of negative binomial models showed that although models with only hydrographic region and ecosystem type were the most likely, the models with years since introduction had about 28% of the likelihood and were <2 ΔAICc (Table 1). Heat maps (Fig. 6) suggest that in reservoirs with older introductions, e.g. reservoirs in Rio de Janeiro state, i.e. SE Atlantic hydrographic region, such as Lajes, with *Cichla* introduced ca. 63 years before the study period (Santos et al., 2001) or Vigário, 48 years (Marques et al., 2016), several native species (e.g. *Astyanax fasciatus*, *Gymnotus carapo*, *Hoplias malabaricus*, and *Rhamdia quelen*) disappeared and relative abundances shifted towards a greater dominance of other introduced species (e.g. *Plagioscion squamosissimus, Coptodon rendalli,* and *Oreochromis niloticus*), some of them less sensitive to piscivory (e.g. *Metynnis lippincotianus*).

4. Discussion

Our findings are the first in demonstrating, through a broad spatial coverage (~32 latitudinal degrees; 3500 km of distance range), that peacock bass experienced a noticeable population boom in reservoirs wherein it was introduced. The hypothesis of positive additive effects of river damming on non-native peacock bass populations (i.e. lowering the proportion of native predators and competitors and increasing the predation effects of this invader) is supported by the trend of decreased relative abundances of peacock bass with water depth in rivers within its native range, wherein running waters (and probably more turbulent and turbid conditions) prevailed over lentic conditions (Agostinho et al., 2007; Espínola et al., 2015). The influence of depth on the relative abundance of introduced peacock bass in reservoirs was stronger than geographical, physical, or other limnological features. Using peacock bass

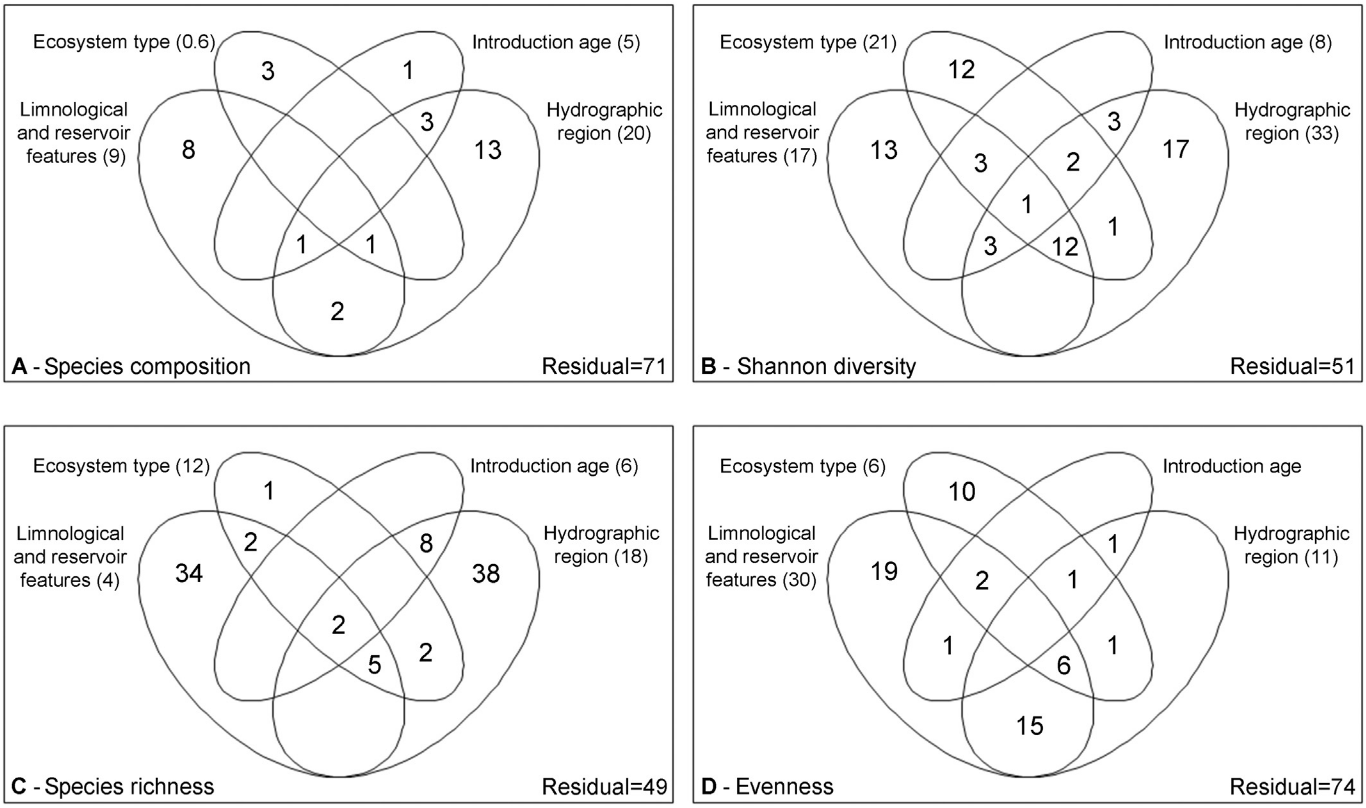


Fig. 4. Variation partitioning of species composition (A), Shannon's diversity index (B), species richness (C), and Pielou's evenness (D) using limnological and reservoir features, ecosystem type, time since introduction, and hydrographic region as predictor sets. The overall variation explained by each predictor set is given between parentheses. Values ≤0 are not shown.

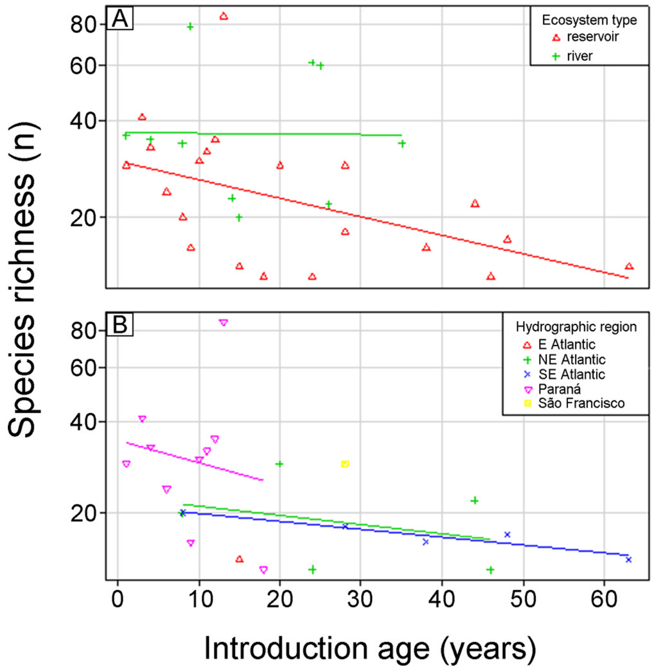


Fig. 5. Relationship of fish species richness with time since introduction by ecosystem type and hydrographic region. Linear models are shown (note the log-scale for species richness).

relative abundance allowed us to perform robust comparisons of varied systems widespread through South America and of studies using different fishing gears (mostly gillnets) and effort, with no apparent limitations in capturing signals of the major environmental factors and fish assemblage attributes related to shifts of peacock bass abundance. We believe that studies in other continents would have similar results of the predictors for the establishment of peacock basses and the impact on native fish fauna that would follow.

Peacock bass experienced a large demographic growth with increased water depth of reservoirs located outside its native range. Similar predictions were provided in studies spanning only local or regional scales (e.g. Upper Paraná and Paraíba do Sul river basins) and excluding comparisons with less-altered systems (e.g. lakes and rivers) of both native and introduced areas (Pelicice and Agostinho, 2009; Espínola et al., 2010; Franco et al., 2018). These studies focused on presence-absence data (Pelicice and Agostinho, 2009; Espínola et al., 2010) or used raw abundance data (Franco et al., 2018) to infer the environmental features that contributed most to the invasibility of reservoirs by peacock bass.

Table 1
Information criteria of negative binomial models of fish species richness using as predictors ecosystem type (reservoirs vs. rivers), hydrographic region and years since introduction of peacock bass.

Model	Explained deviance (%)	AIC$_c$	Delta AIC$_c$ (ΔAIC$_c$)	d. f.	Akaike weight (w_i)
ALL SITES					
Ecosystem type + Region	46.9	254.9	0.0	7	0.714
Ecosystem type + Region + Years	47.1	256.8	1.9	8	0.280
Constant	–	265.1	10.1	2	0.005
Ecosystem type × Region × Years	50.1	267.0	12.1	14	0.002
RESERVOIRS ONLY					
Region	41.4	170.6	0.0	6	0.583
Region + Years	42.8	172.1	1.5	7	0.275
Constant	–	174.1	3.5	2	0.100
Region × Years	43.3	175.9	5.3	9	0.041

This strong positive effect of water depth on peacock bass abundance could be explained because deep reservoirs are also generally associated with the prevalence of lentic, transparent and warmer waters, and structurally-simple habitat conditions, which altogether favor the predation exerted by this visual piscivore (Winemiller, 2001; Espínola et al., 2015; Franco et al., 2018). Another non-mutually exclusive explanation is that these conditions typical of deeper reservoirs also adversely affected the whole fish assemblage, decreasing the relative abundances of non-adapted native species and strengthening the contribution of peacock bass.

River impoundment leads to environmental disturbances on the whole ecosystem, impacting native communities through critical alterations in the hydrological regime, habitat architecture and energy flow (Bailly et al., 2016; Baumgartner et al., 2017). Shifts on the composition and structure of native fish assemblages caused by river damming also seem to facilitate the establishment and spread of invasive species (Havel et al., 2005; Liew et al., 2016), as predicted for *Cichla* spp. introduced into reservoirs of Upper Paraná river basin and other Brazilian regions (Espínola et al., 2010; Franco et al., 2018). This mechanism apparently occurs through the occupation and exploitation by invasive species of vacant niches, after the extirpation of those native species which could not tolerate the change from lotic to lacustrine conditions, resulting thus in the impoverishment and biotic homogenisation of native fish assemblages (Havel et al., 2005; Liew et al., 2016).

Although the abundances of peacock bass were mostly influenced by the ecosystem type and introduced status, fish assemblage attributes were largely explained by local limnological conditions (i.e. water physical and chemical variables) and historical effects (i.e. hydrographic region, as previously stated by Tedesco et al., 2005 and Franco et al., 2018). Relationships among invasive species and fish assemblages are often confounded by local factors, such as environmental heterogeneity at the landscape, variation in resource availability, human alterations, and also the invasion stage (Fitzgerald et al., 2016). Furthermore, many studies covering large spatial scales face low partitioning among predictors, often sharing much of the explained variation among the predictive variables or accounting for great amounts of unexplained variation (Diniz-Filho and Bini, 2005; Diniz-Filho et al., 2009; Bailly et al., 2016). However, years since introduction of peacock bass accounted for 5–8% of variation in the species composition and fish diversity assessed in our study, regardless of physical and chemical water variables, with information criteria also suggesting negative effects of peacock bass on fish richness.

Cumulative impacts of peacock bass introduction on native fish assemblages have been previously reported, ranging from biotic homogenisation and decreases of native richness and diversity to trophic cascading effects (Zaret and Paine, 1973; Latini and Petrere, 2004; Pelicice and Agostinho, 2009; Menezes et al., 2012). In our study, peacock bass effects were apparently lower than other local or historical predictors of fish assemblages, probably due to the influence of our large-scale approach, but also because peacock bass was present in all systems used in our analyses. The approach used here, although not designed to directly split the synergistic effects of peacock bass introduction and river damming, showed that the cumulative impacts of this invasive species are likely, regardless of ecosystem type. Increased peacock bass abundance can be related to adverse effects on species composition, diversity, and richness, especially for non-native populations in the northeastern and southeastern Atlantic and also in Paraná hydrographic basins, the regions wherein this invader was introduced the earliest.

In this sense, reservoirs with the oldest peacock bass introduction also experienced considerable changes on fish assemblage composition, with increased contributions of other invasive species (i.e. the South American silver croacker *P. squamosissimus*, the tilapias *C. rendalli* and *O. niloticus*, and the silver dollar *M. lippincotianus*) together with the disappearance of native ones (*A. fasciatus*, *G. carapo*, *H. malabaricus*, and *R. quelen*). Further, in addition to stressing the potential impacts through predation on native species of small sizes (< 150 mm TL,

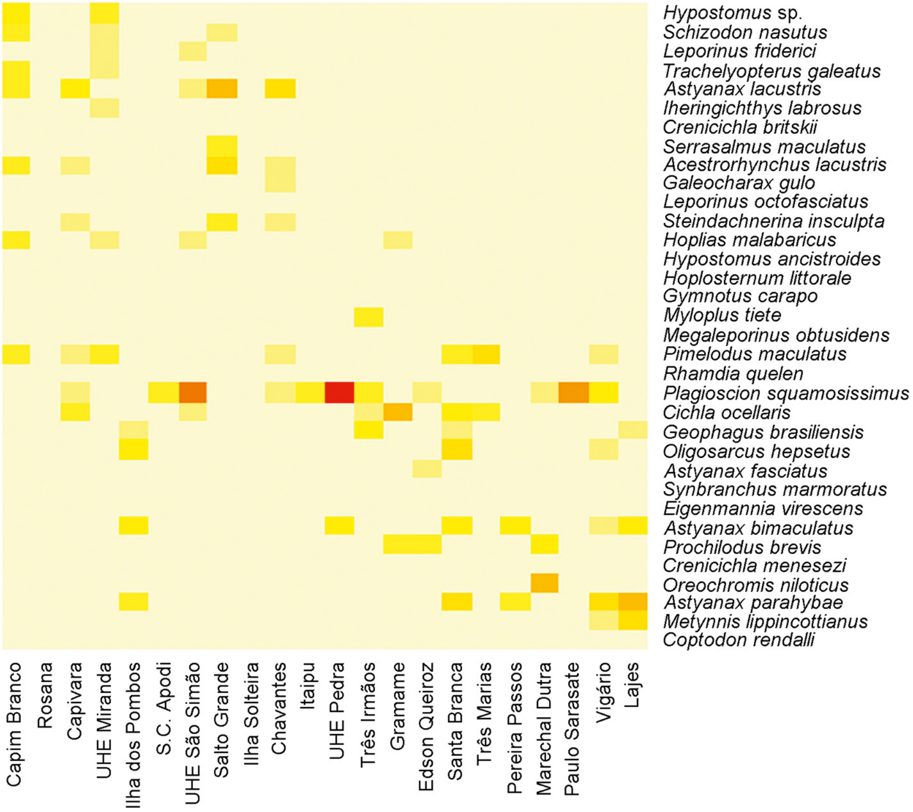


Fig. 6. Heatmap of species composition (relative abundance) as a function of increasing time since introduction (from left to right) in the study reservoirs. The more reddish color indicates higher relative abundance; light yellow indicates species not recorded in that reservoir. Species appearing in less than ten systems were omitted.

such as the tetra *A. fasciatus*) or slender-bodied (such as the banded knifefish *G. carapo*), our study also stresses the likely negative effects of peacock bass on the native piscivores (South American catfish *R. quelen* and trahira *H. malabaricus*). Although feeding interactions of peacock bass with *H. malabaricus* have been previously reported (Pompeu and Godinho, 2001; Pereira et al., 2015), no study has provided evidence of extirpation of native piscivores through peacock bass effects before, which is still more surprising when considering that *H. malabaricus* is a species fully adapted to lentic systems. Even so, this issue should be more deeply addressed through experimental trials that are able to control for potential confounding effects of dam age on the adverse consequences on native fish.

Finally, taking into account that peacock basses are highly valued as game fish in sport fisheries (Azevedo-Santos et al., 2015; Freire et al., 2016), we anticipate that they will continue to be introduced and thrive, particularly in deep and lentic systems of tropical or subtropical climates, as our findings highlighted. This is of especial concern considering the predictions of increasingly number of reservoirs worldwide, and especially in South America and tropical regions of Africa and Asia (Tollefson, 2011; Zarfl et al., 2015). Although imposing a great threat for native fish species, especially on small sized and slender-bodied species (Santos et al., 2001), but apparently also on native piscivores through competition (Fugi et al., 2008), if the spread of non-native peacock bass populations increases over time, it will be an opportunity to test whether our predictions are accurate. In this sense, further long-term studies using standardized sampling methods and effort and incorporating systems wherein peacock basses are not present or using before-after introduction designs are necessary. We find extremely important that further studies focus on evaluating the impacts on ecosystem functioning level, and also on the functional and phylogenetic diversities of the invaded systems. Despite their little implementation by hydroelectric companies, if management measures that increase water flow in reservoirs were carried out (thus decreasing water residence time and depth), they would be also an interesting opportunity to test our predictions about the response of peacock bass abundance to water depth and residence time. Educational campaigns should be directed to sport fishermen at risky systems in order to inform them about the adverse effects caused by the peacock bass and also to restrain "catch-and-release" practices to attempt to prevent further introductions of this top predator fish.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2020.143296.

Data availability statement

The literature review was made using data available online in Google Scholar, Scopus, and Web of Science databases. All occurrence records, systems features, limnological variables and species richness used in the analyses and also to generate the maps are available in the tables and studies listed in Supporting Information. The shapefile used to generate the map are also publicly available in the FEOW database.

CRediT authorship contribution statement

Ana Clara Sampaio Franco: Data gathering, Methodology, Writing - Original draft preparation. Emili García-Berthou: Methodology, Formal analysis, Writing - Review & Editing. Luciano Neves dos Santos: Conceptualisation, Methodology, Writing - Review & Editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The authors state that they do not have any conflict of interest. This study was funded in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES) – Code 001 (sandwich doctorate scholarship to ACSF, ref. 88887.127440/2016-00 and visiting professorship to EGB, ref. 88881.068352/2014-01), Fundação Carlos Chagas Filho de Amparo à Pesquisa do Estado do Rio de Janeiro, Brazil (postdoctoral fellowship to ACSF, E-26/202.423/2019; and research grant to LNS, E-26/202.755/2018), and National Council for Scientific and Technological Development (CNPq), Brazil (research grant to LNS, ref. 314379/2018-5). EGB was also supported by the Spanish Ministry of Science (projects PID2019-103936GB-C21 and RED2018-102571-T) and the Government of Catalonia (ref. 2017 SGR 548).

References

Agostinho, A.A., Gomes, L.C., Pelicice, F., 2007. Ecologia e Manejo dos Recursos Pesqueiros em Reservatórios do Brazil. EDUEM, Maringá.

Azevedo-Santos, V.M., Pelicice, F.M., Lima-Junior, D.P., Magalhães, A.L.B., Orsi, M.L., Vitule, J.R.S., Agostinho, A.A., 2015. How to avoid fish introductions in Brazil: education and information as alternatives. Natureza & Conservação 13, 123–132.

Bailly, D., Cassemiro, F.A.S., Winemiller, K.O., Diniz-Filho, J.A.F., Agostinho, A.A., 2016. Diversity gradients of Neotropical freshwater fish: evidence of multiple underlying factors in human-modified systems. J. Biogeogr. 43, 1679–1689.

Baumgartner, M.T., Baumgartner, G., Gomes, L.C., 2017. The effects of rapid water level changes on fish assemblages: the case of a spillway gate collapse in a Neotropical reservoir. River Res. Appl. 33, 548–557.

Bennett, J.R., Vellend, M., Lilley, P.L., Cornwell, W.K., Arcese, P., 2013. Abundance, rarity and invasion debt among exotic species in a patchy ecosystem. Biol. Invasions 15, 707–716.

Bezerra, L.A.V., Angelini, R., Vitule, J.R.S., Coll, M., Sánchez-Botero, J.I., 2017. Food web changes associated with drought and invasive species in a tropical semiarid reservoir. Hydrobiologia 817, 475–489.

Borcard, D., Legendre, P., Drapeau, P., 1992. Partialling out the spatial component of ecological variation. Ecology 73, 1045–1055.

Borcard, D., Gillet, F., Legendre, P., 2011. Numerical Ecology With R. Springer, New York (302p).

Brändle, M., Kühn, I., Klotz, S., Belle, C., Brandl, R., 2008. Species richness of herbivores on exotic host plants increases with time since introduction of the host. Divers. Distrib. 14, 905–912.

Breiman, L., 2001. Random forests. Mach. Learn. 45, 5–32.

Britton, J.R., Orsí, M.L., 2012. Non-native fish in aquaculture and sport fishing in Brazil: economic benefits versus risks to fish diversity in the upper River Paraná Basin. Rev. Fish Biol. Fish. 22, 555–565.

Burnham, K.P., Anderson, D.R., 1998. Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach. Springer, New York.

Carol, J., Benejam, L., Benito, J., García-Berthou, E., 2009. Growth and diet of European catfish *Silurus glanis* in early and late invasion stages. Fundam. Appl. Limnol. 174, 317–328.

Concepcion, G.B., Nelson, S.G., 1999. Effects of a dam and reservoir on the distributions and densities of macrofauna in tropical streams of Guam Mariana Islands. J. Freshw. Ecol. 14, 447–454.

Cutler, D., Edwards, T., Beard, K., Cutler, A., Hess, K., Gibson, J., Lawler, J., 2007. Random forests for classification in ecology. Ecology 88, 2783–2792.

Dick, J.T.A., Gallagher, K., Avlijas, S., Clarke, H.C., Lewis, S.E., Leung, S., Minchin, D., Caffrey, J., Alexander, M.E., Maguire, C., Harrod, C., Reid, N., Haddaway, N.R., Farnsworth, K.D., Penk, M., Ricciardi, A., 2013. Ecological impacts of an invasive predator explained and predicted by comparative functional responses. Biol. Invasions 15, 837–846.

Dick, J.T.A., Alexander, M.E., MacNeil, C., 2013b. Natural born killers: an invasive amphipod is predatory throughout its life-history. Biol. Invasions 15, 309–313.

Dick, J.T.A, Laverty, C., Lennon, J.J., Barrios-O'Neil, D., Mensink, P.J., Britton, J.R., ... Caffrey, J.M., 2017. Invader Relative Impact Potential: a new metric to understand and predict the ecological impacts of existing, emerging and future invasive alien species. J. Appl. Ecol. 54, 1259–1267.

Diniz-Filho, J.A.F., Bini, L.M., 2005. Modelling geographical patterns in species richness using eigenvector-based spatial filters. Glob. Ecol. Biogeogr. 14, 177–185.

Diniz-Filho, J.A.F., Oliveira, G., Lobo, F., Guimarães, L., 2009. Agriculture, habitat loss and spatial patterns of human occupation in a biodiversity hotspot. Sci. Agric. 66, 764–771.

Dourado, O.F., Davies, W.D., 1978. Length-weight relationships and condition indexes of fishes from reservoirs of Ceará, Brasil. Research & Development Series No. 18. International Center for Aquaculture, Auburn, Alabama.

Ellender, B.R., Woodford, D.J., Weyl, O.L.F., 2015. The invasibility of small headwater streams by an emerging invader, *Clarias gariepinus*. Biol. Invasions 17, 57–61.

Espínola, L.A., Minte-Vera, C.V., Júlio, H.F., 2010. Invasibility of reservoirs in the Paraná basin, Brazil, to *Cichla kelberi* Kullander and Ferreira, 2006. Biol. Invasions 12, 1873–1888.

Espínola, L.A., Minte-Vera, C., Julio Junior, H.F., Santos, L.N., Winemiller, K.O., 2015. Evaluation of factors associated with dynamics of *Cichla ocellaris* invasion of the Upper Paraná River floodplain system, Brazil. Mar. Freshw. Res. 66, 33–40.

Figueiredo, C.C., Giani, A., 2005. Ecological interactions between Nile tilapia (*Oreochromis niloticus*, L.) and the phytoplanktonic community of the Furnas Reservoir (Brazil). Freshw. Biol. 50, 1391–1403.

Fitzgerald, D.B., Tobler, M., Winemiller, K.O., 2016. From richer to poorer: successful invasion by freshwater fishes depends on species richness of donor and recipient basins. Glob. Chang. Biol. 22, 2440–2450.

Franco, A.C.S., Santos, L.N., Petry, A.C., García-Berthou, E., 2018. Abundance of invasive peacock bass increases with water residence time of reservoirs in southeastern Brazil. Hydrobiologia 817, 155–166.

Freire, K.M.F., Tubino, R.A., Monteiro-Neto, C., Andrade-Tubino, M.F., Belruss, C.G., Tomás, A.R.G., Tutui, S.L.S., Castro, P.M.G., Maruyama, L.S., Catella, A.C., Crepaldi, D.V., Daniel, C.R.A., Machado, M.L., Mendonça, J.T., Moro, P.S., Motta, F.S., Ramires, M., Silva, M.H.C., Vieira, J.P., 2016. Brazilian recreational fisheries: current status, challenges and future direction. Fish. Manag. Ecol. 23, 276–290.

Friedman, J.H., 2001. Greedy function approximation: a gradient boosting machine. Ann. Stat. 29, 1189–1232.

Fugi, R., Luz-Agostinho, K.D.G., Agostinho, A.A., 2008. Trophic interaction between an introduced (peacock bass) and a native (dogfish) piscivorous fish in a Neotropical impounded river. Hydrobiologia 607, 143–150.

Garcia, D.A.Z., Costa, A.D.A., Leme, G.L.A., Orsi, M.L., 2014. Biology of black bass *Micropterus salmoides* Lacepède, 1802 fifty years after the introduction in a small drainage of the Upper Paraná River basin, Brazil. Biodiversitas 15, 180–185.

Golani, D., Sonin, O., Snovsky, G., David, L., Tadmor-Levi, R., 2019. The occurrence of the peacock bass (*Cichla kelberi* Kullander and Ferreira, 2006)in Lake Kinneret (Sea of Galilee), Israel. BioInvasions Records 8, 706–711.

Guerrero, R.D., 2014. Impacts of introduced freshwater fishes in the Philippines 1905–2013: a review and recommendations. Philipp. J. Sci. 143, 49–59.

Havel, J.E., Lee, C.E., Vander Zanden, M.J., 2005. Do reservoirs facilitate invasions into landscapes? Bioscience 55, 515–525.

Hawkes, C.V., 2007. Are invaders moving targets? The generality and persistence of advantages in size, reproduction, and enemy release in invasive plant species with time since introduction. Am. Nat. 170, 832–843.

Hickley, P., Muchiri, M., Britton, R., Boar, R., 2008. Economic gain versus ecological damage from the introduction of non-native freshwater fish: case studies from Kenya. The Open Fish Science Journal 1, 36–46.

Hothorn, T., Bühlmann, P., Dudoit, S., Molinaro, A., Van Der Laan, M.J., 2006. Survival ensembles. Biostatistics 7, 355–373.

Howeth, J.G., Gantz, C.A., Angermeier, P.L., Frimpong, E.A., Hoff, M.H., Keller, R.P., Mandrak, N.E., Marchetti, M.P., Olden, J.D., Romagosa, C.M., Lodge, D.M., 2015. Predicting invasiveness of species in trade: climate match, trophic guild and fecundity influence establishment and impact of non-native freshwater fishes. Divers. Distrib. 22, 1–13.

Ilhéu, M., Matono, P., Bernardo, J.M., 2014. Invasibility of mediterranean-climate rivers by non-native fish: the importance of environmental drivers and human pressures. PLoS One 9, e109694.

Kolar, C.S., Lodge, D.M., 2001. Progress in invasion biology: predicting invaders. Trends Ecol. Evol. 16, 199–204.

Kullander, S.O., Ferreira, E.J.G., 2006. A review of the South American cichlid genus *Cichla*, with descriptions of nine new species Teleostei: Cichlidae. Ichthyological Exploration of Freshwater 17, 289–398.

Latini, A.O., Petrere, M., 2004. Reduction of a native fish fauna by allien species: an example from Brazilian freshwater tropical lakes. Fish. Manag. Ecol. 11, 71–79.

Legendre, P., Gallagher, E.D., 2001. Ecologically meaningful transformations for ordination of species data. Oecologia 129, 271–280.

Lévêque, C., Oberdorff, T., Paugy, D., Stiassny, M.L.J., Tedesco, P.A., 2008. Global diversity of fish Pisces in freshwater. Hydrobiologia 595, 545–567.

Liaw, A., Wiener, M., 2002. Classification and regression by randomforest. R News 2, 18–22.

Liew, J.H., Tan, H.H., Yeo, D.C.J., 2016. Dammed rivers: impoundments facilitate fish invasions. Freshw. Biol. 61, 1421–1429.

Lodge, D.M., Stein, R.A., Brown, K.M., Covich, A.P., Brönmark, C., Garvey, J.E., Klosiewski, S.P., 1998. Predicting impact of freshwater exotic species on native biodiversity: challenges in spatial scaling. Aust. J. Ecol. 23, 53–67.

Magellan, K., García-Berthou, E., 2015. Influences of size and sex on invasive species aggression and native species vulnerability: a case for modern regression techniques. Rev. Fish Biol. Fish. 25, 537–549.

Marques, A.C.P.B., Franco, A.C.S., Salgueiro, F., García-Berthou, E., Santos, L.N., 2016. Genetic divergence among invasive and native populations of the yellow peacock cichlid *Cichla kelberi*. J. Fish Biol. 89, 2595–2606.

Menezes, R.F., Attayde, J.L., Lacerot, G., Kosten, S., Souza, L.C., Costa, L.S., ... Jeppesen, E., 2012. Lower biodiversity of native fish but only marginally altered plankton biomass in tropical lakes hosting introduced piscivorous Cichla cf. ocellaris. Biol. Invasions 14, 1353–1363.

Oksanen, J., Blanchet, F.G., Friendly, M., Kindt, R., Legendre, P., McGlinn, D., ... Wagner, H., 2016. vegan: Community Ecology Package. R package version 2.4-1. https://CRAN.R-project.org/package=vegan.

Parker, I.M., Simberloff, D., Lonsdale, W.M., Goodell, K., Wonham, M., Kareiva, P., ... Goldwasser, L., 1999. Impact: toward a framework for understanding the ecological effects of invaders. Biol. Invasions 1, 3–19.

Pelicice, F.M., Agostinho, A.A., 2009. Fish fauna destruction after the introduction of a non-native predator *Cichla kelberi* in a Neotropical reservoir. Biol. Invasion 11, 1789–1801.

Pelicice, F.M., Latini, J.D., Agostinho, A.A., 2015. Fish fauna disassembly after the introduction of a voracious predator: main drivers and the role of the invader's demography. Hydrobiologia 746, 271–283.

Pereira, F.W., Vitule, J.R.S., 2019. The largemouth bass *Micropterus salmoides* (Lacepède, 1802): impacts of a powerful freshwater fish predator outside of its native range. Rev. Fish Biol. Fish. 29, 639–652.

Pereira, L.S., Agostinho, A.A., Gomes, L.C., 2015. Eating the competitor: a mechanism of invasion. Hydrobiologia 746, 223–231.

Pinto-Coelho, R.M., Bezerra-Neto, J.F., Miranda, F., Mota, T.G., Resck, R., Santos, A.M., ... Barbosa, F.A.R., 2008. The inverted trophic cascade in tropical plankton communities: impacts of exotic fish in the Middle Rio Doce lake district, Minas Gerais, Brazil. Braz. J. Biol. 68, 1025–1037.

Pompeu, P.S., Godinho, A.L., 2001. Mudança na dieta da traíra *Hoplias malabaricus* Bloch Erythrinidae, Characiformes em lagoas da bacia do rio Doce devido à introdução de peixes piscívoros. Rev. Bras. Zool. 18, 1219–1225.

Prasad, A.M., Iverson, L.R., Liaw, A., 2006. Newer classification and regression tree techniques: bagging and random forests for ecological prediction. Ecosystems 9, 181–199.

Pyšek, P., Jarošík, V., 2005. Residence time determines the distribution of alien plants. In: Inderjit (Ed.), Invasive Plants: Ecological and Agricultural Aspects. Birkhäuser Basel, pp. 77–96.

R Core Team, 2016. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria http://www.r-project.org/.

Rahim, K.A.A., Esa, Y., Arshad, A., 2013. The influence of alien fish species on native fish community structure in Malaysian waters. Kuroshio Science 7, 81–93.

Reis, R.E., Kullander, S.O., Ferraris Jr., C.J., 2003. Checklist of the Freshwater Fishes of South and Central América. EDIPUCRS, Porto Alegre.

Ricciardi, A., Avlijas, S., Marty, J., 2012. Forecasting the ecological impacts of the *Hemimysis anomala* invasion in North America: lessons from other freshwater mysid introductions. J. Great Lakes Res. 38, 7–13.

Ripley, B., Venables, B., Bates, D.M., Hornik, K., Gebhardt, A., Firth, D., 2017. Package 'MASS'. R package version 7.3-47. https://cran.r-project.org/web/packages/MASS/MASS.pdf.

Salo, P., Korpimäki, E., Banks, P.B., Nordström, M., Dickman, C.R., 2007. Alien predators are more dangerous than native predators to prey populations. Proc. R. Soc. B 274, 1237–1243.

Santos, L.N., Gonzales, A.F., Araújo, F.G., 2001. Dieta do tucunaré-amarelo *Cichla monoculus* Bloch and Schneider Osteichthyes, Cichlidae, no reservatório de Lajes, Rio de Janeiro, Brasil. Rev. Bras. Zool. 18, 191–204.

Shafland, P.L., 1996. Reviews in fisheries science exotic fishes of Florida — 1994. Reviews in Fish Science 4, 101–122.

Sharpe, D.M.T., De León, L.F., González, R., Torchin, M.E., 2017. Tropical fish community does not recover 45 years after predator introduction. Ecology 98, 412–424.

Simberloff, D., 2009. The role of propagule pressure in biological invasions. Annu. Rev. Ecol. Evol. Syst. 40, 81–102.

Strobl, C., Boulesteix, A.L., Zeileis, A., Hothorn, T., 2007. Bias in random forest variable importance measures: illustrations, sources and a solution. BMC Bioinformatics 8, 25.

Strobl, C., Boulesteix, A.L., Kneib, T., Augustin, T., Zeileis, A., 2008. Conditional variable importance for random forests. BMC Bioinformatics 9, 307.

Strobl, C., Hothorn, T., Zeileis, A., 2009. Party on! A new, conditional variable-importance measure for random forests available in the party package. The R Journal ½, 14–17.

Tedesco, P.A., Oberdorff, T., Lasso, C.A., Zapata, M., Hugueny, B., 2005. Evidence of history in explaining diversity patterns in tropical riverine fish. J. Biogeogr. 32, 1899–1907.

Tollefson, J., 2011. A struggle for power. Nature 479, 160–161.

Tuulaikhuu, B.-A., Guasch, H., García-Berthou, E., 2017. Examining predictors of chemical toxicity in freshwater fish using the Random Forest technique. Environ. Sci. Pollut. Res. 24, 10172–10181.

van Kleunen, M., Dawson, W., Schlaepfer, D., Jeschke, J.M., Fischer, M., 2010. Are invaders different? A conceptual framework of comparative approaches for assessing determinants of invasiveness. Ecol. Lett. 13, 947–958.

Williamson, M., Dehnen-Schmutz, K., Kühn, I., Hill, M., Klotz, S., Milbau, A., Stout, J., Pyšek, P., 2009. The distribution of range sizes of native and alien plants in four European countries and the effects of residence time. Divers. Distrib. 15, 158–166.

Willis, S.C., Macrander, J., Farias, I.P., Ortí, G., 2012. Simultaneous delimitation of species and quantification of interspecific hybridization in Amazonian peacock cichlids genus *Cichla* using multi-locus data. BMC Evol. Biol. 12, 96.

Winemiller, K.O., 2001. Ecology of peacock cichlids *Cichla* spp. in Venezuela. J. Aquaric. Aquat. Sci. 9, 93–112.

Yeo, D.C.J., Chia, C.S.W., 2010. Introduced species in Singapore: an overview. Cosmos 6, 23–37.

Zaret, T.M., Paine, R.T., 1973. Species introduction in a tropical lake. Science 182, 449–455.

Zarfl, C., Lumsdom, A.E., Berlekamp, J., Tydecks, L., Tockner, K., 2015. A global boom in hydropower dam construction. Aquat. Sci. 77, 161–170.

Ecological impacts of an invasive top predator fish across South America

Ana Clara Sampaio Franco[a,*], Emili García-Berthou[a,b] , Luciano Neves dos Santos [a]

[a] *Graduate Course in Neotropical Biodiversity, Federal University of Rio de Janeiro State, Av. Pasteur, 458 – R506A, 22290-240 Rio de Janeiro, RJ, Brazil*
[b] *GRECO, Institute of Aquatic Ecology, University of Girona, 17003 Girona, Catalonia, Spain*

* Corresponding author. E-mail: anaclara306@gmail.com

Table S1. Location and features of the study sites compiled and analysed where *Cichla ocellaris* has been recorded.

Study site	Latitude	Longitude	Hydrographic region	Ecosystem type	Native status or introduction year	References
Anavilhanas	2° 32' S	60° 47' W	Amazon	lake	native	Petry et al. (2003); Yamamoto et al. (2014)
Araçá	3° 19' 54" S	58°18' 25" W	Amazon	lake	native	Santos (2013); Soares et al. (2014)
Araguaia	13° 15' S	50° 35' W	Tocantins-Araguaia	river	native	Tejerina-Garro et al. (1998)
Cana Brava	13° 24' S	48° 9' W	Tocantins-Araguaia	reservoir	native	Buchmann (2014); Silva et al. (2007)
Capim Branco	18° 47' 22" S	48° 8’ 36” W	Paraná	reservoir	2006	Pizetta (2007); Rêgo (2008)
Capivara	22° 40’ 44” S	51° 19’ 55” W	Paraná	reservoir	1997	Bennemann et al. (2011); Marcucci et al. (2005); Naliato (2009)
Chavantes	23° 07’ 50” S	49° 42’ 4” W	Paraná	reservoir	1995	Ayroza (2012); Magnoni (2009); Nobile (2010)
Coaracy Nunes	0° 54' 12" N	51° 16' 16" W	Amazon	reservoir	native	Oliveira (2012); Sá-Oliveira et al. (2015)
Curuá-Una	2º 54' S	54º 27' W	Amazon	river	native	Junk et al. (1981); Vieira (2000)
Cuyuní	6° 23' 18" N	58° 41' 39" W	Essequibo	river	native	Machado-Allison et al. (2000); Pisapia et al. (2013)
Edson Queiroz	4° 13′ 27″ S	40° 2′ 08″ W	NE Atlantic	reservoir	1987	Batista et al. (2014); Gurgel-Lourenço et al. (2015)
Gramame	7° 17' 49" S	34° 57' 37" W	NE Atlantic	reservoir	1990	Barbosa (2012); Souza (2013)
Grande	20° 36' 9" S	46° 35' 27" W	Paraná	river	1990	Castro et al. (2004); Rolla et al. (1992); Vono et al. (1997)
Guariba	8° 13' S	60° 28' W	Amazon	river	native	Pedroza et al. (2012)

Ilha das Onças	1º 26' S	48º 34' W	Amazon	river	native	Silva (2006); Torres (2010)
Ilha dos Pombos	21° 50' 40" S	42° 34' 43" W	SE Atlantic	reservoir	2000	Araújo & Rocha (2012); Uehara et al. (2015)
Ilha Solteira	19° 19' 2" S	51° 04' 34" W	Paraná	reservoir	1990	Mello (2012); Pagotto & Souza (2006); Vasilio (2006)
Ipixuna-Maici	6° 09' 52" S	61° 46' 4" W	Amazon	river	native	Anjos (2009)
Itaipu	25° 24' 20" S	54° 35' 10" W	Paraná	reservoir	1985	Abes et al. (2001); Baumgartner et al. (2008); Mello (2012); Oliveira et al. (2005); Ribeiro-Filho et al. (2011)
Jacaré-Guaçu	21° 41' 14" S	49° 12' 20" W	Paraná	river	1998	Esguícero & Arcifa (2011); Rodríguez (2001)
Lago Batata	1° 31' 46" S	56° 16' 0" W	Amazon	lake	native	Cardoso (2009); Soares (2015)
Lago Jacaré	2° 19' S	56º 31' W	Amazon	lake	native	Freitas & Garcez (2004); Sousa & Freitas (2008)
Lago Tupé	4° 53' 36" S	64° 0' 22" W	Amazon	lake	native	Soares & Yamamoto (2005); Trevisan & Forsberg (2007)
Lagos do rio Solimões	3° 51' 33" S	62° 35' 8" W	Amazon	lake	native	Freitas et al. (2014); Prado et al. (2009); Trevisan & Forsberg (2007)
Lajes	22° 45' 35" S	43° 55' 24" W	SE Atlantic	reservoir	1945	Araújo & Rocha (2012); Santos et al. (2011); Soares et al. (2008); Uehara et al. (2015)
Madeira	6° 44' 58" S	62° 22' 10" W	Amazon	river	native	Couto (2009); Torrente-Vilara et al (2011)
Mamoré	14° 36' 0” S	65° 0' 16” W	Amazon	river	native	Couto (2009); Pouilly et al (2014)
Marechal Dutra	6° 25' 15" S	36° 36' 1" W	NE Atlantic	reservoir	1965	Duarte (2011); Nascimento et al. (2011)
Nanay	3º 48' S	73º 23' W	Amazon	river	native	Correa & Ortega (2010);

						Lindgren & Röttorp (2009)
Negro	2° 03' S	60° 24' W	Amazon	river	native	Goulding et al. (1988); Trevisan & Forsberg (2007)
Pandeiros	15° 39' 54" S	44° 38' 7" W	São Francisco	river	1982	Mascarenhas et al. (2013); Rezende et al. (2012; 2016); Santos et al. (2015); Souza (2016)
Paraíba do Sul	22º 30' 31" S	44º 13' 2" W	SE Atlantic	river	1982	Araújo et al. (2001); Silva (2001)
Paraná	22° 46' 13" S	53° 18' 10" W	Paraná	river	1992	Mello (2012); Baumgartner et al. (2008); Petry (2001)
Pardo	20° 9' 42" S	48° 37' 37" W	Paraná	river	1990	Castagnolli (2008); Meletti et al. (2003); Meschiatti et al. (2000)
Paulo Sarasate	4° 14′ 3″ S	40° 27′ 40″ W	NE Atlantic	reservoir	1964	Batista et al. (2014); Gurgel-Lourenço et al. (2015)
Pereira Passos	22° 41' 1" S	43° 49' 26" W	SE Atlantic	reservoir	1970	Araújo & Rocha (2012); Uehara et al. (2015)
Purus	7° 23' S	65° 11' W	Amazon	river	native	Duarte (2008); Silva et al. (2010)
Ribeirão Diamante	22° 37' 21" S	52° 50' 59" W	Paraná	river	2004	Fonseca et al. (2009); Granado et al. (2009); Morales et al. (2009)
Rio das Mortes (MT)	12° 32' 45" S	50° 56' 19" W	Tocantins-Araguaia	river	native	Melo (2006); Melo et al. (2007; 2009); Lima (2009)
Rios do Semi-árido	6° 18' 22" S	37° 10' 44" W	São Francisco	river	1971	Carvalho et al. (2013); Dias (2006); Gurgel & Fernando (1994); Medeiros et al. (2010); Silva (2012)
Rosana	22° 36’ S	52° 52’ W	Paraná	reservoir	2004	Bagatini et al. (2007); Feitosa (2007); Fonseca et al. (2009); Mello (2012); Pelicice (2007)
Rupununi	3° N	59° 45' W	Essequibo	river	native	Lowe-McConnell (1964)
Santa Cruz do Apodi	5° 46' 1" S	37° 47' 59" W	NE Atlantic	reservoir	2002	Novaes et al. (2014); Segundo

						(2013); Silva (2013)
Salto Grande	22° 54’ 13” S	49° 59’ 0” W	Paraná	reservoir	1995	Brandão (2007); Brandão et al. (2009); Carmo (2000); Dornfeld (2002); Mello (2012)
Samuel	8º 51' 6" S	63º 21' 26" W	Amazon	reservoir	native	Nascimento et al. (2009); Silva (2007); Viana (2002)
Santa Branca	23° 20' 7" S	45° 47' 56" W	SE Atlantic	reservoir	1980	Araújo & Rocha (2012); Uehara et al. (2015)
São Francisco	11° 6' 55" S	43° 11' 40" W	São Francisco	river	1982	Luz et al. (2009; 2012); Mascarenhas et al. (2013); Medeiros et al. (2007); Normando et al. (2014)
Saracá-Araticum	1° 37' S	56° 29' W	Amazon	river	native	Cardoso (2009); Reis (2011)
Serra da Mesa	14° 5′ 42″ S	48° 17′ 23″ W	Tocantins-Araguaia	reservoir	native	Mazzoni et al. (2012); Silva et al. (2014)
Tapajós	2° 46' 20" S	55° 5' 36" W	Amazon	river	native	Galvão-Miranda et al. (2009); Keppeler (2015)
Três Irmãos	20° 39' 36" S	51° 17' 38" W	Paraná	reservoir	1985	Barrella & Petrere (2003); Granado et al. (2009); Liliamtis (2007); Mello (2012)
Três Marias	18° 12' 56" S	45° 15' 55" W	São Francisco	reservoir	1982	Brito (2010); Brito et al. (2013); Prado & Pompeu (2014)
Trombetas	7° 24' S	72° 25' W	Amazon	river	native	Cardoso (2009); Ferreira (1993); Ropke et al. (2014)
Tucuruí	3° 50' 3" S	49° 38' 53" W	Tocantins-Araguaia	reservoir	native	Botelho (2007); Mérona et al. (2001)
UHE Curuá-Una	2° 49' 2" S	54° 18' 4" W	Amazon	reservoir	native	Gunkel et al. (2003); Junk et al. (1981); Vieira (2000)
UHE Miranda	18° 54' 29" S	48° 01' 2" W	Paraná	reservoir	2005	Callisto et al. (2002); Flauzino (2014); Garcia (2005)

UHE Pedra	13° 52' 5" S	40° 14' 15" W	E Atlantic	reservoir	1989	Calado-Neto (2007); Severi et al. (2010)
UHE São Simão	19° 0' 59" S	50° 29' 1" W	Paraná	reservoir	1997	Mello (2012); Neves et al. (2006)
Urucu	4º 10' S	63º 32' W	Amazon	river	native	Costa & Freitas (2010; 2013; 2014); Trevisan & Forsberg (2007)
Verde	20° 4' 5" S	53° 10' 41" W	Paraná	river	1987	Almeida & Coelho (2014); Pesoa & Cardoso (2015)
Vigário	22° 37' 56" S	43° 53' 36" W	SE Atlantic	reservoir	1960	Araújo & Rocha (2012); Gomes et al. (2008); Uehara et al. (2015)
Yurimáguas	4º 56' S	74º 21' W	Amazon	river	native	Lindgren & Röttorp (2009); Ortega et al. (2007)

Table S2. Limnological features and observed fish species richness of the study sites compiled and analysed. See Table S1 for location of the sites.

System	Altitude (m)	Precipitation (mm)	Maximum depth (m)	Minimum water temperature (°C)	Mean water temperature (°C)	pH	Conductivity (µS/cm)	Dissolved oxygen (mg/L)	Transparency (m)	Total phosphorus concentration (mg/L)	Observed fish species richness
Anavilhanas	13	1750	27.6	26.2	29.0	4.2	15.6	3.9	0.8	0.034	95
Araçá	12	2033	9.8	26.9	30.7	6.7	61.5	3.6	0.5	0.168	26
Araguaia	220	1869	6.6	27.0	28.5	6.9	45.5	3.4	0.6	0.113	90
Cana Brava	289	1421	3.5	23.9	27.6	7.5	94.1	5.9	3.8	0.017	93
Capim Branco	597	1566	52.0	22.9	23.0	6.0	30.7	6.4	4.0	0.009	29
Capivara	325	1256	50.0	20.6	24.2	6.3	78.9	7.6	1.5	0.029	33
Chavantes	474	1357	67.0	20.9	23.2	7.3	52.7	7.0	2.9	0.039	35
Coaracy Nunes	45	2500	30.0	26.5	27.7	6.1	20.5	5.2	1.2	0.140	41
Curuá-Una	29	1772	18.0	27.4	28.0	5.9	21.4	6.3	1.9	0.033	59
Cuyuní	1	1650	7.0	23.0	24.0	5.5	27.7	4.4	0.5	0.006	88
Edson Queiroz	193	855	24.0	26.3	27.9	8.0	259.5	3.7	1.0	0.456	13
Gramame	375	1514	35.0	26.0	27.9	6.9	93.4	6.6	4.8	0.250	29
Grande	660	1524	1.15	21.7	25.2	7.4	45.0	7.7	0.8	0.021	35
Guariba	81	2550	5.95	27.1	29.2	5.7	6.7	4.0	1.5	0.035	139
Ilha das Onças	1	2532	17.0	23.5	28.2	6.0	46.1	6.2	0.2	0.015	34
Ilha dos	132	1265	32.0	25.2	25.3	7.6	59.0	8.8	0.1	0.075	20

Pombos										
Ilha Solteira	300	1316	10.0	28.0	29.8	6.3	80.0	5.3	3.0	0.053	32
Ipixuna-Maici	27	2525	0.75	28.0	29.1	6.0	23.0	3.4	0.7	0.052	36
Itaipu	253	1728	220.0	21.9	29.5	7.4	53.0	7.6	1.2	0.031	85
Jacaré-Guaçu	377	1491	1.7	19.9	24.4	6.7	66.6	7.1	0.5	0.255	79
Lago Batata	1	2300	9.5	28.5	29.7	6.1	10.5	5.9	1.6	0.222	157
Lago Jacaré	5	2748	9.5	27.0	30.2	6.6	93.5	2.3	1.1	0.027	45
Lago Tupé	45	2290	13.5	27.0	29.0	4.6	15.9	4.5	1.2	0.168	50
Lagos do rio Solimões	31	2290	10.5	28.2	29.2	6.6	67.0	2.5	0.9	0.168	115
Lajes	423	1362	50.0	24.2	29.1	7.3	33.0	8.0	2.5	0.015	14
Madeira	29	2200	25.0	20.9	25.2	5.9	14.6	5.2	0.7	0.018	170
Mamoré	158	1557	17.0	28.4	29.4	6.7	126.5	4.9	0.4	0.040	139
Marechal Dutra	297	521	25.0	25.0	27.0	8.6	439.5	7.5	0.9	0.254	22
Nanay	88	2857	1.5	28.5	28.9	6.8	7.0	3.8	0.1	0.003	35
Negro	11	2154	10.0	28.6	29.8	4.3	8.6	5.2	1.1	0.027	297
Pandeiros	456	1060	1.2	19.8	24.1	7.3	81.0	4.4	0.8	0.033	22
Paraíba do Sul	384	2250	12.0	20.3	22.8	6.6	13.0	5.8	0.9	0.080	20
Paraná	238	1280	13.0	17.9	23.1	6.8	45.5	6.6	1.3	0.043	34
Pardo	438	1550	5.0	18.0	20.2	6.4	77.0	7.7	0.8	0.029	23
Paulo Sarasate	147	926	34.0	27.6	28.5	7.8	223.5	5.6	1.0	0.166	13

Pereira Passos	91	1454	18.6	24.6	24.9	5.8	108.0	7.5	0.4	0.075	16
Purus	59	2227	9.4	29.3	32.7	6.5	67.8	5.6	0.2	0.098	83
Ribeirão Diamante	252	1300	3.0	20.4	21.3	7.2	46.7	8.0	3.0	0.014	36
Rio das Mortes (MT)	201	1500	39.7	24.4	27.4	6.2	10.4	4.7	0.8	0.137	104
Rios do Semi-árido	118	600	3.0	29.3	30.7	8.0	370.0	3.7	1.3	0.049	34
Rosana	256	1125	25.0	20.5	24.8	6.7	69.3	8.1	1.8	0.030	41
Rupununi	99	1780	8.0	26.0	30.5	6.1	30.8	4.4	0.6	0.006	61
Santa Cruz do Apodi	60	767	57.5	25.0	28.3	8.0	281.7	6.2	4.0	0.034	20
Salto Grande	385	1365	19.8	17.7	20.9	6.6	120.4	4.7	0.5	0.216	30
Samuel	87	2194	87.4	21.0	32.0	6.5	29.7	7.1	2.9	0.013	110
Santa Branca	621	1301	45.0	24.3	28.3	7.5	38.0	7.9	2.1	0.017	18
São Francisco	402	1000	3.5	22.5	23.7	5.9	66.8	7.0	1.5	0.100	61
Saracá-Araticum	173	2000	1.55	28.7	26.0	4.9	11.5	5.8	1.4	0.042	113
Serra da Mesa	474	1638	154.0	24.0	26.0	8.0	100.0	10.0	3.0	0.012	51
Tapajós	6	2460	7.7	29.6	29.7	7.4	45.1	5.8	1.2	0.009	29
Três Irmãos	321	1199	60.0	20.0	25.2	7.6	153.8	7.4	1.3	0.039	13
Três Marias	567	1214	75.0	22.5	24.9	8.2	55.6	6.1	2.7	0.004	29

Trombetas	169	2431	11.0	24.2	29.5	5.7	27.3	7.5	1.5	0.010	143
Tucuruí	70	1600	75.0	29.2	30.3	6.9	55.5	7.0	1.1	0.060	61
UHE Curuá-Una	28	2096	17.0	26.5	27.7	5.3	17.5	7.9	1.8	0.016	30
UHE Miranda	700	1479	80.0	23.0	24.0	7.2	12.3	5.0	4.8	0.040	24
UHE Pedra	228	703	41.0	27.7	30.0	8.5	268.5	6.3	2.6	0.132	14
UHE São Simão	398	1474	127.0	27.14	28.0	7.4	46.4	6.0	2.0	0.015	16
Urucu	16	2290	14.5	27.3	28.3	5.4	44.5	1.9	0.7	0.168	33
Verde	330	1370	3.5	26.8	28.0	7.7	23.3	7.5	0.8	0.039	60
Vigário	418	1362	20.0	24.6	24.6	7.1	83.0	7.0	0.4	0.040	17
Yurimáguas	117	1188	5.0	22.5	27.1	7.3	140.0	5.0	0.3	0.003	52

Fig. S1. Beanplots of the year of the introduction of peacock bass in each hydrographic region. A beanplot is a one-dimensional scatter plot which shows the individual observations as small vertical lines, the estimated density next to that and an average line for the distribution (Kampstra, 2008). The dotted line represents the average for the whole plot.

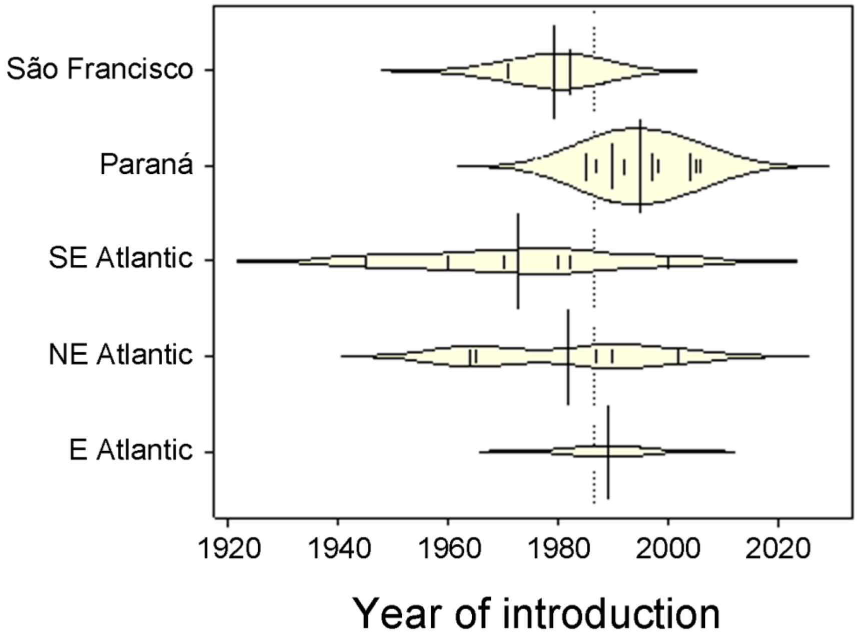
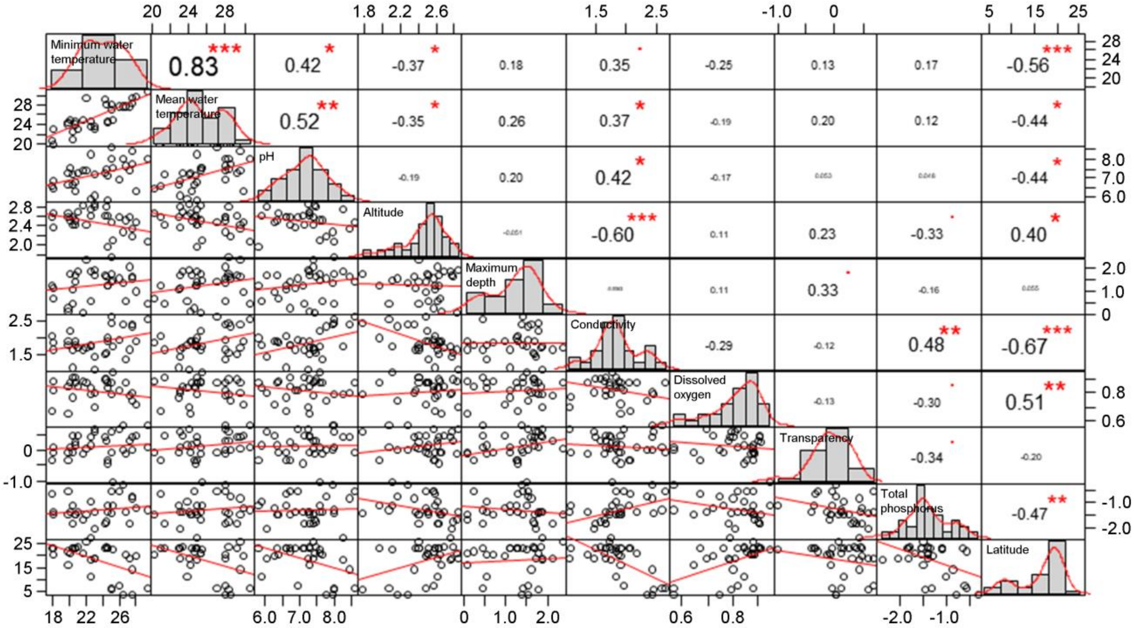


Fig. S2. Pairwise relationships of selected features of the study sites: minimum and mean water temperature, pH, altitude, maximum depth, conductivity, dissolved oxygen, transparency, total phosphorus concentration and absolute latitude. The histogram and density function of each variable is given in the diagonal, the bivariate scatterplots with the regression line below the diagonal and the Pearson correlation value with the significance level above the diagonal (*, $P < 0.05$; **, $P < 0.01$, ***, $P < 0.001$)



References

Abes, S.S., Agostinho, A.A., Okada, E.K., and Gomes, L.C. (2001). Diet of *Iheringichthys labrosus* (Pimelodidae, Siluriformes) in the Itaipu Reservoir, Paraná River, Brazil-Paraguay. Brazilian Archives of Biology and Technology 44: 101-105.

Almeida, C.C.V, and Coelho, W.M. (2014). Monitoramento da qualidade das águas superficiais e das comunidades aquáticas na Usina Hidrelétrica São Domingos / MS - relatório técnico conclusivo. Technical report.

Anjos, M.R. (2009). Distribuição e diversidade da fauna de peixes nas sub-bacias do Maici e Ipixuna médio Madeira - AM/Brasil. Master’s Thesis, Universidade Federal de Rondônia.

Araújo, F.G., Fichberg, I., Pinto, B.C.T., and Peixoto, M.G. (2001). Variações espaciais na assembléia de peixes no rio Paraíba do Sul (Barra Mansa, Barra do Piraí), Rio de Janeiro, Brasil. Revista Brasileira de Zoologia 18: 483-492.

Araújo, FG., and Rocha, R. (2012). Composição e riqueza da ictiofauna e relações com variáveis ambientais em sete reservatórios da Light. In Bacia Hidrográfica dos Rios Guandu, da Guarda e Guandu-Mirim Experiências para a gestão dos recursos hídricos Pages 117-136 (Ed.) Tubbs-Filho, D., Antunes, J.C.O., and Vettorazzi, J.S., Rio de Janeiro: INEA, Instituto Estadual do Meio Ambiente.

Ayroza, D.M.M.R. (2012). Características limnológicas em área sob influência de piscicultura em tanques-rede no reservatório da UHE Chavantes, rio Paranapanema, SE/S, Brasil. PhD Thesis, Universidade Estadual Paulista.

Bagatini, Y.M., Benedito-Cecilio, E., and Higuti, J. (2007). Caloric variability of *Corbicula fluminea* (Mollusca, Bivalvia) in Rosana reservoir, Brazil. Brazilian Archives of Biology and Technology 50: 85-90.

Barbosa, E.A. (2012). Macrófitas aquáticas em um reservatório da grande João Pessoa, Paraíba - Brasil. Monograph, Universidade Estadual da Paraíba.

Barrella, W., and Petrere, M.Jr. (2003). Fish community alterations due to pollution and damming in Tietê and Paranapanema rivers (Brazil). River Research and Applications 19: 59-76.

Batista, A.A., Meireles, A.C.M., Andrade, E.M., Izidio, N.S.C., and Lopes, F.B. (2014). Sazonalidade e variação espacial do índice de estado trófico do açude Orós, Ceará, Brasil. Revista Agroambiente 8: 39-48.

Baumgartner, G., Nakatani, K., Gomes, L.C., Bialetzki, A., Sanches, P.V., and Makrakis, M.C. (2008). Fish larvae from the upper Paraná River: do abiotic factors affect larval density? Neotropical Ichthyology 6: 551-558.

Bennemann, S.T., Galves, W., and Capra, L.G. (2011). Recursos alimentares utilizados pelos peixes e estrutura trófica de quatro trechos no reservatório Capivara (Rio Paranapanema). Biota Neotropica 11: 63-71.

Botelho, M.C. (2007). A pesca comercial dos “tucunarés” *Cichla* spp. (Perciformes, Cichlidae) no reservatório da UHE-Tucuruí, rio Tocantins, PA. Master’s Thesis, Museu Paraense Emilio Goeldi.

Brandão, H. (2007). A ictiofauna da represa de salto grande (Médio Rio Paranapanema – SP/PR): composição, estrutura e atributos ecológicos. Master’s Thesis, Universidade Estadual Paulista.

Brandão, H., Vidotto-Magnoni, A.P., Ramos, I.P., and Carvalho, E.D. (2009). Assessment of the ichthyofauna in stretches under the influence of Salto Grande Reservoir (Middle Paranapanema River, SP/PR, Brazil). Acta Limnologica Brasiliensia 21: 451-463.

Brito, S.L. (2010). Caracterização limnológica e produtividade secundária das principais espécies de microcrustáceos em dois braços dos reservatórios de Três Marias e Furnas, Minas Gerais, Brasil. PhD Thesis, Universidade Federal de Minas Gerais.

Brito, S.L., Maia-Barbosa, P.M., and Pinto-Coelho, R.M. (2013). Length-weight relationships and biomass of the main microcrustacean species of two large tropical reservoirs in Brazil. Brazilian Journal of Biology 73: 593-604.

Buchmann, F.F. (2014). Malacofauna límnica do reservatório da Usina Hidrelétrica de Cana Brava – GO, com ênfase em *Biomphalaria straminea* (Dunker, 1848), transmissora natural da esquistossomose. Master's Thesis, Instituto Oswaldo Cruz.

Calado-Neto, A.V. (2007). Características limnológicas e dimensionamento da capacidade ambiental de aproveitamento do reservatório de Pedra - BA para implantação de piscicultura de tanques-rede. Master's Thesis, Universidade Federal Rural de Pernambuco.

Callisto, M., Vono, V., Barbosa, F.A.R., and Santeiro, S.M. (2002). Chironomidae as a food resource for *Leporinus amblyrhynchus* (Teleostei: Characiformes) and *Pimelodus maculatus* (Teleostei:Siluriformes) in a Brazilian reservoir. Lundiana 3: 67-73.

Cardoso, S.J. (2009). Influência da morfometria de lagos na diversidade fitoplanctônica. Master's Thesis, Universidade Federal de Juiz de Fora.

Carmo, D.F. (2000). Avaliação da presença de clorofenóis no reservatório de Salto Grande, situado na região de Americana, estado de São Paulo. Master's Thesis, Universidade de São Paulo.

Carvalho, L.K., Farias, R.L., and Medeiros, E.S.F. (2013). Benthic invertebrates and the habitat structure in an intermittent river of the semi-arid region of Brazil. Neotropical Biology and Conservation 8: 57-67.

Castagnolli, M.C. (2008). Ictiofauna nos trechos médio e baixo rio Pardo, Alto Paraná. Master’s Thesis, Universidade Estadual Paulista.

Castro, R.M.C., Casatti, L., Santos, H.F., Melo, A.L.A., Martins, L.S.F., Ferreira, K.M., ... and Langeani, F. (2004). Estrutura e composição da ictiofauna de riachos da bacia do rio Grande no estado de São Paulo, sudeste do Brasil. Biota Neotropica, 4, 1-38.

Correa, O., and Ortega, H. (2010). Diversidad y variación estacional de peces en la cuenca baja del río Nanay, Perú. Revista Peruana de Biología, 17, 37-42.

Costa, D.I., and Freitas, E.C. (2010). Variação nictemeral na composição e abundância da ictiofauna em um trecho do rio Urucu - Coari/Amazon/Brasil. Revista Colombiana de Ciencia Animal, 2, 355-364.

Costa, D.I., and Freitas, E.C. (2013). Trophic ecology of the ichthyofauna of a stretch of the Urucu River (Coari, Amazon, Brazil). Acta Limnologica Brasiliensia, 25, 54-67.

Costa, D.I., and Freitas, E.C. (2014). Assembléias de peixes do rio Urucu, Amazon, Brasil. Novas Edições Acadêmicas.

Couto, J.M. (2009). Programa de monitoramento limnológico da UHE Jirau. Technical report.

Dias, J.B. (2006). Impactos sócio-econômicos e ambientais da introdução da tilápia do Nilo, Oreochromis niloticus, em açudes públicos do semi-árido nordestino, Brasil. Master’s Thesis, Universidade Federal do Rio Grande do Norte.

Dornfeld, C.B. (2002). Utilização de análises limnológicas, bioensaios de toxicidade e macroinvertebrados bentônicos para o diagnóstico ambiental do reservatório de Salto Grande (Americana, SP). Master’s Thesis, Universidade de São Paulo.

Duarte, C. (2008). Ictiofauna associada às praias de desova de quelônios no baixo rio Purus, Amazon, Brasil. Master’s Thesis, Instituto Nacional de Pesquisas da Amazônia.

Duarte, M.A.C. (2011). Tratamento de água para consumo humano de reservatório eutrofizado através de pré e interoxidação, adsorção em carvão ativado e dupla filtração. PhD Thesis, Universidade de São Paulo.

Esguícero, A.L.H., and Arcifa, M.S. (2011). The fish fauna of the Jacaré-Guaçu River basin, Upper Paraná River basin. Biota Neotropica, 11, 103-114.

Feitosa, M.F. (2007). Ictiofauna (juvenil e de pequeno porte) e características limnológicas das lagoas marginais do reservatório de Rosana (Rio Paranapanema, SP/PR). Master's Thesis, Universidade Estadual Paulista.

Ferreira, E.J.G. (1993). Composição, distribuição e aspectos ecológicos da ictiofauna de um trecho do rio Trombetas, na área de influência da futura UHE Cachoeira Porteira, Estado do Pará, Brasil. Acta Amazonica, 23, 1-89.

Flauzino, F.S. (2014). Qualidade da água e dos sedimentos nos reservatórios das usinas hidrelétricas de Nova Ponte e Miranda. PhD Thesis, Universidade Federal de Uberlândia.

Fonseca, I.A., Siqueira, N.S., and Rodrigues, L. (2009). Algas perifíticas a montante e a jusante do local de instalação de tanques-rede em tributários do reservatório de Rosana, Estado do Paraná, Brasil. Acta Scientiarum. Biological Sciences, 31, 135-141.

Freitas, C.E.C., and Garcez, R.C.S. (2004). Fish communities of natural channels between floodplain lakes and Solimões-Amazon River (Amazon-Brazil). Acta Limnologica Brasiliensia, 16, 273-280.

Freitas, C.E.C., Siqueira-Souza, F.K., Florentino, A.C., and Hurd, L.E. (2014). The importance of spatial scales to analysis of fish diversity in Amazonian floodplain lakes and implications for conservation. Ecology of Freshwater Fish, 23, 470-477.

Galvão-Miranda, R., Pinheiro-Pereira, S.F., Valeriano-Alves, D.T., and

Fonseca-Oliveira, G.R. (2009). Qualidade dos recursos hídricos da Amazônia - Rio Tapajós: avaliação de caso em relação aos elementos químicos e parâmetros físico-químicos. Ambiente and Água - An Interdisciplinary Journal of Applied Science, 4, 75-92.

Garcia, E.Q. (2005). Monitoramento anual da ictiofauna do reservatório e a jusante da UHE Miranda, rio Araguari, bacia do Paraná. Technical report.

Gomes, J.H.C., Dias, A.C.I.M., and Branco, C.C. (2008). Fish assemblage composition in three reservoirs in the State of Rio de Janeiro. Acta Limnologica Brasiliensia, 20, 373-380.

Goulding, M., Carvalho, M.L., and Ferreira, E.G. (1988). Rio Negro, rich life in poor water: Amazonian diversity and foodchain ecology as seen through fish communities. The Netherlands: SPB Academic Publishing.

Granado, D.C., Henry, R., and Tucci, A. (2009). Influência da variação do nível hidrométrico na comunidade fitoplanctônica do Rio Paranapanema e de uma lagoa marginal na zona de desembocadura na Represa de Jurumirim (SP). Hoehnea, 36, 113-129.

Gunkel, G., Lange, U., Walde, D., and Rosa, J.W.C. (2003). The environmental and operational impacts of Curuá-Una, a reservoir in the Amazon region of Pará, Brazil. Lakes and Reservoirs: Research and Management, 8, 201–216.

Gurgel, J.J.S., and Fernando, C.H. (1994). Fisheries in semi-arid northeast Brazil with special reference to the role of tilapias. Internationale Revue der gesamten Hydrobiologie, 79, 77-94.

Gurgel-Lourenço, R.C., Rodrigues-Filho, C.A.S., Angelini, R., Garcez, D.S., and Sanchéz-Botero, J.I. (2015). On the relation amongst limnological factors and fish abundance in reservoirs at semiarid region. Acta Limnologica Brasiliensia, 27, 24-38.

Junk, W.J., Robertson, B.A., Darwich, A.J., and Vieira, I. (1981). Investigações limnológicas e ictiológicas em Curuá-Una, Amazônia Central. Acta Amazonica, 11, 689-716.

Kampstra, P. (2008). Beanplot: A Boxplot Alternative for Visual Comparison of Distributions. Journal of Statistical Software, 28, 1 - 9.

Keppeler, F.W. (2015). Influência de áreas protegidas e de variação ambiental na assembléia de peixes em um rio de água clara na Amazônia. Master’s Thesis, Universidade Federal do Rio Grande do Sul.

Liliamtis, T.B. (2007). Avaliação da adição de nitrato de amônio para redução de odor nos esgotos de Pereira Barreto - SP: reflexos na qualidade da água do reservatório de Três Irmãos após dez anos de aplicação. PhD Thesis, Universidade de São Paulo.

Lima, J.D. (2009). Conectividade e análise da estrutura taxonômica e trófica da ictiofauna em lagos do rio das Mortes, Mato Grosso-Brasil. PhD Thesis, Universidade Federal de São Carlos.

Lindgren, S., and Röttorp, A. (2009). Physical and chemical assessment of streams in the sub-Andean Amazon, Peru. Master’s Thesis, Uppsala Universitet.

Lowe-McConnell, R.H. (1964). The fishes of the Rupununi savanna district of British Guiana, South America. Zoological Journal of the Linnean Society, 45, 103-144.

Luz, S.C.S., El-Deir, A.C.A., França, E.J., and Severi, W. (2009). Estrutura da assembléia de peixes de uma lagoa marginal desconectada do rio, no submédio Rio São Francisco, Pernambuco. Biota Neotropica, 9, 117-129.

Luz, S.C.S., Lima, H.C., and Severi, W. (2012). Composição da ictiofauna em ambientes marginais e tributários do médio-submédio rio São Francisco. Revista Brasileira de Ciências Agrárias, 7, 358-366.

Machado-Allison, A., Chernoff, B., Royero-León, R., Mago-Leccia, F., Velázquez, J., Lasso, C., … and Silvera, C. (2000). Ictiofauna de la cuenca del río Cuyuní em Venezuela. Interciencia, 25, 13-21.

Magnoni, A.P.V. (2009). Ecologia trófica das assembléias de peixes do reservatório de Chavantes (Médio rio Paranapanema, SP/PR). PhD Thesis, Universidade Estadual Paulista.

Marcucci, K.M.I., Orsi, M.L., and Shibatta, O.A. (2005). Abundância e aspectos reprodutivos de *Loricariichthys platymetopon* (Siluriformes, Loricariidae) em quatro trechos da represa Capivara, médio rio Paranapanema. Iheringia. Série Zoologia, 95, 197-203.

Mascarenhas, G.L., Cunha, M.C.C., Martins, L.R., Ferreira, J.T., and Lopes, D.V. (2013). Caracterização do fitoplâncton das bacias do rio São Francisco, Moxotó e Paraíba, inseridas no projeto de integração do rio São Francisco. Revista Brasileira de Geografia Física, 6, 1050-1068.

Mazzoni, R., Caramaschi, E.P., and Iglesias-Rios, R. (2012). Usina Hidrelétrica de Serra da Mesa: 15 anos de estudos da ictiofauna do alto Tocantins. Furnas: Rio de Janeiro.

Medeiros, P.R.P., Knoppers, B.A., Santos, R.C.Jr., and Souza, W.F.L. (2007). Aporte fluvial e dispersão de matéria particulada em suspensão na zona costeira do rio São Francisco (SE/AL). Geochimica Brasiliensis, 21, 212-231.

Medeiros, E.S.F., Silva, M.J., Figueiredo, B.R.S., Ramos, T.P.A., and Ramos, R.T.C. (2010). Effects of fishing technique on assessing species composition in aquatic systems in semi-arid Brazil. Brazilian Journal of Biology, 70, 255-262.

Meletti, P.C., Rocha, O., and Martinez, C.B.R. (2003). Avaliação da degradação ambiental na bacia do rio Mogi-Guaçu por meio de testes de toxicidade com sedimento e de análises histopatológicas em peixes. In Limnologia fluvial: um estudo no rio Mogi-Guaçu, (pp. 149-180) Brigante, J., and Espíndola, E.L.G. (Ed.). São Carlos: RiMa Editora.

Melo, T.L. (2006). Diversidade da ictiofauna e interação peixe-habitat no baixo rio das Mortes, planície do Bananal – Mato Grosso, Brasil. Master's Thesis, Universidade Federal de Goiás.

Melo, T.L., Tejerina-Garro, F.L., and Melo, C.E. (2007). Diversidade biológica da comunidade de peixesno baixo rio das Mortes, Mato Grosso, Brasil. Revista Brasileira de Zoologia, 24, 657–665.

Melo, T.L., Tejerina-Garro, F.L., and Melo, C.E. (2009). Influence of environmental parameters on fish assemblage of a Neotropical river with a flood pulse regime, Central Brazil. Neotropical Ichthyology, 7, 421-428.

Mello, D.A. (2012). Estudo da distribuição e das densidades larvais do bivalve invasor *Limnoperna fortunei* (Dunker, 1857) nos principais corpos d'água da bacia do rio da Prata. Monograph, Universidade Estadual Paulista.

Mérona, B., Santos, G.M., and Almeida, R.G. (2001). Short term effects of Tucuruí Dam (Amazonia, Brazil) on the trophic organization of fish communities. Environmental Biology of Fishes, 60, 375-392.

Meschiatti, A.J., Arcifa, M.S., and Fenerich-Verani, N. (2000). Fish communities associated with macrophytes in Brazilian floodplain lakes. Environmental Biology of Fishes, 58, 133–143.

Morales, B.F., Cionek, V.M., and Benedito, E. (2009). Ictiofauna do ribeirão Diamante, Estação Ecológica do Caiuá (Diamante do Norte, Estado do Paraná): monitoramento de sua composição e estrutura. Acta Scientiarum. Biological Sciences, 31, 143-148.

Naliato, D.A.O. (2009). Efeitos dos pulsos de vazão turbinada dos reservatórios do baixo rio Paranapanema (SP/PR) sobre os sistemas de jusante – variáveis físicas, químicas e assembléias zooplanctônicas (Cladocera e Copepoda). Master’s Thesis, Universidade Estadual Paulista.

Nascimento, E.L., Gomes, J.P.O., Carvalho, D.P., Almeida, R., Bastos, W.R., and Miyai, K.R. (2009). Mercúrio na comunidade planctônica do reservatório da Usina Hidrelétrica de Samuel (RO), Amazônia Ocidental. Geochimica Brasiliensis, 23, 101-116.

Nascimento, W.S., Araújo, A.S., Gurgel, L.L., Yamamoto, M.E., Chellappa, N.T., Rosa, R.S., and Chellappa, S. (2011). Endemic fish communities and environmental variables of the Piranhas-Assu hydrographic basin in the Brazilian caatinga ecoregion. Animal Biology Journal, 2, 97-112.

Neves, A.L.R.A. (2006). Monitoramento de ictiofauna no reservatório e a jusante da UHE São Simão, rio Paranaíba, bacia do Paraná. Technical report.

Nobile, A.B. (2010). A ictiofauna agregada a um sistema de piscicultura em tanques-rede na represa oligotrófica de Chavantes (médio rio Paranapanema, SP/PR): composição de espécies e atributos ecológicos. Master’s Thesis, Universidade Estadual Paulista.

Normando, F.T., Santiago, K.B., Gomes, M.V.T., Rizzo, E., and Bazzoli, N. (2014). Impact of the Três Marias dam on the reproduction of the forage fish *Astyanax bimaculatus* and *A. fasciatus* from the São Francisco River, downstream from the dam, southeastern Brazil. Environmental Biology of Fishes, 97, 309-319.

Novaes, J.L.C., Moreira, S.I.L., Freire, C.E.C., Sousa, M.M.O., and Costa, R.S. (2014). Fish assemblage in a semi-arid Neotropical reservoir: composition, structure and patterns of diversity and abundance. Brazilian Journal of Biology, 74, 290-301.

Oliveira, E.F., Minte-Vera, C.V., and Goulart, E. (2005). Structure of fish assemblages along spatial gradients in a deep subtropical reservoir (Itaipu Reservoir, Brazil-Paraguay border). Environmental Biology of Fishes, 72, 283-304.

Oliveira, J.C.S. (2012). Ecologia da ictiofauna e análise ecossistêmica das áreas de influência direta da UHE Coaracy Nunes, Ferreira Gomes - AP. PhD Thesis, Universidade Federal do Pará.

Ortega, H., Rengifo, B., Samanez, I., and Palma, C. (2007). Diversidad y el estado de conservación de cuerpos de agua Amazónicos en el nororiente del Perú. Revista Peruana de Biología, 13, 189-193.

Pagotto, T.C.S., and Souza, P.R. (2006). Biodiversidade do Complexo Aporé-Sucuriú: subsídios à conservação e ao manejo do Cerrado. Campo Grande/MS: Editora UFMS.

Pedroza, W.S., Ribeiro, F.R.V., Teixeira, T.F., Ohara, W.M., and Pry-Daniel, L.H.R. (2012). Ichthyofaunal survey of stretches of the Guariba and Rooselvelt Rivers, in Guariba State Park and Guariba Extractive Reserve, Madeira River basin, Amazon, Brazil. Check List, 8, 8-15.

Pelicice, F.M. (2007). A introdução de *Cichla kelberi* Kullander and Ferreira determinando a destruição de assembleias de peixes associadas a bancos de *Egeria* no reservatório de Rosana, rio Paranapanema. PhD Thesis, Universidade Estadual de Maringá.

Pesoa, N.A., and Cardoso, A.R. (2015). Relatório final do monitoramento de ictiofauna e ictioplâncton na UHE São Domingos - MS, Brasil. Technical report.

Petry, A.C. (2001). Variação espacial na estrutura das assembléias de peixes da planície de inundação do alto rio Paraná, Brasil. Master's Thesis. Universidade Estadual de Maringá.

Petry, P., Bayley, P.B., and Markle, D.F. (2003). Relationships between fish assemblages, macrophytes and environmental gradients in the Amazon River floodplain. Journal of Fish Biology, 69, 547-579.

Pisapia, D., Mora, A., Farina, O., Lasso, C.A., Jaffe, R., and Briceño, H.O. (2013). Geoquímica de los ecosistemas acuáticos de la cuenca alta del río Cuyuní, Estado Bolívar, Venezuela: RAP Alto Cuyuní 2008. In Evaluación Rápida de la Biodiversidad de los Ecosistemas Acuáticos de la Cuenca Alta del Río Cuyuní, Guayana Venezolana (pp. 60-73). Conservation Internacional.

Pizetta, G.T. (2007). Alterações nas características limnológicas e na estrutura da comunidade fitoplanctônica durante as obras hidráulicas da Usina Hidrelétrica Capim Branco I, Rio Araguari-MG. Mater's Thesis, Universidade Federal de Minas Gerais.

Pouilly, M., Yunoki, T., Rosales, C., and Torres, L. (2004). Trophic structure of fish assemblages from Mamoré River floodplain lakes (Bolivia). Ecology of Freshwater Fish, 13, 245-257.

Prado, K.L., Freitas, C.E., and Oliveira, A.S. (2009). Assembléias de peixes associadas a diferentes bancos de macrófitas aquáticas em lagos de várzea do baixo rio Solimões. Revista Colombiana de Ciéncia Animal, 1, 185-201.

Prado, I.G., and Pompeu, P.S. (2014). Vertical and seasonal distribution of fish in Três Marias reservoir. Lake and Reservoir Management, 30, 393-404.

Rêgo, A.C.L. (2008). Composição, abundância e dinâmica reprodutiva e alimentar de populações de peixes de um reservatório recém-formado (UHE Capim Branco I/MG). Mater's Thesis, Universidade Federal de Uberlândia.

Reis, V.C.S. (2011). Relações entre o gradiente ambiental e a distribuição das assembléias de peixes em diferentes drenagens da Floresta Nacional Saracá-Taquera (PA). Master's Thesis, Universidade Federal do Rio de Janeiro.

Rezende, R.S., Santos, A.M., and Gonçalves, J.F.Jr. (2012). Avaliação ambiental do rio Pandeiros utilizando macroinvertebrados como indicadores de qualidade da água. Ecología Austral, 22, 159-179.

Rezende, R.S., Graça, M.A.S., Santos, A.M., Medeiros, A.O., Santos, P.F., Nunes, Y.R., and Gonçalves, J.F.Jr. (2016). Organic matter dynamics in a tropical gallery forest in a grassland landscape. Biotropica, 48, 301-310.

Ribeiro-Filho, R.A., Petrere, M.Jr., Benassi, S.F., and Pereira, J.M.A. (2011). Itaipu Reservoir limnology: eutrophication degree and the horizontal distribution of its limnological variables. Brazilian Journal of Biology, 71, 889-902.

Rodríguez, M.P. (2001). Avaliação da qualidade da água da bacia do alto Jacaré-Guaçu/SP (ribeirão do Feijão e rio do Monjolinho) através de variáveis físicas, químicas e biológicas. PhD Thesis, Universidade de São Paulo.

Rolla, M.E., Dabés, M.B.G.S., França, R.C., and Ferreira, E.M.V.M. (1992). Inventário limnológico do rio Grande na área de influência da futura usina hidrelétrica (UHE) Igarapava. Acta Limnologica Brasiliensia, 4, 139-162.

Röpke, C.P., Ferreira, E., and Zuanon, J. (2014). Seasonal changes in the use of feeding resources by fish in stands of aquatic macrophytes in an Amazonian floodplain, Brazil. Environmental Biology of Fishes, 97, 401-414.

Santos, A.F.G.N., Santos, L.N., and Araújo, F.G. (2011). Digestive tract morphology of the Neotropical piscivorous fish *Cichla kelberi* (Perciformes: Cichlidae) introduced into an oligotrophic Brazilian reservoir. Revista de Biología Tropical, 59, 1245-1255.

Santos, C.J.A. (2013). Composição e estrutura trófica de assembleias de peixes em praias de lago da Amazônia central e suas relações com variáveis ambientais locais. Master's Thesis, Instituto Nacional de Pesquisas da Amazônia.

Santos, U., Silva, P.C., Barros, L.C., and Dergam, J.A. (2015). Fish fauna of the Pandeiros River, a region of environmental protection for fish species in Minas Gerais state, Brazil. Check List, 11, 1507.

Sá-Oliveira, J.C., Angelini, R., and Isaac-Nahum, V.J. (2015). Population parameters of the fish fauna in a long-established Amazonian reservoir (Amapá, Brazil). Journal of Applied Ichthyology, 31, 290-295.

Segundo, A.L.N.M. (2013). Estrutura trófica da assembleia de peixes presente na barragem Santa Cruz, Apodi-RN/Brasil. Master's Thesis, Universidade do Estado do Rio Grande do Norte.

Severi, W., El-Deir, A.C.A., Félix, R.T.S., Araújo, I.M.S., Luz, S.C.S., Calado-Neto, A.V., ... and Barretto, M.G. 2010. Composição e abundância da ictiofauna na área de influência dos reservatórios de Pedra e Funil, bacia do Rio das Contas, Bahia. In Reservatórios do Nordeste do Brasil: biodiversidade, ecologia e manejo, Moura, A.N., Araújo, E.L., Bittencourt-Oliveira, M.C., Pimentel, R.M.M., and Albuquerque, U.P. Bauru: Canal6.

Silva, M.A.L., Calasans, C.F., Ovalle, A.R.C., and Rezende, C.E. (2001). Brazilian Archives of Biology and Technology, 44, 365-371.

Silva, D.E.A. (2006). Variações espaço-temporais das associações macrobentônicas em áreas sujeitas à contaminação ambiental no estuário Guajará (Belém-Pará). Master's Thesis, Universidade Federal do Pará.

Silva, R.N.L. (2007). Monitoramento da ictiofauna do rio Jamari a montante e a jusante da UHE de Samuel - RO. Master's Thesis, Universidade Federal de Rondônia.

Silva, N.J.S, Silva, H.L.R., Tonial, I.J., Barbosa, J.J., Pinto, G.N., Costa, M.C., and Soares, M.L. (2007). Programa de monitoramento da ictiofauna da UHE Cana Brava: monitoramento pós-enchimento (relatório final). Technical report.

Silva, F.R., Ferreira, E.J.G., and Deus, C.P. (2010). Structure and dynamics of stream fish communities in the flood zone of the lower Purus River, Amazon State, Brazil. Hydrobiologia, 651, 279–289.

Silva, M.J. (2012). Ecologia trófica da assembléia de peixes em um rio intermitente do semiárido. Master's Thesis, Universidade Estadual da Paraíba.

Silva, A.P.C. (2013). Biomonitoramento da qualidade de água e percepção ambiental na bacia hidrográfica Apodi-Mossoró, RN. Master's Thesis, Universidade Federal do Rio Grande do Norte.

Silva, M.J., Ramos, T.P.A., Diniz, V.D., Ramos, R.T.C., and Medeiros, E.S.F. (2014). Ichthyofauna of Seridó/Borborema: a semi-arid region of Brazil. Biota Neotropica, 14, e20130077.

Soares, B.E. (2015). O assoreamento por rejeito de bauxita e sua relação com a diversidade taxonômica e filogenética: um estudo da ictiofauna de um lago da Amazônia Central (Lago Batata, PA). Master's Thesis, Universidade Federal do Rio de Janeiro.

Soares, M.C.S., Marinho, M.M., Huszar, V.L.H., Branco, C.W.C., and Azevedo, S.M.F.O. (2008). The effects of water retention time and watershed features on the limnology of two tropical reservoirs in Brazil. Lakes and Reservoirs: Research and Management, 13, 257–269.

Soares, M.G.M., and Yamamoto, K.C. (2005). Diversidade e composição da ictiofauna do Lago Tupé. In Diversidade Biológica e Sociocultural do Baixo Rio Negro, Amazônia Central, Santos-Silva, E.N., Aprile, F.M., Scudeller, V.V., and Melo, S., Biotupé: Meio Físico, Manaus: Editora INPA.

Soares, M.G.M., Freitas, C.E.C., and Oliveira, A.C.B. (2014). Assembleias de peixes associadas aos bancos de macrófitas aquáticas em lagos manejados da Amazônia Central, Amazon, Brasil. Acta Amazonica, 44, 143-152.

Sousa, R.G.C., and Freitas, C.E.C. (2008). The influence of flood pulse on fish communities of floodplain canals in the Middle Solimões River, Brazil. Neotropical Ichthyology, 6, 249-255.

Souza, J.E.R.T. (2013). Ictiofauna e bioacumulação de metais pesados na cadeia trófica, rio Gramame, bacia do rio Gramame, Paraíba. PhD Thesis, Universidade Federal da Paraíba.

Souza, M.A. (2016). Relações entre a ictiofauna e macrófitas aquáticas em lagoas do rio Pandeiros, Minas Gerais. Master’s Thesis, Universidade Federal de Lavras.

Tejerina-Garro, F., Fortin, R., and Rodríguez, M.A. (1998). Fish community structure in relation to environmental variation in floodplain lakes of the Araguaia River, Amazon Basin. Environmental Biology of Fishes, 51, 399-410.

Torrente-Vilara, G., Zuanon, J., Leprieur, F., Oberdorff, T., and Tedesco, P.A. (2011). Effects of natural rapids and waterfalls on fish assemblage structure in the Madeira River (Amazon Basin). Ecology of Freshwater Fish, 20, 588-597.

Torres, D.G. (2010). A ictiofauna e a atividade pesqueira na Ilha das Onças, Barcarena - Pará. Master’s Thesis, Universidade Federal do Pará.

Trevisan, G.V., and Forsberg, B.R. (2007). Relationships among nitrogen and total phosphorus, algal biomass and zooplankton density in the central Amazonia lakes. Hydrobiologia, 586, 357-365.

Uehara, W., Albieri, R.J., and Araújo, F.G. (2015). Structure of fish assemblages in seven tropical reservoirs in southeastern Brazil during the rainy season; what matters: physico-chemical or hydrological connectivity influences? Journal of Applied Ichthyology, 31, 1034-1042.

Vasílio, V.A.A. (2006). Balneabilidade, índice de qualidade da água e bioensaios de toxicidade nas praias do reservatório de Ilha Solteira/SP. Master’s Thesis, Universidade Estadual Paulista.

Viana, J.P. (2002). Physical and chemical post-dam alterations in the Jamari River, a hydroelectric-developed river of the Brazilian Amazon. Hydrobiologia, 472, 235–247.

Vieira, I. (2000). Frequência, constância, riqueza e similaridade da ictiofauna da bacia do rio Curuá-Una, Amazônia. Revista Brasileira de Zoociências, 2, 51-76.

Vono, V., Alves, C.B.M., and Magalhães, A.L.B. (1997). A ictiofauna dos cursos d'água tributários do reservatório da futura UHE Igarapava, rio Grande. Acta Limnologica Brasiliensia, 9, 33-43.

Yamamoto, K.C., Freitas, C.E.C., Zuanon, J., and Hurd, L.E. (2014). Fish diversity and species composition in small-scale artificial reefs in Amazonian floodplain lakes: Refugia for rare species? Ecological Engineering, 67, 165-170.