

PONTIFÍCIA UNIVERSIDADE CATÓLICA DE MINAS GERAIS
Programa de Pós-graduação em Zoologia de Vertebrados

Diego Mendes Ferreira Nunes

INFLUÊNCIA DA BARRAGEM DE TRÊS MARIAS E IMPORTÂNCIA DO RIO ABAETÉ SOBRE A REPRODUÇÃO DE *Brycon orthotaenia* GÜNTHER, 1864 (PISCES: CHARACIDAE) NO RIO SÃO FRANCISCO, SUDESTE DO BRASIL.

Belo Horizonte
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Dissertação apresentada ao Programa de Pós-graduação em Zoologia de Vertebrados da PUC Minas, como requisito parcial para obtenção do grau de Mestre em Zoologia de Vertebrados.

Orientador: Prof. Dr. Nilo Bazzoli

Belo Horizonte
2013

FICHA CATALOGRÁFICA

Elaborada pela Biblioteca da Pontifícia Universidade Católica de Minas Gerais

N972i Nunes, Diego Mendes Ferreira
Influência da barragem de Três Marias e importância do Rio Abaeté sobre a reprodução de *Brycon Orthotaenia* Günther, 1864 (pisces: characidae) no Rio São Francisco, sudeste do Brasil / Diego Mendes Ferreira Nunes. Belo Horizonte, 2013.
44 f. : il.

Orientador: Nilo Bazzoli
Dissertação (Mestrado) – Pontifícia Universidade Católica de Minas Gerais.
Programa de Pós-graduação em Zoologia de Vertebrados

1. Peixe de água doce - Reprodução - São Francisco, Rio do. 2. Peixe tropical - Conservação. 3. Gônadas. 4. Characidae. I. Bazzoli, Nilo. II. Pontifícia Universidade Católica de Minas Gerais. Programa de Pós-Graduação em Zoologia de Vertebrados. III. Título.

SIB PUC MINAS

CDU: 597.5(815.1)

“Influência da barragem de Três Marias e importância do rio Abaeté sobre a reprodução de *Brycon othotaenia* Günther, 1864 (Pisces: Characidae) no rio São Francisco, Sudeste do Brasil”

Diego Mendes Ferreira

Defesa de Dissertação em 18/03/2013

Resultado: *APROVADA*

Banca Examinadora:

Fernanda Radicchi C. Lobato de Almeida

Profa. Dra. Fernanda Radicchi C. Lobato de Almeida (UFMG)

Ronald Kennedy Luz

Prof. Dr. Ronald Kennedy Luz (UFMG)

Nilo Bazzoli

Prof. Dr. Nilo Bazzoli (Orientador-PUC Minas)

Essa dissertação foi desenvolvida no Laboratório de Ictiologia do Programa de Pós-graduação em Zoologia de Vertebrados da Pontifícia Universidade Católica de Minas Gerais, sob orientação do Professor Dr. Nilo Bazzoli e com apoio das seguintes instituições:

- Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES);
- Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq);
- Fundação de Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG);
- Companhia de Desenvolvimento dos Vales do São Francisco e do Parnaíba (CODEVASF).

À memória de minha amada tia Zélia, por tudo.

AGRADECIMENTOS

Ao Professor Dr. Nilo Bazzoli pela paciente orientação, por todos os ensinamentos e incentivos, pelo apoio e amizade ao longo de todos esses anos de convivência;

Aos membros da banca, Dra. Fernanda e Dr. Ronald pelas valiosas contribuições;

Ao Rogério pela companhia, amizade e pela confecção das lâminas histológicas;

Aos grandes companheiros André (Bode) e Rafael Zeferino pela amizade e toda a colaboração durante o mestrado;

A todos os amigos, em especial ao Yuri (Cabeça) e Felipe Talin, pela cooperação e presença em todos os momentos;

A galera do Programa: Ivana, Paulo, Vitão, Tio Dani, Marcella, Mari, Zizú, Nath, Luiz, Fred, Paloma, Bárbara Becker, Sara, Tiagão, Alessandro, Dani, Lívio, Rafael, Wine, Marina, Naiara, Lilian, Thalita, Luíza e Bela;

Ao Kléber pelo apoio e companheirismo durante as coletas;

A todos os professores e funcionários do Programa, especialmente ao Prof. Dr. José Enemir, ao Dr. Fábio Arantes e à Cledma;

À Márcia, ao Ricardo e ao Renê por todas as oportunidades;

À minha mãe e minha tia (*in memoriam*), por toda a força, cooperação, paciência e amor durante todos os passos de minha vida;

A todos aqueles que, diretamente ou não, contribuem para o meu crescimento pessoal e profissional.

RESUMO

A matrinxã *Brycon orthotaenia*, espécie endêmica do rio São Francisco, apresenta grande porte, é importante na pesca comercial e esportiva, e realiza migração reprodutiva. Esta espécie encontra-se ameaçada em algumas regiões da bacia do São Francisco devido à degradação ambiental. Considerando que poucos estudos têm avaliado os efeitos do represamento de rios sobre as comunidades de peixes a jusante dos barramentos, o objetivo do presente estudo foi analisar a reprodução da matrinxã em dois trechos do rio São Francisco a jusante da barragem de Três Marias, Sudeste do Brasil. Um total de 312 peixes adultos (123 fêmeas e 189 machos) foram capturados, bimestralmente entre 2011 e 2012, em dois trechos do rio: imediatamente a jusante da barragem de Três Marias (trecho 1) e na confluência com o rio Abaeté (trecho 2). Foram obtidos dados biométricos de todos os peixes capturados e fragmentos de gônadas foram submetidos às técnicas histológicas de rotina. Análises físico-químicas da água foram realizadas nos dois trechos do rio São Francisco durante as amostragens. Todos os parâmetros analisados foram submetidos aos testes estatísticos adequados. Exemplares de *B. orthotaenia* do trecho 2 apresentaram maiores valores de comprimento total (fêmeas: $F = 32,2$ cm, machos: $M = 28,9$ cm) e peso corporal ($F = 506,7$ g, $M = 267,4$ g), quando comparados aos exemplares do trecho 1 ($F = 28,9$ cm e $348,8$ g, $M = 24,5$ cm e $203,0$ g). No trecho 2 registraram-se as maiores médias de índice gonadossomático ($F = 9,97$, $M = 0,93$), em relação às médias do trecho 1 ($F = 6,15$, $M = 0,91$). Ao contrário do trecho 2, no trecho 1 não foram capturados fêmeas desovadas e machos espermiados. A temperatura, oxigênio dissolvido e turbidez da água apresentaram maiores valores no trecho 2. Esses resultados mostram que a matrinxã encontra condições favoráveis para a reprodução somente no trecho 2, provavelmente devido às melhores condições físico-químicas da água, e que o rio Abaeté deve ser preservado para assegurar o sucesso reprodutivo da matrinxã do rio São Francisco.

Palavras-chave: Conservação; índice gonadossomático; peixes neotropicais; peixes migradores; reprodução.

ABSTRACT

The "matrinxã" *Brycon orthotaenia*, an endemic species to the São Francisco River basin, is a large and important fish for commercial and sport fishing that migrates during its reproductive period. The species is endangered in some regions of the São Francisco River basin mainly due to environmental degradation. Considering that few studies have evaluated the damming effects over downstream fish communities, the goal of this study was, for the first time, analyse *B. orthotaenia*'s reproduction in two sections of the São Francisco River downstream from Três Marias dam, South-eastern Brazil. A total of 312 adult fishes (123 females and 189 males) were captured bimonthly, between 2011 and 2012, from both river sections: immediately downstream from the Três Marias dam (section 1) and in the confluence with the Abaeté River (section 2). Biometric data were obtained from all captured fishes and gonadal fragments were submitted to usual histological techniques. Physical and chemical analyses of water were made during sampling on both São Francisco river sections. All the analysed parameters were submitted to the suitable statistical tests. Specimens of *B. orthotaenia* from section 2 presented higher values of total length (females = F: 32.2 cm, males = M: 26.6 cm) and body weight (F: 506.7g, M: 267.4g), when compared with the section 1 fishes (F: 28.9 cm and 348.8g, M: 24.5 cm and 203.0g). Reproduction period occurred from October to February, with GSI peaks occurring in November/December. In section 2 was registered the highest IGS means (F: 9.97, M:0.93), compared with the section 1 means (F: 6.15, M: 0.91). Unlike section 2, no spawned females or spent males were captured in section 1. Water temperature, dissolved oxygen and turbidity presented higher values in section 2. These results show that *B. orthotaenia* finds favourable conditions to reproduction just in section 2, probably due the better physical and chemical water conditions, and that the Abaeté River must be preserved to provide reproduction success to the São Francisco's River fishes.

Key words: Conservation; Gonadosomatic index; Neotropical fish; Migratory fish; Reproduction.

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1 APRESENTAÇÃO

O século XX foi marcado por transformações econômicas e sociais drásticas, as quais culminaram com o aumento da população humana, acelerado desenvolvimento econômico e, conseqüentemente, maior demanda de energia. Tal suprimento energético tem sido proveniente de diversas fontes naturais, principalmente do aproveitamento hidráulico de rios pela construção de usinas hidrelétricas (Costanza *et al.*, 2007; Dugan *et al.*, 2010).

Alguns estudos sobre os impactos de barramentos em ecossistemas aquáticos têm sido realizados principalmente sobre as comunidades de peixes. Tais estudos mostram que os barramentos alteram o regime hidrológico natural dos rios, interferindo diretamente no ciclo biológico da ictiofauna (Preece & Jones, 2002; Todd *et al.*, 2005). Em reservatórios, as camadas inferiores de água (hipolímnio) possuem características desfavoráveis para a reprodução de peixes, tais como baixa temperatura, menor concentração de oxigênio dissolvido, entre outras. Usinas hidrelétricas normalmente utilizam a água proveniente dessas camadas no processo de geração de energia, fazendo então com que a qualidade da água do rio logo a jusante seja comprometida e, conseqüentemente, colocando em risco o sucesso reprodutivo da comunidade de peixes ali residente (Sato *et al.*, 2005; Olden & Naiman, 2010).

A Usina Hidrelétrica (UHE) de Três Marias, construída no alto rio São Francisco em 1961 para geração de energia elétrica e controle de cheias, possui reservatório com cerca de 100 km de extensão e 105.000 ha de área inundada. No verão há uma estratificação térmica da água do reservatório, com diferença de 2 a 3°C entre as camadas superiores e inferiores (Sato & Godinho, 2003). No processo de geração de energia pela UHE Três Marias, a água mais fria proveniente do hipolímnio é liberada no rio, provocando alterações termais e hidrodinâmicas que prejudicam a reprodução de peixes logo a jusante da barragem. No entanto, aproximadamente 34 km abaixo da barragem de Três Marias, o afluente rio Abaeté deságua no São Francisco restabelece os parâmetros físico-químicos da água (Arantes *et al.*, 2010). Estudos recentes com a espécie *Prochilodus argenteus* mostraram que, no trecho do rio São Francisco após a confluência com o rio Abaeté, os peixes encontram condições favoráveis para reprodução (Sato *et al.*, 2005; Arantes *et al.*, 2011; Thomé *et al.*, 2012).

A matrinxã *Brycon orthotaenia* Günther, 1864 (Figura 1), é espécie onívora pertencente a subfamília Bryconinae e endêmica da bacia do rio São Francisco (Lima, 2003; Gomes *et al.*, 2011). Ela pode alcançar peso corporal acima de 7kg, sendo importante na pesca comercial e esportiva. A espécie encontra-se ameaçada em algumas regiões da bacia do São Francisco, além de constar na Lista Vermelha da União Internacional para a Conservação da Natureza (IUCN), incluída na categoria de vulnerável (Gonçalves *et al.*, 2006; Reis & Lima, 2009).



Figura 1: Exemplar de *Brycon orthotaenia* Günther, 1864. Barra = 5 cm.

Embora seja comum o represamento de rios de bacias hidrográficas no sudeste do Brasil, poucos estudos têm avaliado seus efeitos sobre as comunidades de peixes residentes a jusante dos barramentos (Agostinho *et al.*, 1993; Sato *et al.*, 2005). Considerando-se que ainda não foram realizados estudos de impacto de barramentos sobre a reprodução de *B. orthotaenia*, o presente estudo tem como objetivo analisar a reprodução dessa espécie ameaçada em dois trechos do rio São Francisco, a jusante da barragem de Três Marias e na confluência com o rio Abaeté.

2 OBJETIVOS

2.1 Objetivo geral

Analisar a reprodução de *Brycon orthotaenia* em dois trechos do rio São Francisco, a jusante da barragem de Três Marias.

2.2 Objetivos específicos

- Comparar o comprimento total (CT) e peso corporal (PC) de fêmeas e machos;
- Determinar estádios e frequência de maturação gonadal, época de reprodução e tipo de desova de *B. orthotaenia*;
- Calcular o índice gônado-somático (IGS) e fator de condição de Fulton (K);
- Determinar o diâmetro dos ovócitos vitelogênicos (DO), fecundidade absoluta (FA) e fecundidade relativa (FR);
- Obter os parâmetros físico-químicos da água;
- Correlacionar CT, PC, IGS, K, DO, FA e FR com os parâmetros físico-químicos da água dos dois trechos de estudo.

3 ARTIGO SUBMETIDO

Journal of Fish Biology

Influence of a Dam and importance of a tributary River on the reproduction of the endangered Neotropical species *Brycon orthotaenia* (Characidae: Bryconinae).
--Manuscript Draft--

Manuscript Number:	
Full Title:	Influence of a Dam and importance of a tributary River on the reproduction of the endangered Neotropical species <i>Brycon orthotaenia</i> (Characidae: Bryconinae).
Short Title:	Reproduction of <i>Brycon orthotaenia</i>
Article Type:	Regular paper
Keywords:	Damming effects; Hypolimnion water; Water temperature; Reproductive parameters; Canonical correlation.
Corresponding Author:	N Bazzoli, PhD Catholic University of Minas Gerais Belo Horizonte, Minas Gerais BRAZIL
Corresponding Author Secondary Information:	
Corresponding Author's Institution:	Catholic University of Minas Gerais
Corresponding Author's Secondary Institution:	
First Author:	Diego Mendes Ferreira Nunes, Doctor

Influence of a Dam and importance of a tributary River on the reproduction of the endangered Neotropical species *Brycon orthotaenia* (Characidae: Bryconinae).

D. M. F. NUNES*; A. A. WEBER*; R. Z. GOMES*; K. B. SANTIAGO‡; E. RIZZO† AND N. BAZZOLI*§

* Programa de Pós-graduação em Zoologia de Vertebrados, Pontifícia Universidade Católica de Minas Gerais, Av. Dom José Gaspar, 500, CEP 30.535-610, Belo Horizonte, Minas Gerais, Brazil,

‡ Centro Integrado de Recursos Pesqueiros e Aquicultura de Três Marias, CODEVASF, Estação de Piscicultura s/n, CEP 39.205-000, Três Marias, Minas Gerais, Brazil,

† Departamento de Morfologia do Instituto de Ciências Biológicas, Universidade Federal de Minas Gerais, Av. Antônio Carlos, 6627, CEP 31.270-910, Belo Horizonte, Minas Gerais, Brazil.

§Author to whom correspondence should be addressed. Tel.: +55 31 33194936; email: bazzoli@pucminas.br

Abstract

The "matrinxã" *Brycon orthotaenia* an endemic species of São Francisco River basin, is a large and important fish for commercial and sport fishing that migrates during its reproductive period. The species is endangered in some regions of the São Francisco River basin mainly due to environmental degradation. Considering that few studies have evaluated the damming effects over downstream fish communities, the goal of this study was, for the first time, analyse the *B. orthotaenia*'s reproduction in two sections of the São Francisco River downstream of Três Marias dam, South-Eastern Brazil. A total of 312 adult fishes (123 females and 189 males) were captured bimonthly, between 2011 and 2012, in both river sections: immediately downstream of the Três Marias dam (section 1) and in the confluence with the Abaeté River (section 2). Biometric data were obtained from all captured fishes and gonadal fragments were submitted to usual histological techniques. Physical and chemical analyses of water were made during sampling on both São Francisco river sections. All the analysed parameters were submitted to the suitable statistical tests. Specimens of *B. orthotaenia* from section 2 presented higher values of total length (females = F: 32.2 cm, males = M: 26.6 cm) and body weight (F: 506.7g, M: 267.4g), when compared with the section 1 fishes (F: 28.9 cm and 348.8g, M: 24.5 cm and 203.0g). Reproduction period occurred from October to February, with GSI peaks occurring in November/December. In section 2 was registered the highest IGS means (F: 9.97, M:0.93), compared with the section 1 means (F: 6.15, M: 0.91). Unlike section 2, no spawned females or spent males were captured in section 1. Water temperature, dissolved oxygen and turbidity presented higher values in section 2. These results show that *B. orthotaenia* finds favourable conditions to reproduction just in section 2, probably due the better physical and chemical water conditions, and that the Abaeté River must be preserved to provide reproduction success to the São Francisco's River fishes.

Introduction

Species of the *Brycon* genus, Bryconinae subfamily, are widely distributed throughout South and Central America, being endemic to the major river basins of Brazil. The high zootechnical potential has made it interesting for studies in pisciculture since the 1930's (Zaniboni Filho *et al.*, 2006). *Brycon orthotaenia* Günther, 1864, is an omnivorous species endemic to the São Francisco River basin which migrates during its reproductive period (Lima, 2003). Its body weight may reach more than 7 kg, thus it is an important fish for commercial and sport fishing. The species is endangered in some regions of the São Francisco River basin, and it is included in the Red List of the International Union for Conservation of Nature (IUCN), in the category of vulnerable, mainly due to environmental degradation (Reis & Lima, 2009; Gomes *et al.*, 2011).

The impacts of dams on aquatic ecosystems have been a topic for discussion, especially relating to fish communities. Besides altering the natural hydrological regime of rivers, dams directly interfere with species' biological cycle, causing changes in the composition of the ichthyofauna, an increase in vulnerability to predation, ease exotic species introduction, behavioural changes and blocking of natural migratory routes (Haxton & Findlay, 2008; Agostinho *et al.*, 2008; Dugan *et al.*, 2010). Changes to the environmental conditions downstream from dams negatively affect fish populations and their established reproduction patterns, due to the release of water with different physical and chemical patterns than those of the natural river (Olden & Naiman, 2010; Domingos *et al.*, 2012; Thomé *et al.*, 2012).

The Três Marias dam was built in the upper São Francisco River for power generation and flood control. In summer occurs a stratification of the reservoir water, with a difference of 3°C between the upper and lower layers (Sato *et al.*, 2005). In the power generation process, the colder water from the hypolimnion is released in the river, causing thermal and hydrodynamic changes that impact fish reproduction just downstream of the dam. Recent studies have shown the importance, for fish reproduction, of tributaries downstream from dams, acting as alternative routes for migratory species and minimising unfavourable water conditions (Sato *et al.*, 2005; Godinho *et al.*, 2007; Arantes *et al.*, 2010). This shows that the tributaries can provide survival conditions for fish populations in rivers with dams, thus contributing to the conservation of the ichthyofauna.

Considering that there are no studies to evaluate the impacts of damming and the importance of free dam tributaries on the *B. orthotaenia* reproduction, this study aims to analyse the reproduction of this species in two sections of the São Francisco River, immediately downstream from the Três Marias dam and in the confluence with the Abaeté River.

Materials and Methods

Samples

Specimens of *B. orthotaenia* were captured bimonthly, between July 2011 and August 2012 on two sections of the São Francisco River: section 1, immediately downstream from the Três Marias dam (18°11'S, 45°14'W) and section 2, in the confluence with the Abaeté River (18°02'S; 45°11'W) (Fig. 1). A total of 312 specimens, of which there were 58 females and 50 males from section 1 and 65 females and 139 males from section 2, were captured using gillnets by professional fishermen, with the authorization of the Brazilian Institute for the Environment and Renewable Resources (IBAMA). The fish were immediately transported to the Hydrobiology and Pisciculture Station of Três Marias – CODEVASF. The fish, if alive, were killed by transversal section of the cervical medulla, following the ethical principles of animal handling established by the Brazilian College for Animal Experimentation (COBEA). For each specimen, total length (TL), body weight (BW) and gonadal weight (GW) were recorded. In order to perform histological analyses, fragments of ovaries and testis were collected and fixed in Bouin's fluid for 24 hours. Fragments of mature ovaries were weighed and transferred to Gilson's solution in order to determine fecundity.

Gonadal maturation, follicular diameter, biological indices and body-weight ratio

The gonadal maturation stages (GMS) were determined based on the macroscopic and microscopic characteristics of the gonads and gonadosomatic index (GSI) variation, according to Gonçalves *et al.* (2006).

In order to determine the GMS and histometric data, fragments of the ovaries and testis, previously fixed in Bouin's fluid, were submitted to routine histological techniques: embedding in paraffin, sectioned at a 4 to 5 µm thickness and stained with haematoxylin and eosin.

The diameters of the vitellogenic follicles were obtained from histological slides of mature ovaries. At least 50 follicles of 10 females captured from each section were measured using an ocular micrometer attached to a light microscope (average \pm standard deviation).

From the biometric data obtained, we determined each sample's gonadosomatic index ($GSI = 100 GwBW^{-1}$, where Gw = gonad weight and BW = body weight) and Fulton's condition factor ($K = 100 BW(TL^3)^{-1}$ where TL = total length).

The length-weight ratio was determined for females and males of each section, through the expression: $Bw = aTL^b$, where a = arithmetic coefficient and b = growth exponent.

Fecundity

Fragments from mature ovaries of 10 females from section 2, previously weighed and kept in a modified Gilson's solution (100 ml of 60% ethanol, 880 ml distilled water, 15 ml of 80% nitric acid, 18 ml of glacial acetic acid and 20 g of mercury chloride) until the complete dissociation of the oocytes, were observed under a stereoscopic microscope in order to count the vitellogenic follicles and thus determine fecundity. Absolute fecundity (AF) was estimated using the expression: $AF = OVA \cdot GW$; in which OVA: number of oocytes per ovary gram and GW = gonadal weight. The relative fecundity was estimated using the following expressions: $RF = AF \cdot TL^{-1}$, $RF = AF \cdot BW^{-1}$, in which AF = absolute fecundity; TL = total length; BW = body weight.

The ovaries of females from section 1 did not reach full maturation which is needed for determining fecundity.

Physical and chemical parameters of the water

Water temperature, dissolved oxygen concentration, pH and electric conductivity were recorded during the sampling for both sections, using a Horiba model W-10 probe. The water flow rates were supplied by Companhia Energética de Minas Gerais (CEMIG).

Statistical Analysis

All studied parameters were submitted to the Liliefors normality test. For parametric data, we used the T-student test for independent samples and the Mann-Whitney test for non-parametric data. Canonical correlation between biological

parameters and environmental factors were conducted to females and males of both sections.

For comparison between the gonadal maturation stages of females and males, we used the variance Kruskal-Wallis test, followed by the Dunn post-test. The stages of gonadal maturation for each section of the river were expressed in graphics and tables with means with standard deviation with a significance level of $P < 0.05$.

Results

Biometry

Specimens of *B. orthotaenia* captured from section 2 showed statistically higher values of total length and body weight compared to females and males captured from section 1 (Tables I and II).

Reproductive Activity

Based on macro and microscopic characteristics of the gonads, the following maturation stages were identified for females (F) and males (M): resting (F1/M1), maturing / mature (F2/M2) and spawned (F3) and spent (M3) (Table III, Fig. 2 and 3). Testis in stages M2 and M3 presented spermatozoa in acidophilic secretion on the seminiferous tubules' lumen.

More specimens of *B. orthotaenia* in reproductive rest were found in section 1, whereas the highest quantity of mature fish was recorded for section 2 for both sexes. Spawned females and spent males were only captured in section 2, after the confluence with the Abaeté River (Tables IV and V, Fig. 4).

The spawning period occurred in the January/February and March/April (Fig. 4) and GSI peaked for females and males in the November/December (Fig. 5). For both sexes, the average GSI by GMS was higher in section 2 in relation to section 1 during the breeding season, showing a statistical difference only for females (Tables I and II, Fig. 6). The short reproductive period and histological characteristics of the spawned ovaries indicate that *B. orthotaenia* presents total spawning.

Condition factor and weight-length ratio

The Fulton's condition factor (K) did not show a statistical difference between fishes of the two sections of the river (Tables I and II). Regarding the length-weight ratio, females of section 1 presented $b = 3.31$ and $r^2 = 0.93$ and females of section 2 presented $b = 3.12$ and $r^2 = 0.97$. For males of section 1 we recorded $b = 3.02$ and $r^2 = 0.86$ and males of section 2 $b = 3.05$ and $r^2 = 0.90$, indicating positive allometric growth for both sexes (Fig. 7).

Vitellogenic follicle diameter, absolute and relative fecundity

The vitellogenic follicle diameter (FD) for section 2 showed a slightly higher average than that of section 1, but with no statistical difference. The fecundity analysis was done only for females of section 2 (Table I).

Physical and chemical parameters of the water

Temperature, dissolved oxygen and flow rates were higher downstream from the confluence with the Abaeté River, section 2, with statistical differences between the sections. Electrical conductivity and pH showed no statistical difference between the sections (Table VI).

Canonical correlation

The canonical correlation between biological parameters and environmental factors showed high correlation and significant difference for females in the two sections of the São Francisco River (section 1, $R_c = 0.66$; $P < 0.0006$ and section 2, $R_c = 0.95$; $P < 0.0001$). However, males of two sections showed low correlation with significance difference between biological parameters and environmental factors only in section 2 (section 1, $R_c = 0.41$; $P = 0.1199$ and section 2, $R_c = 0.33$; $P = 0.0259$).

TABLE I. Biological variables of *B. orthotaenia* females captured in two sections of São Francisco River, downstream from the Três Marias Dam.

	Section 1		Section 2	
	Mean \pm SD	Range	Mean \pm SD	Range
TL (cm)	28.86 \pm 4.17 ^a	24.00-43.70	32.24 \pm 5.70 ^b	24.90-49.00
BW (g)	348.82 \pm 203.73 ^a	170.00-1134.00	506.66 \pm 332.17 ^b	191.20-1780.00
GSI (%)	6.15 \pm 2.30 ^a	2.89-8.30	9.97 \pm 2.96 ^b	6.90-14.48
K	1.36 \pm 0.17 ^a	0.84-1.76	1.41 \pm 0.17 ^a	1.11-2.14
FD (μ m)	755.41 \pm 54.62 ^a	631.00-878.30	762.10 \pm 61.91 ^a	619.50-881.70
AF (10 ³)	-	-	112.02 \pm 67.48	46.58-247.20
RFTL (10 ³)	-	-	3.02 \pm 1.47	1.48-5.94
RFBW (10 ²)	-	-	1.68 \pm 0.52	1.09-2.28

Section 1: Immediately downstream from the Três Marias dam; Section 2: in the confluence with the Abaeté River; total length (TL), body weight (BW), gonadosomatic index for mature females (GSI), Fulton condition factor (K), follicular diameter (FD), absolute fecundity (AF), relative fecundity total length (RFTL), relative fecundity body weight (RFBW); data are expressed as mean \pm standard deviation (SD); different superscripts with means indicate differences between river sections ($P < 0.05$).

TABLE II. Biological variables of *B. orthotaenia* males captured in two sections of São Francisco River, downstream from the Três Marias Dam.

	Section 1		Section 2	
	Mean \pm SD	Range	Mean \pm SD	Range
TL (cm)	24.45 \pm 2.66 ^a	20.50-34.20	26.64 \pm 3.79 ^b	20.60-40.90
BW (g)	202.96 \pm 90.85 ^a	125.00-582.00	267.36 \pm 145.84 ^b	121.40-1104.00
GSI (%)	0.91 \pm 0.67 ^a	0.18-1.95	0.93 \pm 0.52 ^a	0.17-2.07
K	1.31 \pm 0.19 ^a	0.96-1.75	1.30 \pm 0.20 ^a	0.90-2.37

Section 1: Immediately downstream from the Três Marias dam; Section 2: in the confluence with the Abaeté River; total length (TL), body weight (BW), gonadosomatic index for mature males (GSI), Fulton condition factor (K), data are expressed as mean \pm standard deviation (SD); different superscripts with means indicate differences between river sections ($P < 0.05$).

TABLE III. Macro and microscopic characteristics of the gonadal maturity stage of females (F) and males (M) of *B. orthotaenia*.

Stage		Macroscopic diagnostic	Microscopic diagnostic
F1	Resting	Translucent and thin ovaries.	Initial (O1) and advanced (O2) perinucleolar follicles.
F2	Maturation/ mature	Greenish, voluminous and containing abundant follicles visible through the naked eye.	Presence of follicles in different developmental stages: O1, O2, pre-vitellogenic (O3) and abundant vitellogenic follicles (O4).
F3	Spawned	Reddish and flaccid, containing residual follicles. Blood vessels more evident.	Abundant postovulatory follicles (POF) and vitellogenic follicles in atresia (AF). Presence of O1 and O2.
M1	Resting	Slender and translucent testis.	Seminiferous tubules with occluded lumen and containing only spermatogonia.
M2	Maturation/ mature	Voluminous with a milky white color.	Seminiferous tubules containing cysts of all spermatogenic cells, lumen full of spermatozoa and acidophilic secretion.
M3	Spent	Reduced volume with apparent blood vessels and with a reddish color.	Open seminiferous tubules containing residual spermatozoa in the lumen.

TABLE IV. Absolute frequency of the gonadal maturation stages of females of *B. orthotaenia* captured in two sections of the São Francisco River, downstream from the Três Marias dam.

Bimester	Section 1				Section 2				Grand total
	F1	F2	F3	Total	F1	F2	F3	Total	
Jul/Aug	1	-	-	1	1	-	-	1	2
Sep/Oct	9	2	-	11	13	6	-	19	30
Nov/Dec	23	9	-	32	6	13	-	19	51
Jan/Feb	5	-	-	5	5	1	1	7	12
Mar/Apr	8	-	-	8	12	-	6	18	26
May/Jun	1	-	-	1	1	-	-	1	2
Total	47	11	-	58	38	20	7	65	123

F1 = resting, F2 = maturation/mature, F3 = spawned.

TABLE V. Absolute frequency of the gonadal maturation stages of males of *B. orthotaenia* captured in two sections of the São Francisco River, downstream from the Três Marias dam.

Bimester	Section 1				Section 2				Grand total
	M1	M2	M3	Total	M1	M2	M3	Total	
Jul/Aug	1	-	-	1	2	-	-	2	3
Sep/Oct	6	3	-	9	18	13	-	31	40
Nov/Dec	6	14	-	20	4	25	4	33	53
Jan/Feb	1	-	-	1	8	15	6	29	30
Mar/Apr	10	2	-	12	14	5	14	33	45
May/Jun	7	-	-	7	9	1	1	11	18
Total	31	19	-	50	55	59	25	139	189

M1 = resting, M2 = maturation/mature, M3 = spent.

TABLE VI. Abiotic parameters of the water in two sections of the São Francisco River, downstream from the Três Marias dam, between July/11 and August/12.

	Section 1		Section 2	
	Mean \pm SD	Range	Mean \pm SD	Range
Temperature (°C)	23.21 \pm 0.57 ^a	22.68 - 24.00	24.31 \pm 0.71 ^b	23.58 - 25.40
Oxygen (mg/L)	5.55 \pm 1.67 ^a	4.13 - 8.12	7.97 \pm 0.55 ^b	7.33 - 8.65
pH	5.83 \pm 0.46 ^a	5.12 - 6.24	6.35 \pm 0.51 ^a	5.62 - 7.02
Conductivity (μS/cm)	68.6 \pm 1.51 ^a	67.00 - 71.00	64.2 \pm 7.19 ^a	56.00 - 74.00
Flow (m³/s)	693.22 \pm 100.58 ^a	584.93 - 798.22	815.13 \pm 52.71 ^b	724.57 - 854.51

Section 1: Immediately downstream from the Três Marias dam; Section 2: in the confluence with the Abaeté River. Data are expressed as Mean \pm Standard Deviation (SD); different superscripts with means indicate differences between river sections ($P < 0.05$).

FIG 1. Location of the study sections of the São Francisco River, downstream from the Três Marias dam. Section 1, immediately downstream from the Três Marias dam and section 2, below the confluence with the Abaeté River.

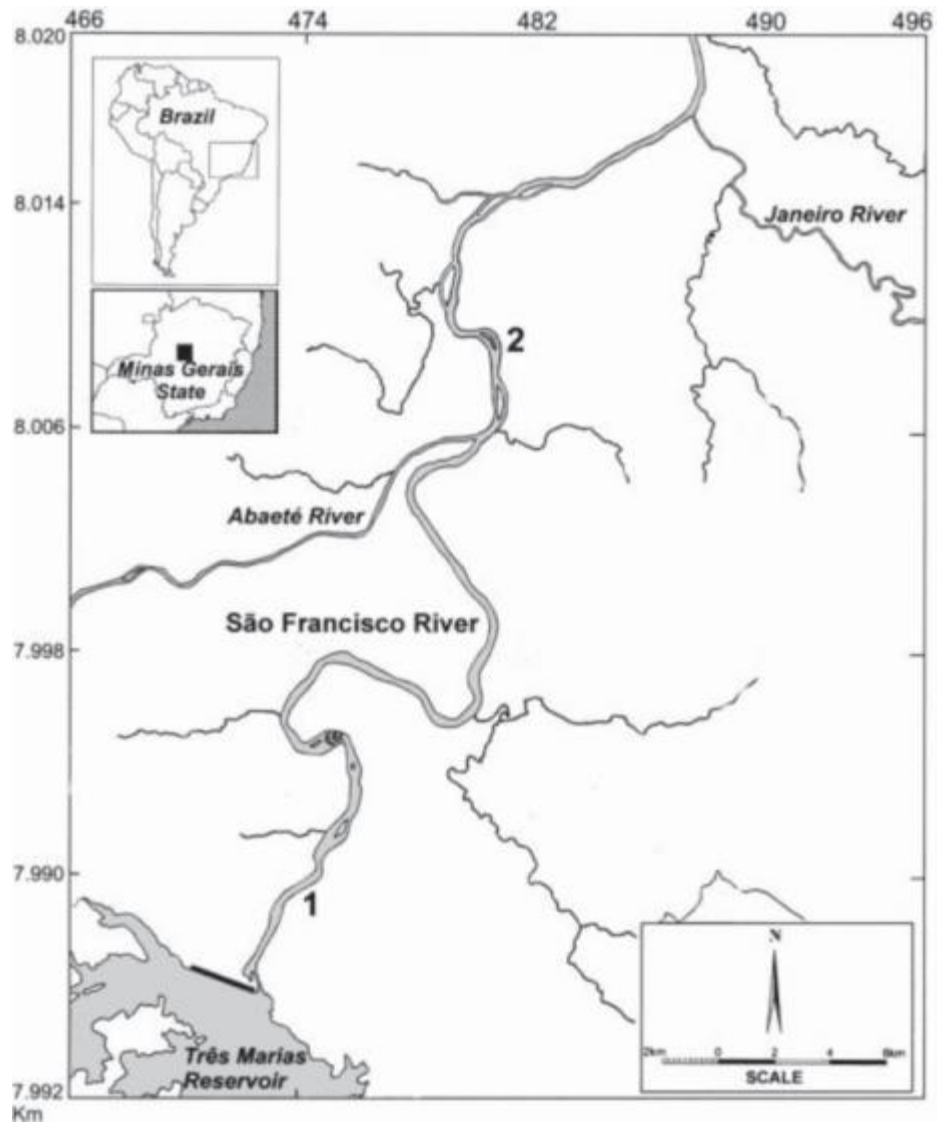


FIG 2. Histological sections of *B. orthotaenia* ovaries stained with Hematoxilin-eosin: (a) resting stage presenting early (O1) and late (O2) perinucleolar follicles, (b) initial maturation stage presenting O1, O2 and previtellogenic follicles (O3), (c) advanced maturation with predominance of vitellogenic follicles (O4), (d) vitellogenic follicles containing yolk globules (Y), zona radiata (ZR) and follicular cells (FC), (e) spawned stage with postovulatory follicles (*) and atretic follicles (AF), (f) vitellogenic follicle in early atresia with fragmented zona radiata (→), (g) hypertrophy of follicular cells, fragmented zona radiata (→) and yolk being degraded in atretic follicle and (h) vitellogenic follicle in advanced atresia. Bar = (a), (b), (h) 70 μm , (c) 160 μm , (d) 40 μm , (e) 100 μm , (f) 120 μm and (g) 50 μm .

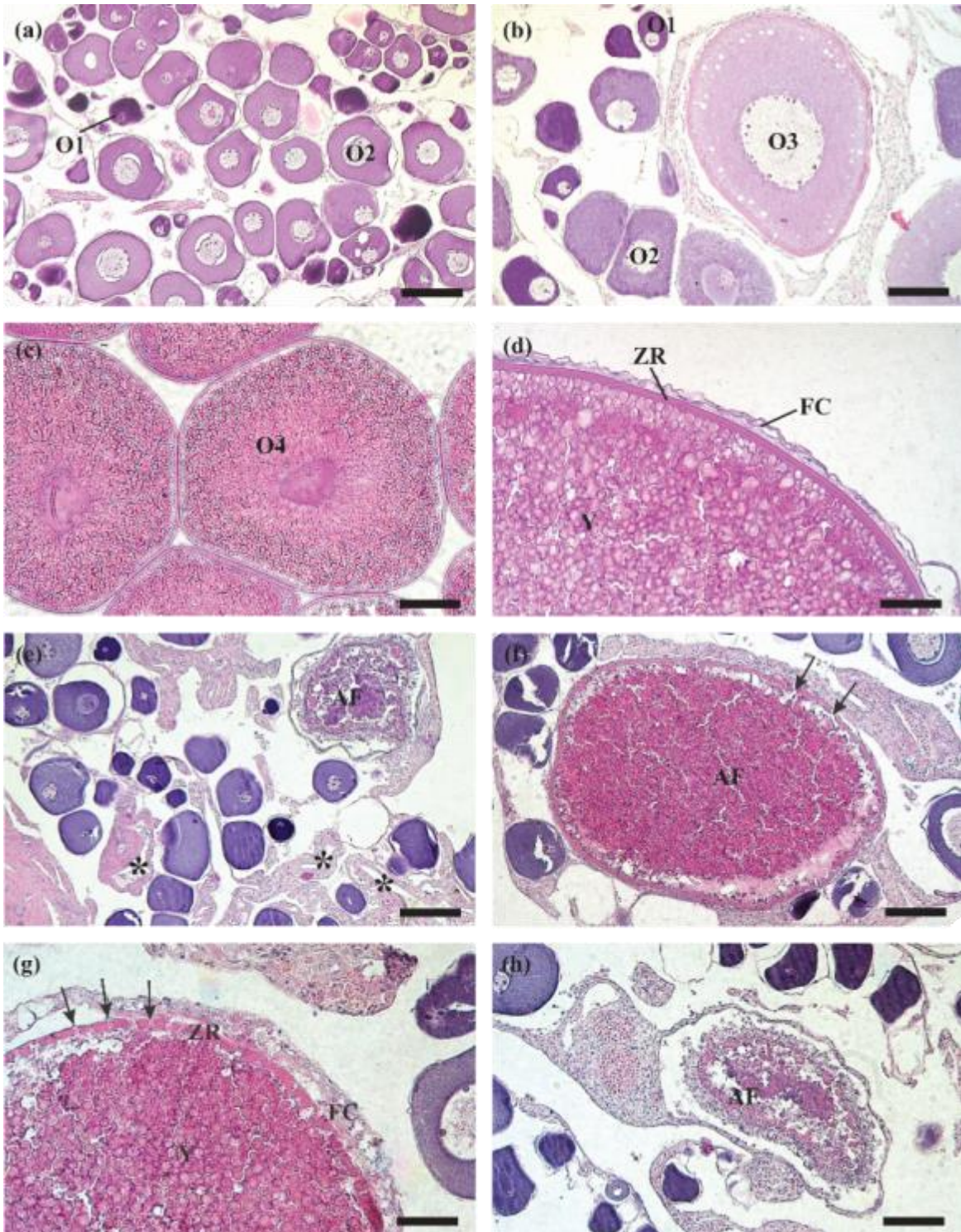


FIG 3. Histological sections of *B. orthotaenia* testis stained with Hematoxilin-eosin: (a) resting stage with seminiferous tubules containing only spermatogonia (S), (b) initial maturation with lumen of seminiferous tubules open with spermatozoa and wall of seminiferous tubules with spermatogenic cells in different stages of development, (c) advanced maturation with seminiferous tubules full of spermatozoa (Z) in acidophilic secretion (→) and (d) spent testis with few spermatozoa (Z) in the lumen (L) in acidophilic secretion (→). Bar = (a) 30 μm , (b), (d) 70 μm , (c) 80 μm .

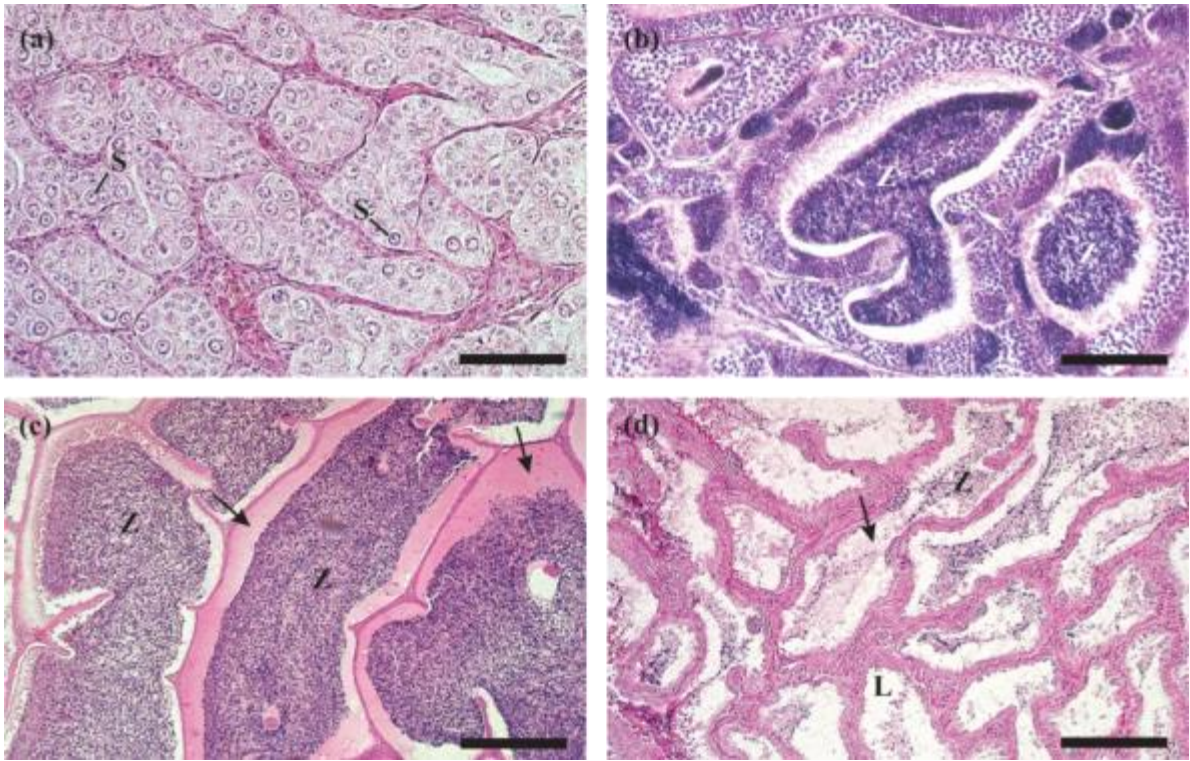


FIG 4. Relative frequency of maturity stages of *B. orthotaenia* captured in two sections of the São Francisco River, downstream from the Três Marias Dam. (a) females from section 1, (b) females from section 2, (c) males from section 1 and (d) males from section 2. Resting, light gray; maturation/mature, dark gray; spawning/spent, black.

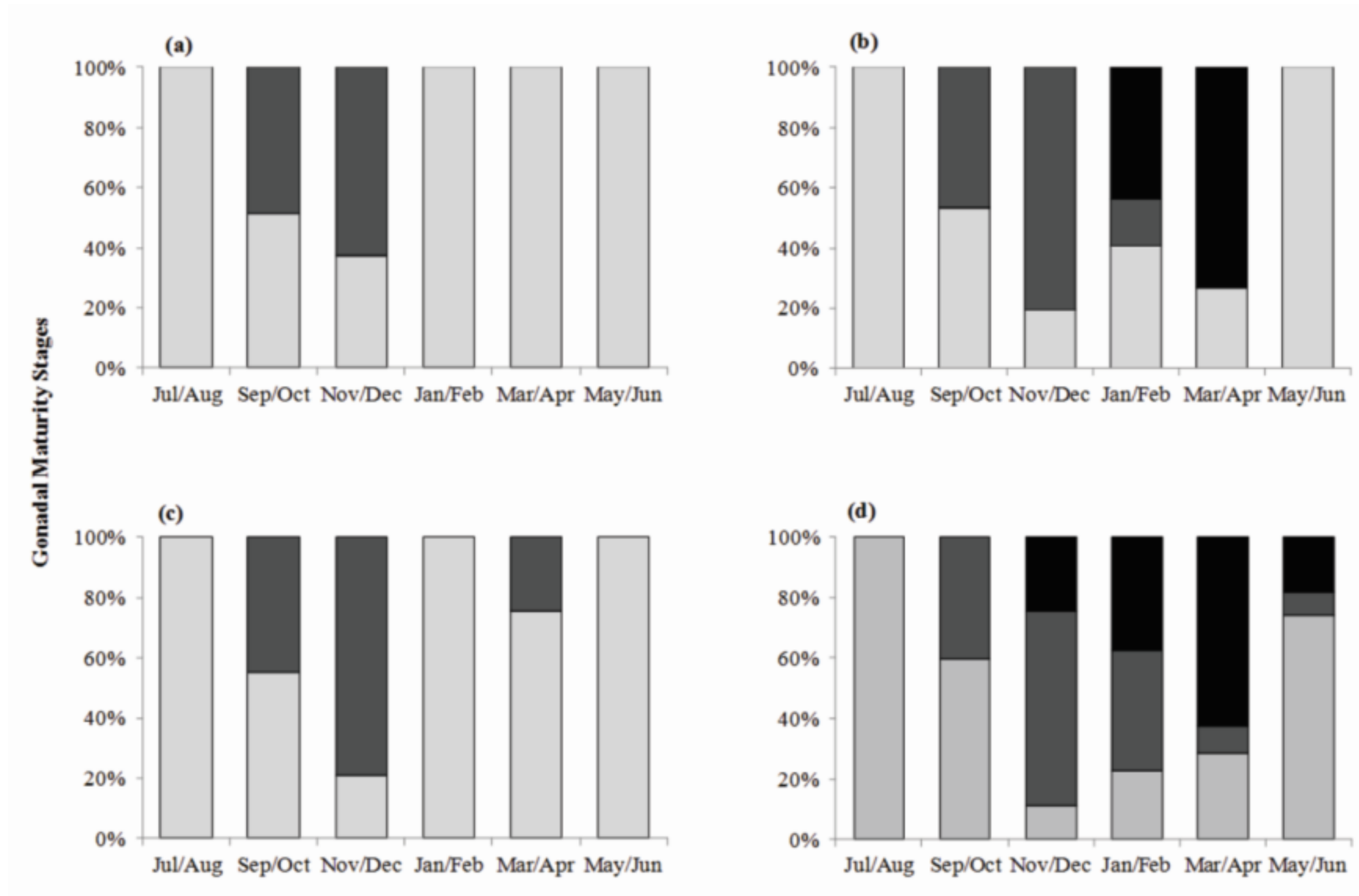


FIG 5. Gonadosomatic index ($GSI = 100 \text{ GwBW}^{-1}$) of (a) females and (b) males of *B. orthotaenia* in two sections of the São Francisco river, downstream Três Marias Dam: section 1, dotted line and section 2, continuous line. Values are expressed as mean. Asterisk indicate statistical difference among GSI values by period ($P < 0.05$).

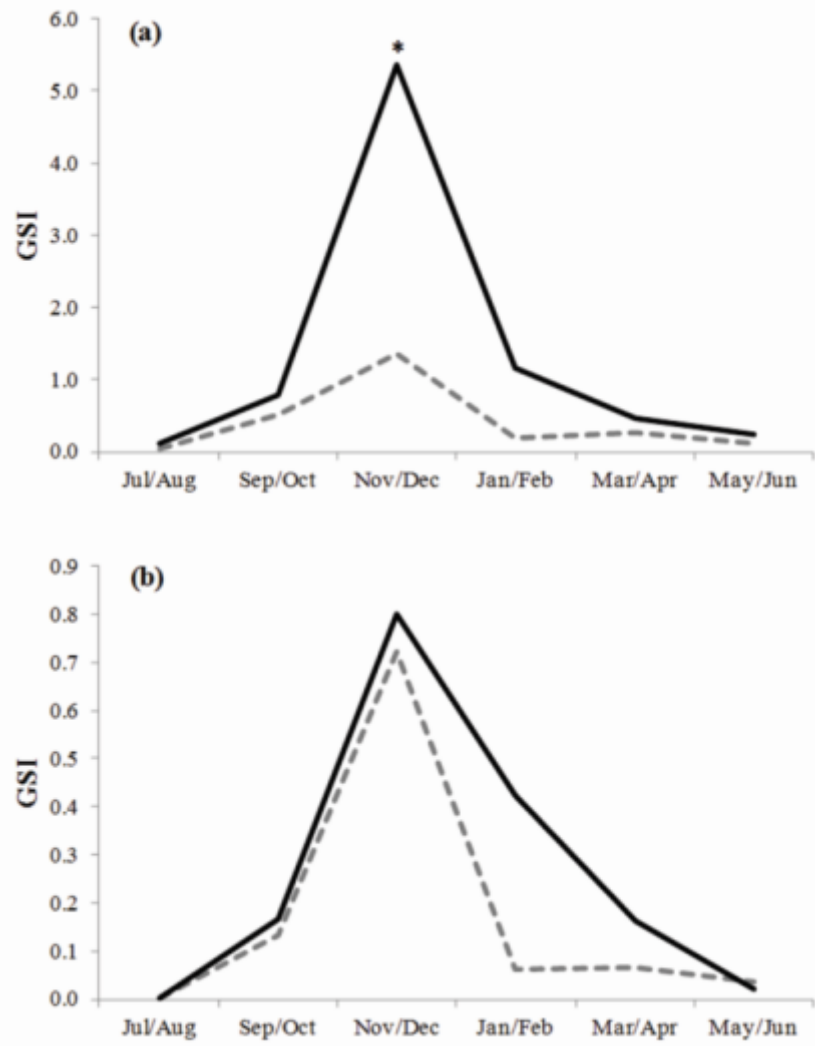


FIG 6. Gonadosomatic index ($GSI = 100 \text{ GWBW}^{-1}$) by gonadal maturation stages of (a) females and (b) males of *B. orthotaenia* captured in two sections of São Francisco River, downstream of Três Marias Dam: section 1, black and section 2, gray. F1/M1, resting; F2/M2, maturation/mature; F3/M3, spawning/spent. Values are expressed as means \pm SD. Different capital letters indicate differences among maturity stages and small letters differences between river sections ($P < 0.05$).

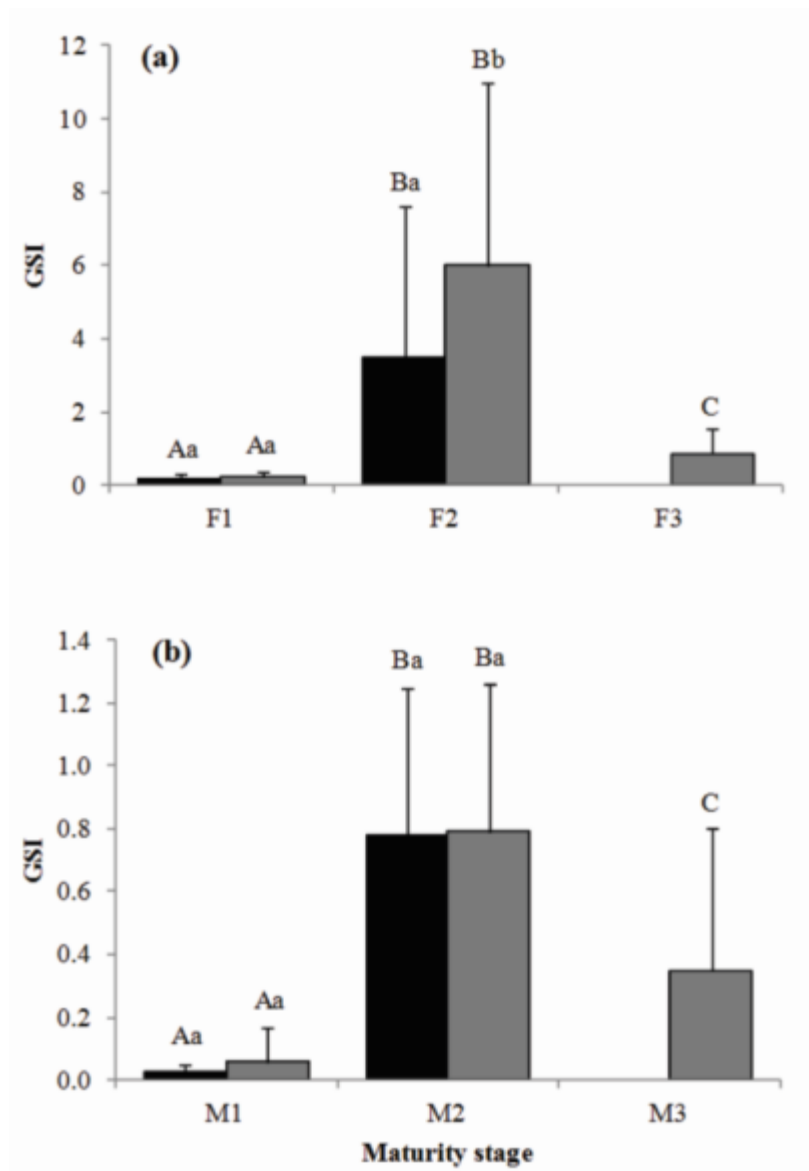
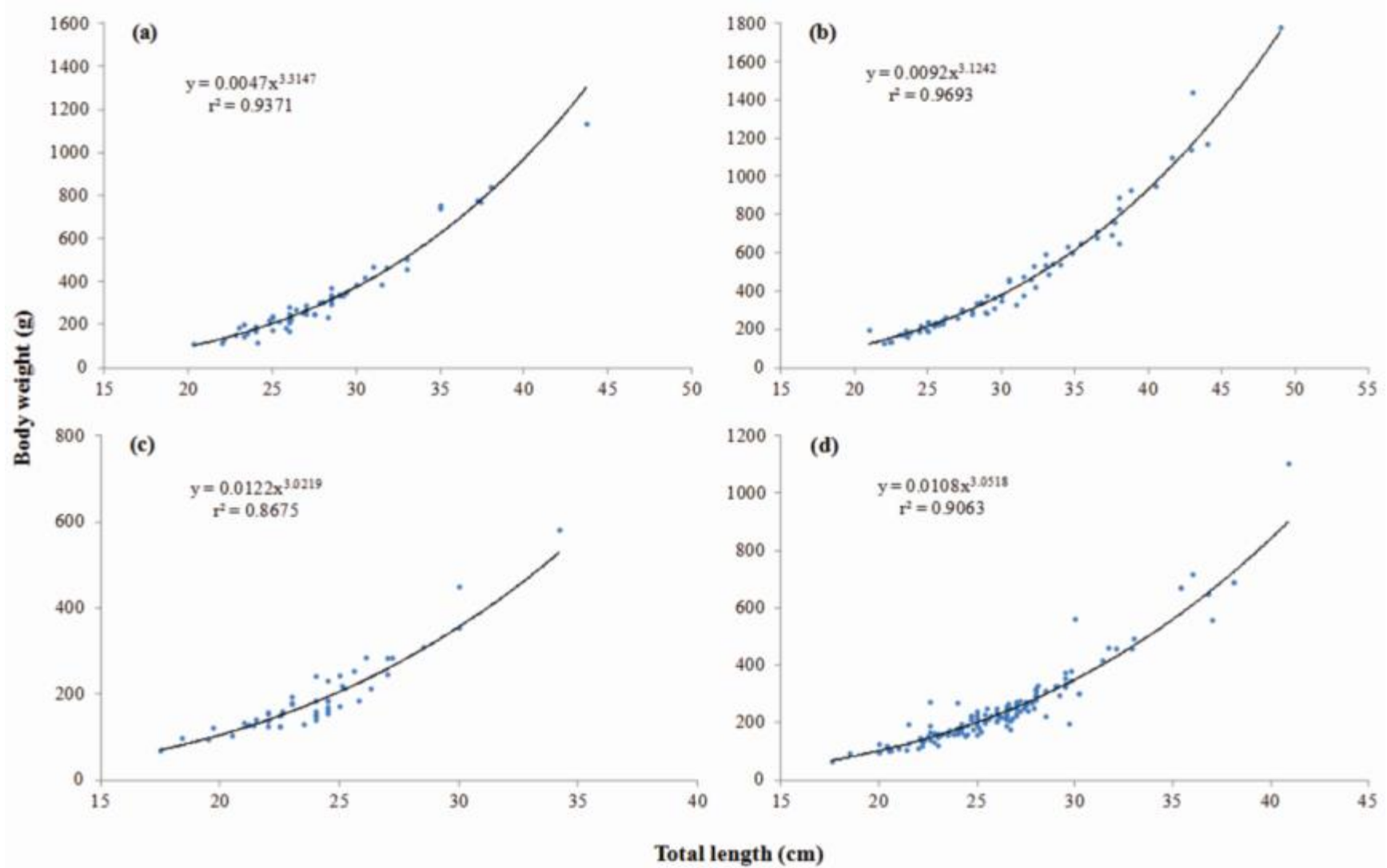


FIG 7. Length-weight relationships ($Bw = aTL^b$) of *B. orthotaenia* captured in two sections of São Francisco River, downstream of Três Marias Dam. (a) females from section 1, (b) females from section 2, (c) males from section 1 and (d) males from section 2. The ratio showed positive allometric growth for females and males of the two sections ($b > 3$).



Discussion

This study showed the inhibition of spermiation and spawning of *B. orthotaenia* immediately downstream from the Três Marias dam, São Francisco River, probably due to the quality of the hypolimnion water released by the power plant. However, in the confluence of the São Francisco River with the Abaeté River, the physical and chemical parameters of water were favourable for spermiation and spawning of this species.

The impact of low temperature water released downstream from dams on the reproductive success of fish has been reported in literature (Hubbs, 1972; Preece & Jones, 2002; Todd *et al.*, 2005; Mantel *et al.*, 2010; Thomé *et al.*, 2012). In this study, the reproductive success of *B. orthotaenia* only occurred after the confluence with the Abaeté River, a midsize tributary, important for homogenizing the water conditions of the São Francisco River.

Total length, body weight and GSI values for females and males captured in section 2 were higher than those of section 1. Such changes may be related to low values of temperature, dissolved oxygen and flow recorded immediately downstream of the Três Marias dam. This is probably due to the unfavourable conditions for the somatic growth and gonadal maturation in this section of the river (Sato *et al.*, 2005; Arantes *et al.*, 2010; Domingos *et al.*, 2012), since under altered thermal conditions, production and release of sex hormones decrease (Blázquez *et al.*, 1998). Koger *et al.* (1999) reported that in *Oryzas latipes*, males reproduction is less susceptible to environmental factors than females, such as our canonical correlation results. This pattern has also been reported for *P. argenteus* (Sato *et al.*, 2005). The length-weight ratio for *B. orthotaenia* showed positive allometric growth according Froese (2006). This growth pattern is observed for other species of Neotropical freshwater fishes (Mello *et al.*, 2011).

The breeding season of most Neotropical fishes occurs in the summer, during the rainy season, that provides the best conditions for the species' reproduction (Lowe-McConnell, 1987). In the present study, the largest number of specimens in the maturing/mature stages were recorded during November/December, similar to observations made by Gonçalves *et al.* (2006) for the same species in the Pirapora area of the São Francisco River (17 ° 20'45" S and 44 ° 56'55" W). Gonadal maturation also peaked in November/ December when values for temperature, photoperiod and rainfall

are high in the Neotropical region, which seems to be a constant among migratory fishes of the São Francisco (Brito & Bazzoli, 2003; Sato *et al.*, 2005; Arantes *et al.*, 2011; Boncompagni-Junior *et al.*, 2013). This type of total spawning, as observed in this study for *B. orthotaenia*, was also reported by Gonçalves *et al.* (2006), and seems to be common for fish of the Brycon genus (Andrade-Talmelli *et al.*, 2001; Alexandre *et al.*, 2009).

The number and diameter of vitellogenic follicles are reproductive parameters related to female health, which are influenced by extrinsic factors such as food availability and water temperature (Kinnison *et al.*, 1998; Patiño & Sullivan, 2002; Armstrong & Witthames, 2012). Fecundity estimates are essential for determining the reproductive potential of fish species, and their values are important for understanding the biological status and the reproductive potential of a population (Kennedy *et al.*, 2009). When compared to some other Neotropical teleost, like those with non-migratory strategy, *B. orthotaenia* showed a high fecundity, a common characteristic for migratory fish that exhibit total spawning (Suzuki *et al.*, 2000; Arantes *et al.*, 2010).

Identifying life strategy is important for the conservation of natural stocks of fish (Lowe-McConnel, 1987). Migratory species typically have a reproductive strategy of periodic type, with high fecundity rates which are dependent of favourable environmental conditions for triggering the reproductive process (Winemiller & Rose, 1992). In the present study, *B. orthotaenia* presented a periodic strategy, with high fecundity rate and total spawning, occurring during the period of high flow, dissolved oxygen concentration and water temperature in section 2.

Maturing and spent testis of *B. orthotaenia* presented spermatozoa embedded in acidophilic secretion. Previous studies showed that this secretion contains glycoproteins and glycoconjugates which probably play a role in maintaining the pH of the seminiferous tubules and spermatozoa nutrition (Gonçalves *et al.*, 2006). This secretion has also been observed in other Neotropical Characiformes and Siluriformes (Melo *et al.*, 2011; Martins *et al.*, 2012).

It is known that the conservation of dam free tributaries is important for fish reproduction in dammed rivers, acting as alternate routes or homogenizing unfavourable water conditions (Godinho *et al.*, 2007; Hoeinghaus *et al.*, 2009). This study showed the importance of Abaeté River, a mid-sized tributary, for the reproduction of *B. orthotaenia*, an endemic and endangered species of the São Francisco River. Preserving

this tributary is important to minimise the impact of the hypolimnion water released from the Três Marias dam which impairs the reproduction of the ichthyofauna.

The authors thank the partnership of CEMIG-GT / CODEVASF and the Brazilian research foundations of CNPq, CAPES and FAPEMIG for financial support, and also Dr. Stephen Latham for his review of the English language in this document.

4 CONCLUSÕES

- *Brycon orthotaenia* não reproduz no trecho do rio São Francisco logo a jusante da barragem de Três Marias;
- Na confluência do rio São Francisco com o rio Abaeté, observa-se o sucesso reprodutivo de *B. orthotaenia*;
- O tributário rio Abaeté deve ser preservado para a conservação da ictiofauna da bacia do rio São Francisco.

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