Acta Limnologica Brasiliensia

Publication of the Brazilian Association of Limnology

Original Article

Acta Limnologica Brasiliensia, 2021, vol. 33, e18

https://doi.org/10.1590/S2179-975X10919

ISSN 2179-975X on-line version

Fish-food interaction network around cage fish farming in a neotropical reservoir

Rede de interações peixe-alimento ao redor de piscicultura com tanque-rede em um reservatório neotropical

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Cite as: Brandão, H. et al. Fish-food interaction network around cage fish farming in a neotropical reservoir. *Acta Limnologica Brasiliensia*, 2021, vol. 33, e18.

Abstract: Aim: Investigating whether wild fish accept residual ration from cage fish farming to the point of changing their diet and the fish-food interaction network. **Methods:** The diet of fish species, *Astyanax lacustris*, *Iheringichthys labrosus*, *Leporinus amblyrhynchus*, *Schizodon nasutus* and *Steindachnerina insculpta*, bred in Chavantes Reservoir, Upper Paraná basin, was evaluated. Samples were collected on a monthly basis - from March 2008 to February 2009 - around the cage fish farming (NC) and in a reference site (RS) free from the influence of the fish farming activity. Results were analyzed through graphs and metrics of complex network analysis, and Permutational analysis of variance. **Results:** The total number of 641 individuals belonging to all five fish species were collected, 292 in NC and 349 in RS. The total amount of food items consumed by them comprised 24 items in NC and 22 items in RS. The fish-food interaction network has shown nested pattern in the two evaluated areas, which evidenced the generalist structure of this interaction. Connectance values and mean degree of interaction networks were low. Detritus was the most representative item consumed in both sampling sites. Three of the five evaluated species (*A. lacustris, S. nasutus* and *I. labrosus*) had residual ration in their diet. Residual ration was the fourth most consumed item in NC. It was also the most representative food item for *A. lacustris* and *S. nasutus*. **Conclusions:** Results have shown that cage fish farming activity can influence trophic interactions in aquatic systems, as well as evidenced the ability of *S. nasutus*, *L. labrosus* and *A. lacustris* to take advantage of new food items in their environment.

Keywords: aquaculture; Chavantes Reservoir; ecological interaction; teleost.

Resumo: Objetivo: Nós verificamos se peixes selvagens se alimentam de ração residual proveniente de piscicultura em tanques-rede, alterando a dieta e a rede de interação peixe-alimento. **Métodos:** Foram avaliadas as dietas de *Astyanax lacustris*, *Iheringichthys labrosus*, *Leporinus amblyrhynchus*, *Schizodon* *nasutus* e *Steindachnerina insculpta* do Reservatório Chavantes, Bacia do Alto Paraná. Os peixes foram coletados mensalmente de março de 2008 a fevereiro de 2009 ao redor da área de piscicultura (*net cage - NC*) e em uma área de referência (*reference site – RS),* sem a influência das atividades de piscicultura. Nós verificamos os resultados usando gráficos e métricas da análise de redes complexas e análise de variância permutacional. **Resultados:** Foram coletados 641 indivíduos das cinco espécies de peixes, 292 na área NC e 349 na RS. No total 24 itens alimentares foram consumidos pelos peixes em NC e 22 em RS. A rede de interação peixe-alimento apresentou padrão aninhado nas duas áreas avaliadas, demonstrando a estrutura generalista desta interação. Os valores de conectância e grau médio da rede de interação foram baixos. Detrito foi o item mais consumido nas duas áreas avaliadas. Três das cinco espécies avaliadas (*A. lacustris*, *S. nasutus* e *I. labrosus*) tiveram ração residual em suas dietas. Ração foi o quarto item mais consumido na área NC, sendo o mais frequente em indivíduos de *A. lacustris* e *S. nasutus*. **Conclusões:** Os nossos resultados mostram que a atividade de piscicultura usando tanques-rede pode influenciar as interações tróficas dos sistemas aquáticos, bem como, demonstram a habilidade de *S. nasutus, L. labrosus* e *A. lacustris* em consumirem o novo item alimentar inserido no ambiente.

Palavras-chave: piscicultura; reservatório Chavantes; interações ecológicas; teleósteos.

1. Introduction

Aquaculture is one of most relevant zootechnical activities in constant development worldwide. It happens due to the demand for aquatic products for human consumption (Vélez et al., 2017). Brazil has 139 registered aquaculture parks distributed in 1,556 different sites that, all together, cover 941,38 hectares (Lima et al., 2018). Although aquaculture is increasing in the Brazilian territory, this activity faces several environmental regulation challenges, such as conflicts of interest and questionable sustainability (Nobile et al., 2020).

Negative effects caused by cage fish farming systems have already been investigated in marine (Bartozek et al., 2014; Hedberg et al., 2015; Price et al., 2015; Tomassetti et al., 2016; Barrett et al., 2019) and freshwater ecosystems (Hakanson, 2005; Carvalho et al., 2012; Demétrio et al., 2012; Ramos et al., 2013; Kliemann et al., 2018; Nobile et al., 2018, 2020) in several regions all around the globe. This activity leads to changes in natural environments, wild animal populations and landscape. Changes in landscape comprise the insertion of physical structures (cages) for fish breeding in captivity (Ramos et al., 2013; Brandão et al., 2014; Zaniboni-Filho et al., 2018). Moreover, high fish-stocking densities within these farms accumulate biomass amounts in open systems far beyond the natural levels and can provide considerable amount of trophic food for wild animals living out of cages (Ramos et al., 2013; Brandão et al., 2014; Barrett et al., 2019). Changes in benthic macroinvertebrate communities (Cyrino et al., 2010; Nabirye et al., 2016) is another negative effect of cage fish farming systems. Thus, researchers have been trying to get to consensus between sustainable fish production and damage to aquatic ecosystems, based on procedures such as delimiting suitable locations for aquaculture sites, using mathematical modeling to determine the carrying capacity of the environment (David et al., 2015) and, more recently, Integrated Multitrophic Aquaculture - IMTA (see Ning et al., 2016; Montalto et al., 2017).

The aim of the current study was to analyze aquaculture-related impacts on wild fish populations. The fish-food interaction network structure in cage fish farming was investigated based on food items consumed by five wild fish species, which were compared to the diet of fish living in environment free from fish farm systems (herein called reference site). The main hypothesis was that the investigated fish would include residual ration from fish farming in the local fish-food interaction system, thus turning it into one of the main consumed food items and changing the food web of the aquatic community living in this environment.

2. Material and Methods

2.1. Study site

The study was carried out in private cage fish farming in Chavantes Reservoir, Paranapanema River, Paraná State, Brazil. The reservoir is located 480 meters above sea level, as well as presents maximum depth ranging from 70 m to 90 m, total volume of 9,410 x 10^6 m^3 and total area of 400 km^2 (Duke Energy, 2008).

Two sites were selected for the current study: one around cage fish farming (NC) (23°7'29.03" S 49°37'38.97" W), and another one located 3 km upstream the fish farming, in order to avoid any kind of influence from it (Reference Site - RS) (23°7'55,58" S 49°36'14,03" W) (Figure 1). The

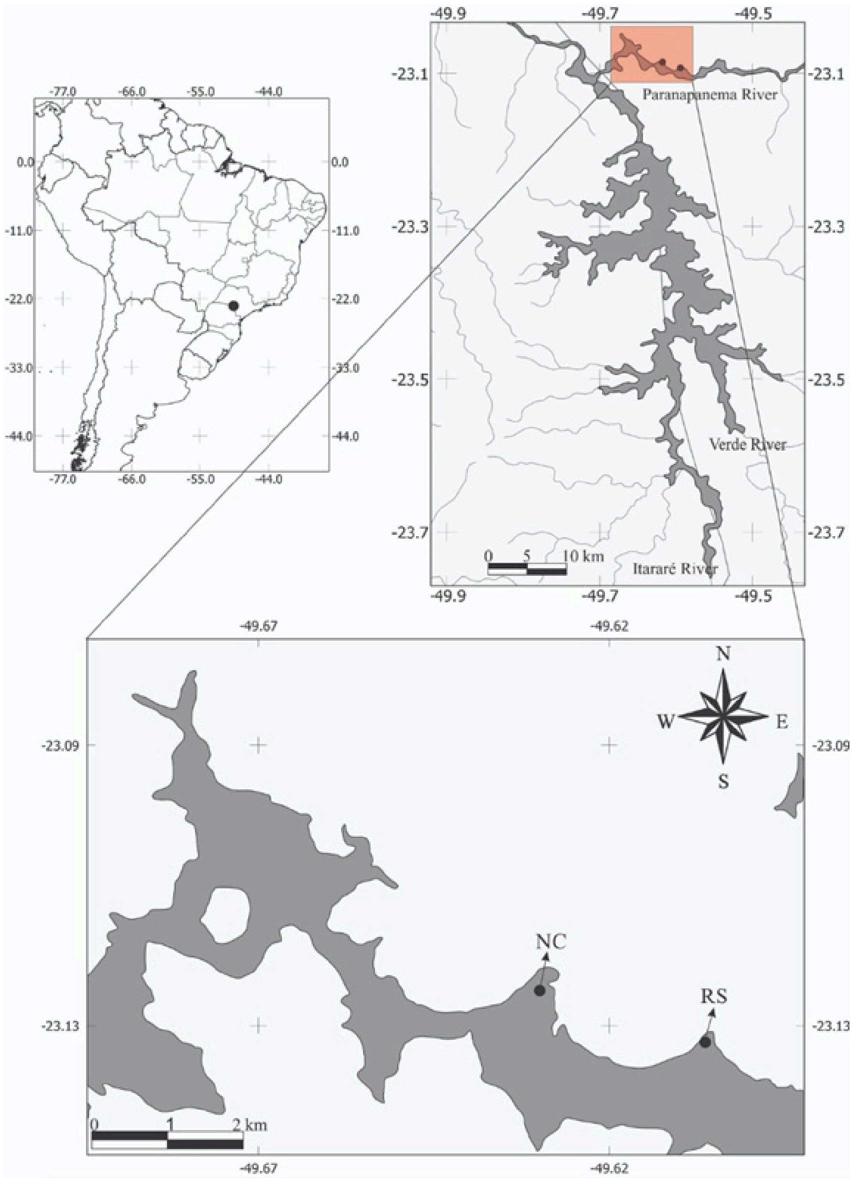

Figure 1. Location of Chavantes Reservoir in Paranapanema River, Brazil. Sites: fish farming with net cage and reference site.

two selected sites present rocks, mesophilic forest fragments and coastline with aquatic macrophytes.

2.2. Fish capture

Fish were captured with gill nets at different mesh sizes (3 cm to 14 cm between nonadjacent knots; height ranging from 1.44 m to 2.20 m), from 5:00 p.m. to 7:00 a.m., on a monthly basis, from March 2008 to February 2009 (IBAMA/ICMBio license: 15549-1). In total, 27 fish species were collected in these sites during this period (see Nobile, 2010); however, only 5 fish species were selected for the current study, based on the following features: (i) presence on both sites (NC and RS) and at the same capture periods, (ii) abundance of individuals to enable comparison between sites, and (iii) recorded incidence in Paraná basin (Buckup et al., 2007; Graça & Pavanelli, 2007; Brandão et al., 2009). *Astyanax lacustris* (Lütken, 1875), *Iheringichthys labrosus* (Lütken, 1874); *Leporinus amblyrhynchus* Garavello and Britski, 1987; *Schizodon nasutus* Kner, 1858; and *Steindachnerina insculpta* Fernández-Yépez, 1948 were the five selected species. Dietary analysis of other collected species had already been published in studies such as Brandão et al. (2012, 2013, 2014).

Vouchers of the evaluated fish species (*A. lacustris* LBP 4794; *I. labrosus* LBP 4811, *L. amblyrhynchus* LBP 4581, *S. nasutus* LBP 4821, *S. insculpta* LBP 4823) were deposited at Laboratório de

Biologia e Genética de Peixes (LBP), Instituto de Biociências of Universidade Estadual Paulista (UNESP), Botucatu County, São Paulo State, Brazil.

2.3. Analysis of stomach contents

Stomach contents were examined in stereomicroscope. Food items were identified based on the following identification keys: Bicudo & Bicudo (1970), for algae; Mugnai et al. (2010), for invertebrates; and Ota et al. (2018), for fish. These items were quantified based on the gravimetric method by Hyslop (1980) by using the mass of each item measured in precision analytical balance (0.0001 g). Whenever this procedure could not be performed, as in the case of small items, a value (%) was attributed to the total mass of stomach contents.

Properties of the interaction network established between individuals belonging to all five investigated species and food items found in their digestive system were analyzed based on two adjacency matrices built (one for each site) with, and without, these interactions. Only individuals presenting food items in their digestive system were taken into consideration in this analysis, namely: *L. amblyrhynchus* (RS = 07; NC = 07), *S. nasutus* (RS = 39; NC = 13), *A. lacustris* (RS = 126; NC = 77), *I. labrosus* (RS = 31; NC = 83), and *S. insculpta* (RS = 49; NC = 10).

2.4. Data analysis

Complex network analysis was applied to test the hypothesis that the residual ration escaping the cages can change the trophic network of the ichthyofauna. Two fish-food interaction networks were built (one for each site) based on two matrices presenting, or not, food items consumed by fish. Metrics used to analyze the interaction network structures were described as follows: network connectance, mean value recorded for food items consumed by fish (mean degree *sensu* Dormann et al., 2009); the principal–peripheral core (Lange et al., 2013) of food items in the networks. The existence of nestedness (NODF - Nestedness metric based on Overlap and Decreasing Fill, Almeida-Neto et al., 2008) in the networks were also investigated in Aninhado software, version 3.0 (Guimarães Júnior & Guimarães, 2006). The significance of NODF index was estimated through Monte Carlo procedure, based on 1,000 randomizations to the null model (Ce), which kept the total value of fixed lines during randomizations (Guimarães Júnior & Guimarães, 2006). NODF index ranges from 0 (no nestedness) to 100 (perfect nestedness) and measures to which extent few fish interactions form a subset of fish interactions accountable for the establishment of more interactions (Almeida-Neto et al., 2008). Thus, bipartite networks are nested when species presenting fewer interactions are preferentially associated with a subset of species that interact with the most connected ones (Bascompte et al. 2003). Connectance of networks (C) is the proportion at which possible interactions are performed: $C = L/(I^{*}J)$, wherein L = performed interactions; I = number of fish individuals; J = number of food items (Jordano, 1987). Maximum connectance value is 1, when all species are connected to food items. In order to assess the composition of food items along the principal–peripheral core of networks, consumption core was calculated based on (G_C): $G_C = (k_i - k_{mean})/z$, wherein k_i is the number of individual food item-fish interactions in each network, k_{mean} is the number of all food item-fish interactions in each network, and z is the standard deviation (SD) of the number of food item-fish interactions in each network. $G_C > 1$ corresponds to food items presenting higher interaction rates than the other items; therefore, these items belong to the principal core. $G_C < 1$ corresponds to food items presenting lower interaction rates than the other items; therefore, these items belong to the peripheral core (Dáttilo et al., 2013). Pajek 5.0 software package (Batagelj & Mrvar, 1998) was used to plot the bipartite graphs.

One-way PERMANOVA analysis was performed based on Bray-Curtis distance to test differences in diet composition between sites (Anderson, 2001). Subsequently, the Percent Similarity method (SIMPER overall pool) was applied, also based on Bray-Curtis distance (Clarke, 1993), to investigate the food items mostly contributing to these differences. One-way PERMANOVA and SIMPER overall pool analyses were performed in the Primer + Permanova 6.0 software. P value < 0.05 was adopted as significance threshold in all statistical analyses.

3. Results

The total number of 641 individuals belonging to five fish species were collected: 292 in NC and 349 in RS. The total amount of food items consumed by the investigated fish comprised 24 items in NC and 22 items in RS (Figure 2). Only NC had exclusive items, spider and residual ration (herein considered as particles). Each fish consumed

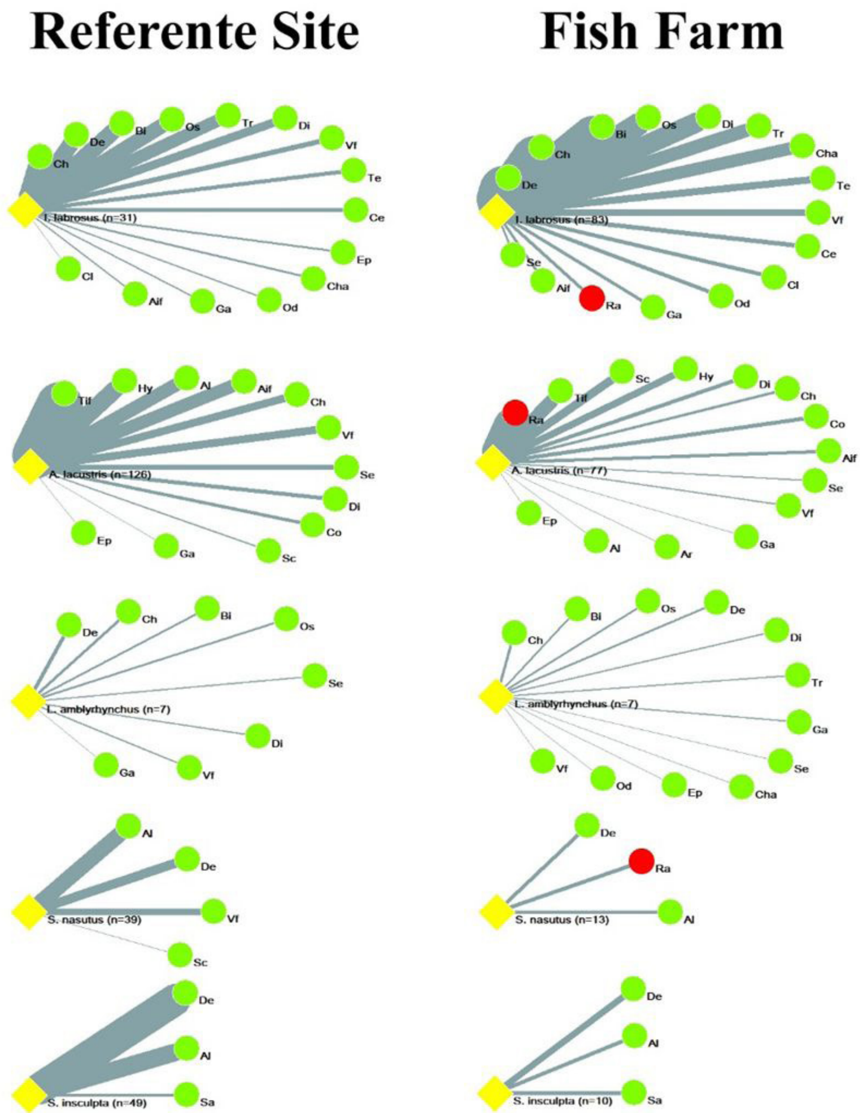

Figure 2. Representation of total interaction network recorded for all five fish species in the fish farming (NC) and reference sites (RS). Edge thickness represents the number of interactions among individuals belonging to the investigated fish species (yellow diamonds), food item (green circles) and residual ration (red circles). For a list with the codes used in the networks, please see Table 3.

2.01 food items in RS and 2.88 in NC, presenting the average degree of fish in network. The low mean degree value reflected the connectance of food item-fish interaction networks, which only resulted in 9.16% possible interactions established in RS and in 12.03%, in NC. These results are indicative that the investigated fish species were generalists, since they consumed different food items.

The two investigated networks presented low, although significant, nested pattern (RS = 13.91; $p < 0.01$, and NC = 13.51; $p<0.01$), and showed that individuals who ate a small variety of food items consumed the same items as those consumed by individuals who ate a larger variety of them. This outcome has indicated that the most specialized individuals in the network were actually a subgroup of more generalist individuals (Figure 2).

Three fish species consumed residual ration, namely: *S. nasutus*, *I. labrosus* and *A. lacustris* (Figure 2). They presented differences in diet composition between sampling sites (*S. nasutus*; $F_{[1]} = 3.730$; *I. labrosus*, $F_{[1]} = 6.535$; and *A. lacustris*, $F_{[1]} = 32.842$; all species $p < 0.001$; Table 1). *Astyanax lacustris* consumed residual ration almost exclusively (87.3%) (Table 1 and Figure 2). *Leporinus amblyrhynchus* ($F_{[1]} = 1.140$, $p = 0.338$) and *S. insculpta* ($F_{[1]} = 8.578$, $p = 0.985$) did not present differences in diet composition between

Table 1. Food item mass percentage consumed by all five fish species caught around the fish farming (NC) and in the reference site (RS) in Chavantes Reservoir, Paraná State, Brazil. The highest values were highlighted in bold. Dashes (-) mean absence of consumption or too low consumption values.

Food items	*S. insculpta*		*I. labrosus*		*A. lacustris*		*S. nasutus*		*L. amblyrhynchus*	
	NC	RS	NC	RS	NC	RS	NC	RS	NC	RS
Number of individuals	**11**	**51**	**121**	**50**	**127**	**146**	**17**	**58**	**16**	**44**
Length class ranges (cm)	*11-15*	*9.6-14.5*	*10.5-21*	*12-20.5*	*6.2-14.5*	*6-11.5*	*10.6-26*	*10.5-29*	*10.3-16.6*	*9.4-14.2*
Algae	6.4	4.3	-	-	0.6	10.5	6.8	**76.6**	-	-
Aquatic Insect fragments	-	-	0.6	1.0	0.5	5.5	-	-	-	-
Araneae	-	-	-	-	0.003	-	-	-	-	-
Bivalvia	-	-	5.1	**39.7**	-	-	-	-	1.5	14.4
Calboridae	-	-	0.3	0.3	-	-	-	-	0.1	-
Ceratopogonidae	-	-	0.03	0.5		-	-	-	-	-
Chironomidae	-	-	7.9	8.0	0.1	0.5	-	-	11.4	16.2
Cladocera	-	-	0.1	0.005	-	-	-	-	-	-
Coleoptera	-	-	-	-	0.6	3.3	-	-	-	-
Cyanophycea	-	-	-	-	-	-	-	-	-	-
Detritus	**47.1**	**93.1**	**74.2**	39.0	-	-	**75.9**	5.2	2.2	**62.2**
Diptera	-	-	0.3	1.2	0.1	0.3	-	-	0.3	1.3
Ephemeroptera	-	-	-	0.1	0.004	0.01	-	-	0.7	-
Gastropoda	-	-	0.1	0.9	0.008	0.1	-	-	**22.8**	0.8
Hemiptera	-	-	-	-	-	-	-	-	-	-
Hymenoptera	-	-	-	-	3.3	29.3	-	-	-	-
Insect fragments	-	-	-	-	-	-	-	-	-	-
Odonata	-	-	0.7	0.9	-	-	-	-	1.7	-
Ostracoda	-	-	0.6	6.0	-	-	-	-	0.1	0.6
Residual ration	-	-	6.0	-	**87.3**	-	17.3	-	-	-
Sand	46.5	2.6	-	-	-	-	-	-	-	-
Scales	-	-	-	-	4.4	0.02	-	0.2	-	-
Seed	-	-	0.3	-	1.5	21.1	-	-	0.03	3.4
Tecameba	-	-	0.1	0.005	-	-	-	-	-	-
Terrestrial insect fragments	-	-	-	-	1.4	**24.4**	-	-	-	-
Trichoptera	-	-	0.5	2.2	-	-	-	-	0.5	-
Vegetable fragments	-	-	3.3	0.1	0.2	4.9	-	17.9	**58.6**	1.1
Total of items	**3**	**3**	**16**	**15**	**14**	**12**	**3**	**4**	**12**	**8**

sampling sites. With respect to habits, *I. labrosus*, *L. amblyrhynchus* and *A. lacustris* consumed food from different origins, which indicated omnivorous diet, whereas *S. insculpta* and *S. nasutus* preferentially consumed detritus, which indicated detritivore diet (Tables 1, 2 and 3, and Figure 2).

Items mostly consumed in the net cage site comprised detritus, Chironomidae, Bivalvia and residual ration (94, 75, 62 and 60 records, respectively (Table 3). Other consumed items encompassed seeds, Coleoptera, sand, Cladocera (six occurrences, each), Ephemeroptera (two occurrences), and spider (one occurrence). Items mostly consumed in the reference site comprised detritus, algae and terrestrial insect fragments (95, 72 and 71, respectively; Table 3). Other items encompassed Ceratopagonidae, Tecameba, Coleoptera and Gastropoda. The incidence of other items can be checked in the Table 3 and in Figure 2.

4. Discussion

Results have shown that three of the five evaluated species (*A. lacustris, S. nasutus*, and *I. labrosus*) consumed residual ration deriving from cage fish farming activities and presented diet composition different from fish populations living under natural environmental conditions. The other evaluated fish species, *L. amblyrhynchus,* fed on gastropods and Chironomidae in RS - which can be associated with local organic enrichment resulting from the entry of organic matter deriving from fish farming (Kliemann et al., 2018), as well as with increased number of pollution-tolerant organisms, such as *Chironomus* sp. (Nabirye et al., 2016). *Leporinus amblyrhynchus* has been evaluated

Table 2. Similarity Analysis (SIMPER) applied to food items consumed by three species that fed on residual ration between sampling sites: fish farming (NC) and reference site (RS) in Chavantes Reservoir, Brazil.

A. lacustris						
AD = 93.18						
Food item	MA - NC	MA - RS	A/D	DISS/SD	C %	CC
Residual ration	0.23	0.0	35.91	1.15	38.54	38.54
Terrestrial insect fragments	0.02	0.07	17.58	0.89	18.86	57.4
Hymenoptera	0.02	0.04	11.19	0.52	12.01	69.41
Algae	0	0.03	6.07	0.38	6.52	75.92
Aquatic insect fragments	0.01	0.02	5.72	0.42	6.13	82.06
Seeds	0.01	0.02	4.07	0.28	4.36	86.42
Coleoptera	0.01	0.01	3.2	0.3	3.44	89.86
Scales	0.02	0.0	3.18	0.33	3.41	93.27
I. labrosus	MA - NC	MA - RS	A/D	DISS/SD	C %	CC
AD = 59.69						
Food item						
Detritus	0.23	0.12	23.18	1.37	38.83	38.83
Bivalvia	0.05	0.07	8.73	0.99	14.62	53.45
Chironomidae	0.07	0.05	7.59	1.05	12.71	66.16
Ostracoda	0.01	0.04	5.13	0.76	8.59	74.75
Trichoptera	0.01	0.02	3.84	0.89	6.43	81.18
Vegetable fragments	0.02	0.01	2.2	0.43	3.68	84.86
Diptera	0.01	0.01	2.04	0.91	3.42	88.28
Residual ration	0.02	0.0	1.63	0.21	2.73	91.01
S. nasutus						
AD = 85.55	MA - NC	MA - RS	A/D	DISS/SD	C %	CC
Food item						
Algae	0.07	0.32	30.38	1.04	35.51	35.51
Detritus	0.2	0.08	24.44	0.89	28.56	64.07
Residual ration	0.13	0.01	18.27	0.82	21.35	85.42
Vegetable fragments	0.0	0.1	11.58	0.5	13.54	98.96

Average dissimilarity AD; Contribution % (C); Cumulative contribution % (CC); Mean abundance in fish farming (MA - NC); Mean abundance in reference site (MA - RS); Average dissimilarity A/D and Standard Deviation of dissimilarity DISS/SD.

Table 3. Number of food item-fish interactions and classification of food items into principal-peripheral core (G_C index) for networks in Figure 2.

Code	Food items	Number of Interactions		Classification of principal-peripheral core	
		RS	NC	RS	NC
De	Detritus	95	94	**Main**	**Main**
Al	Algae	72	12	**Main**	Peripheral
Tif	Terrestrial insect fragments	71	21	**Main**	Peripheral
Ch	Chironomidae	46	75	Peripheral	**Main**
Vf	Vegetable fragments	32	13	Peripheral	Peripheral
Bi	Bivalvia	29	62	Peripheral	**Main**
Hy	Hymenoptera	27	11	Peripheral	Peripheral
Os	Ostracoda	26	38	Peripheral	Peripheral
Aif	Aquatic insect fragments	22	9	Peripheral	Peripheral
Di	Diptera	21	38	Peripheral	Peripheral
Tr	Trichoptera	19	23	Peripheral	Peripheral
Se	Seeds	10	6	Peripheral	Peripheral
Ce	Ceratopogonidae	6	7	Peripheral	Peripheral
Te	Tecameba	6	11	Peripheral	Peripheral
Co	Coleoptera	5	6	Peripheral	Peripheral
Ga	Gastropoda	4	8	Peripheral	Peripheral
Ep	Ephemeroptera	4	2	Peripheral	Peripheral

Table 3. Continued...

Code	Food items	Number of Interactions		Classification of principal-peripheral core	
		RS	NC	RS	NC
Sa	Sand	4	6	Peripheral	Peripheral
Cha	Chaoboridae	3	20	Peripheral	Peripheral
Sc	Scales	3	13	Peripheral	Peripheral
Od	Odonata	2	7	Peripheral	Peripheral
Cl	Cladocera	1	6	Peripheral	Peripheral
Ar	Araneae	-	1	-	Peripheral
Ra	Residual ration	-	60	-	**Main**

as omnivorous (the current study), herbivorous and even as piscivorous (Braga, 1990; Hahn et al., 1998; Luiz et al., 1998). *Schizodon nasutus* and *I. labrosus* also consumed residual ration, although at lower amounts. It seemed like "accidental consumption" since detritus was the main item observed for both species. However, it did not apply to *S. insculpta*, which had detritus as the main food item and did not show evidence of residual ration. However, *S. insculpta* consumed small particles mixed to detritus, and it hindered the proper identification of its stomach contents.

Changes in food availability from allochthonous resources, such as residual ration, can affect populations at all trophic network levels (Ramos et al., 2013). Our outputs revealed that fish species can almost exclusively feed on residual ration, as observed for *A. lacustris* (87.3%) around in fish farming (NC), whereas terrestrial insect fragments were the main food item in the diet of this species in the RS site. Ramos et al. (2013) have investigated *A. lacustris* feeding on diet composed of insect fragments; they observed this very same pattern and vegetable fragments in natural environment. *Astyanax lacustris* is considered omnivorous (Pereira et al., 2016) and its high ration intake can indicate the likely ability to buffer the ration input into the environment as biofilter, as observed in other studies (Felsing et al., 2005; Ramos et al., 2008; Xia et al., 2016). However, it is worth emphasizing that this condition should not be used as isolated solution to control artificial feed import. The addition of trophic changes in the system have led to other negative effects such as reduced richness and diversity of wild ichthyofauna in these changed environments (Nobile et al., 2018).

According to Barrett et al. (2019), the effects of cage fish on fish abundance and diversity are likely dependent on the assessed functional group; most surveys conducted with fish populations at fishing farms and reference sites often target mobile generalist carnivores. The input of allochthonous food resources can favor opportunistic and generalist species belonging to the local ichthyofauna by exploiting the new resource available in the environment.

This outcome was also observed through the greater network connectance in NC. Although the authors claim that node addition to the network tends to decrease connectance (Yodzis, 1980), the potential to use residual ration deriving from cage fish farming in the current study has shown that the network presenting the largest number of nodes was also the most connected one. The strategy of using the new food available in the environment was also observed for *Apareiodon affinis* (Steindachner, 1879) and *Pimelodus maculatus* Lacepede, 1803 in this very same artificial Neotropical reservoir (Brandão et al., 2012, 2014).

It is worth mentioning that resource composition patterns observed in the ecosystem differ among aquatic habitats, as well as that the environmental conditions in the local habitat can significantly affect resource availability in trophic networks (Doi, 2009). Thus, it is necessary enabling the permanent monitoring of environments subjected to strong human influence, such as large artificial reservoirs.

Although both interaction networks presented nested pattern and virtually the same food items, the rank of items in the bipartite graph varied between sites. This difference may have been caused by the presence of residual ration in NC and by variations in food availability. Since nutrient availability was not assessed in these sites, it was not possible getting to a more accurate conclusion about variations in the rank of food items available in the networks. However, the current findings have shown that the presence of residual ration has influenced the fish-food item interaction and, consequently, the food chain in this ecosystem when the investigated fish incorporated ration to the network.

According to Dunne et al. (2002), changes in food chain structure mediate the effects of biodiversity loss, such as secondary and cascading extinctions. The aforementioned authors also argue that these extinctions affect ecosystems in different ways, depending on the trophic functions of the removed species.

Studies about ecological networks have shed light on how complex nature can persist and on how it affects ecosystem functioning (Winemiller, 1990; Woodward & Hildrew, 2002; Woodward, 2009; Ings et al., 2009). It is essential understanding these aspects in order to predict and potentially mitigate the consequences of increasing environmental disturbances, such as habitat loss, climate change and invasion by non-native species (Ings et al., 2009).

Results have confirmed the hypothesis of the current study. They have shown that the fish fauna, which changed the trophic network of local fish-food interactions, used residual ration deriving from fish farms. Thus, these results can contribute to the elaboration of management plans and to the development of policies focused on the conservation and preservation of continental ecosystems.

Acknowledgements

The authors would like to thank Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP processes 2007/58246-4 and 2008/52139-4), for the scholarship granted to the first author and for the auxiliary financial resources (FAPESP process number 07/58246-4). The authors are also grateful to Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), for the financial and scientific support (Finance Code 001). I.P.R. is supported by Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) (process 303311/2018-5). We also thank the team of Laboratório de Biologia e Ecologia de Peixes (LABECO), Instituto de Biociências de Botucatu and the Universidade Estadual Paulista (UNESP), for providing the infrastructure to conduct this study.

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Received: 07 September 2019
Accepted: 01 July 2021

Associate Editors: Ronaldo Angelini