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Length-weight relationships of native and non-native fishes in a subtropical coastal river of the Atlantic Rain Forest

Relação peso-comprimento de espécies nativas e não nativas de um rio subtropical da Mata Atlântica

Barbara Maichak de Carvalho[1*], Larissa Faria[1,2], Natali Oliva Roman Miiller[1,2], Henry Louis Spach[2] and Jean Ricardo Simões Vitule[1,2]

[1]Laboratório de Ecologia e Conservação, Departamento de Engenharia Ambiental, Universidade Federal do Paraná – UFPR, Av. Coronel Francisco Heráclito dos Santos, 100, Jardim das Américas, CEP 81531-980, Curitiba, PR, Brasil

[2]Programa de Pós-graduação em Ecologia e Conservação – PPGECO, Universidade Federal do Paraná – UFPR, Av. Coronel Francisco Heráclito dos Santos, 100, Jardim das Américas, CEP 81531-980, Curitiba, PR, Brasil

*e-mail: bmaicarvalho@gmail.com

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Abstract: Aim: The objective was to describe the LWR of fish species of the Guaraguaçu River, as well as to compare the LWR parameters of the non-native species with the parameters obtained in their native ranges, available in the literature. **Methods:** In this study, the LWR of 10 fish species of the Guaraguaçu River, southern Brazil, were analyzed. Fish were sampled semiannually between 2004 and 2007, using different sampling techniques in the Guaraguaçu River. **Results:** A total of 673 specimens of 10 species were captured. The LWR demonstrated a prevalence of species (six out of 10) with positive allometric growth ($b > 3$). The remaining species presented isometric ($b = 3$, two species) or negative growth ($b < 3$, two species). Native species exhibited the same LWR from previous studies, except *Centropomus parallelus*, which presented an isometric growth in this study. The non-native species *Clarias gariepinus* and *Ictalurus punctatus* showed significant differences between the LWR parameters in the Guaraguaçu River and in their native distribution, but the same growth pattern. *Oreochromis niloticus* did not present significant differences in the allometric coefficient from its native range. **Conclusions:** These results indicate that different environmental conditions may not influence the growth pattern of non-native species, which explains their invasion success due to high adaptability to new environments.

Keywords: alien species; Atlantic Rain Forest; fisheries; ichthyofauna; length-weight relationships.

Resumo: Objetivo: O objetivo foi descrever os parâmetros LWR das espécies nativas e não nativas do rio Guaraguaçu e comparar esses parâmetros das espécies não nativas obtidos no rio Guaraguaçu com os parâmetros de LWR dos seus locais de distribuição nativa disponível na literatura. **Métodos:** Os exemplares foram coletados semestralmente entre 2004 e 2007, usando diferentes técnicas de amostragens. **Resultados:** No total, foram analisados 673 exemplares de 10 espécies. Seis espécies apresentaram alometria positiva ($b>3$) e três alometria negativa ($b<3$) e isometria ($b=3$). Espécies nativas possuem parâmetros de LWR idênticos a estudos prévios, exceto *Centropomus parallelus*, a qual apresentou isometria neste estudo. As espécies não nativas *Clarias gariepinus* e *Ictalurus punctatus* demonstraram diferenças significativas entre os parâmetros de LWR do Guaraguaçu e das suas áreas de distribuição nativa. *Oreochromis niloticus* não apresentou diferença significativa entre os parâmetros de LWR entre o Guaraguaçu e sua área nativa de distribuição. **Conclusões:** O resultado indica que as condições ambientais talvez não influenciem o crescimento das espécies não nativas, o que explicaria o sucesso de invasão destas espécies.

Palavras-chave: espécies exóticas; Floresta Atlântica; pesca; ictiofauna; relação peso-comprimento.

The Neotropical region is one of the richest regions regarding the number of fish species (Abell et al., 2008; Reis et al., 2016). Located in this region is the Atlantic Rain Forest, which harbors a high diversity of fish in a variety of habitats such as lagoons, streams, rivers, and estuaries (Abilhoa et al., 2011). This complex ecosystem is an important hotspot of biodiversity in the world, with a high rate of endemism, and at the same time presenting some of the most degraded habitats due to high human occupation rates (Myers et al., 2000; Laurance, 2009; Ribeiro et al., 2009). Several studies have reported the impact of anthropogenic actions in rivers of the Atlantic Rain Forest (Best, 2019) and one of the most prominent of these, is the introduction of non-native species (Vitule et al., 2006, 2019; Faria et al., 2021).

The length-weight relationship (LWR) is a useful tool for supporting fish biology studies, because it allows to estimate the fish weight based on the length (Le Cren, 1951; Froese, 2006). This data can be applied to estimating biomass and elaborate stock and growth models (Haimovici & Canziani, 2000). Also, the LWR allows the assessment the body condition, which can provide information about fitness, such as growth, reproduction, behavior, and survival, indicating the health of fish populations (Gubiani et al., 2020). The variability in the LWR can be influenced by several factors such as the life stage, season, and environmental conditions, thus re-estimates of LWR are recommended to complement species information and allow comparisons through space and time (Froese, 2006; Possamai et al., 2020). The LWR could be helpful to evaluate the variation in exotic fish communities and the effects of control programs and management policies (Sánchez-González et al., 2020). Also, it is possible to assess the population parameters of native species co-occurring with non-native species, to investigate potential competitive interactions and changes in fitness (Irons et al., 2007).

Despite the great biodiversity of freshwater fish in the Atlantic Rain Forest (Abilhoa et al., 2011), few studies to date have described the LWR of its species. This study aims to describe the LWR of native and non-native species in the Guaraguaçu River and compare the LWR parameters of non-native species to those obtained in their native distribution. The data obtained with this study will provide subsidies for future monitoring of the non-native species' life history in recently colonized environments, unraveling important mechanisms of the invasion process itself.

Fish were sampled semiannually in the Guaraguaçu River (25°42'S - 38°31'W) between 2004 and 2007. Fish samplings were performed using trawl nets, line and hook, cast net, small funnel traps, longline, and gillnets of different mesh sizes (4, 6, and 8 cm).

All specimens were identified and had their total length (Lt, cm) and total body weight (Wt, g) recorded in the laboratory. LWR was adjusted through the following equation (Huxley, 1924): $Wt = a\ Lt^b$, where a is the scaling coefficient, and b is the allometric coefficient. Both coefficients were determined using the least-squares method (Carvalho et al., 2017). The allometric coefficient determines whether the body growth pattern is isometric ($b = 3$) or allometric, where values larger than 3 indicate positive allometry (fish grows faster in weight than in length) and values smaller than 3 indicate negative allometry (fish grows faster in length than in weight).

The allometric coefficients obtained from the LWR of each species were compared with the null hypothesis of $b = 3$ (isometry) to reveal the type of growth pattern, using a *t*-test. To verify differences between the LWR of non-native species in the newly colonized area and their native range, the allometric coefficient of the non-native fish in Guaraguaçu River was compared with the values available in the literature for their native distribution, using a *t*-test. All statistical analyses were performed in the software R 3.6 (R Core Team, 2015) considering a significance level of $p = 0.05$.

A total of 673 individuals of 10 species were captured (seven native and three non-native) belonging to nine families (Table 1). The allometric coefficient ranged from 2.61 to 3.39 (mean ± SD = 3.096 ± 0.24). Three different growth types were identified, and the coefficient of determination ranged from 0.76 to 0.99 (Table 1). Only *Gymnotus carapo* and *Clarias gariepinus* presented negative allometric growth, as this species has an elongated body shape, growing faster in length. *Centropomus parallelus* and *Oreochromis niloticus* showed isometric growth, while all other species exhibited positive allometric growth. In total, 60% of the species showed positive allometric growth ($b > 3$, $p < 0.05$), 20% showed negative allometric growth ($b < 3$, $p < 0.05$), and 20% of the species presented isometric growth ($b = 3$, $p > 0.05$) (Table 1).

The comparison of the allometric coefficient of non-native species between the Guaraguaçu River and their native ranges showed significant

Table 1. Length-weight relationship parameters of ten fish species of Guaraguaçu River, Paraná, Brazil, sampled between 2004 and 2007. Equation parameters: scaling coefficient (*a*), allometric coefficient (*b*), and coefficient of determination (r^2). Deviation from isometric growth ($b = 3$) was tested by a Student's *t*-test. Bold values denote $p < 0.05$. N is a native species and NN is a non-native species.

Family	Species	n	Total Length (cm)		Total Weight (g)		Equation parameters			t-test	
			min	max	min	max	a	b	r^2	t	p-value
Centropomidae	*Centropomus parallelus* (N)	116	2.2	40	0.11	587	0.0094	2.96	0.97	-0.75	0.43
Cichlidae	*Geophagus brasiliensis* (N)	56	2.2	32	0.15	710	0.0127	3.11	0.99	24.4	**<0.0001**
Cichlidae	*Oreochromis niloticus* (NN)	16	17	43.3	96.82	1,750	0.0189	3.01	0.97	1.83	0.086
Clariidae	*Clarias gariepinus* (NN)	51	36	88.5	365	4,550	0.0101	2.92	0.96	-14.8	**<0.0001**
Clupeidae	*Platanichthys platana* (N)	150	2.5	7.2	0.08	3.97	0.047	3.3	0.94	22.7	**<0.0001**
Erythrinidae	*Hoplias malabaricus* (N)	97	6	63	3	3,600	0.0084	3.07	0.96	17.2	**<0.0001**
Gerreidae	*Eugerres brasilianus* (N)	78	2.4	7.8	0.2	5.86	0.075	3.2	0.96	14.3	**<0.0001**
Gymnotidae	*Gymnotus carapo* (N)	10	11	43.8	8	340	0.014	2.61	0.95	-18.8	**<0.0001**
Heptapteridae	*Rhamdia quelen* (N)	79	14.2	40	13	790	0.0024	3.39	0.76	34.6	**<0.0001**
Ictaluridae	*Ictalurus punctatus* (NN)	20	27	66.5	150	3.35	0.002	3.39	0.98	53.9	**<0.0001**

Table 2. Comparison of the allometric coefficient (*b*) estimated for non-native species between their native range (*b*1) and the recently colonized Guaraguaçu River (*b*2). Bold values denote $p < 0.05$.

Species	Allometric coefficient		t-test		Reference of b1
	b1	b2	t	p-value	
Clarias gariepinus	2.84	2.92	13.7	<0.0001	Lederoun et al. (2016)
Ictalurus punctatus	3.49	3.39	-13.42	<0.0001	Hilling (2015)
Oreochromis niloticus	3.017	3.01	-0.014	0.9885	Shalloof & El-Far (2017)

differences for *C. gariepinus* and *I. punctatus,* whereas the *O. niloticus* coefficient did not differ between the two regions (Table 2).

The LWR of six native species presented the same pattern observed in previous studies (Costa et al., 2014; Silveira & Vaz-dos-Santos, 2015; Vaz-dos-Santos & Gris, 2016). Only *C. parallelus* presented a different growth pattern from the previously positive allometric growth described in another location in Southeastern Brazil (Costa et al., 2014). For *C. parellelus* this result may represent a smaller allocation of energy compared to others locations. Even the LWR of *Platanichthys platana* determined earlier by Teixeira-de-Mello et al. (2011) based only on small sample size (n = 9) presented the same pattern in this study (n = 150) showing consistency in the pattern regardless of the sample size.

The non-native species *C. gariepinus*, *I. punctatus* and *O. niloticus* showed the same growth pattern in the Guaraguaçu River compared to their native distribution, despite the significant differences observed in the allometric coefficient value. Many endogenous and exogenous factors may contribute to change patterns of fish growth (Carvalho et al., 2017), such as temperature. *Clarias gariepinus* and *O. niloticus* are native from Asia and Africa and *I. punctatus* is native from North America (Tyus & Nikirk, 1990; De Graaf & Janssen, 1996; Naeem et al., 2010). The Guaraguaçu River has a lower water temperature (Weyl et al., 2016) than most African rivers and higher temperatures when compared to North American rivers (Kaushal et al., 2010; Lawson, 2011). The same allometric coefficient of *O. niloticus* in the Guaraguaçu River and in its native range also indicates the high adaptability of the species to a wide range of conditions. Indeed, the allometric coefficient of *O. niloticus* is already described for many locations, frequently indicating isometric growth (Kosai et al., 2014). This consistent pattern also shows that biotic and abiotic factors have little influence in the growth of this species, which explains its successful invasions.

Although we recognize the limitations of our study, such as the different sampling methods that unbalance the samples, the predominance of juveniles and the small N for certain species, the data presented here is important as a temporal reference for comparison in future monitoring in the Guaraguaçu River. We highlight that measuring LWR parameters was not the main objective in our monitoring, but we identified its importance because for Guaraguaçu River this description was non-existent. The Guaraguaçu River is an important coastal river of the Paraná State, located in a hotspot for conservation, and that serves as a source of subsistence fishing in the region. To date, this is the first study that describes the LWR in the region and draws attention to the differences in the allometry coefficient of non-native species in the Atlantic Rain Forest and in their native ranges. The results obtained are fundamental to understanding the fish biology in the region and subside future studies on fisheries and conservation.

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