










Cage fish farm causes the homogenization of wild fish diets of different sizes

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ABSTRACT

We evaluated the influences of cage fish farm on the individual diet of *Geophagus sveni*, a wild species nonnative to the Paraná river basin, and hypothesized that, in areas where there are no cage fish farms (CT), differences in feeding occur between larger and smaller individuals. In addition, in cage fish farm areas (CF), there are no differences in feeding between smaller and larger individuals due to the consumption of pelleted feed. For this, we evaluated the stomach contents of individuals of different body sizes sampled in CT and CF areas. We observed significant differences in diet between larger and smaller individuals only in the CT area, corroborated by positive and negative relationships between food items and standard length. In the CF area, we observed pelleted feed consumption by individuals of different sizes and only positive relationships between food items and standard length. Thus, the cage fish farms interfered with the consumption of natural food resources, promoting a more homogeneous diet among smaller and larger individuals. In this context, because of the importance of trophic segregation for intrapopulation coexistence and population stability, this homogenization can promote an imbalance in population dynamics.

Keywords: Aquaculture; Anthropic influence; Freshwater; Diet; *Geophagus sveni*.


Piscicultura em tanques-rede causa homogeneização das dietas de peixes silvestres de diferentes tamanhos

RESUMO

Avaliamos as influências de uma piscicultura em tanques-rede na dieta individual de *Geophagus sveni*, uma espécie silvestre não nativa da bacia do rio Paraná, e levantamos a hipótese de que em áreas onde não há piscicultura em tanques-rede (CT) ocorre diferença na alimentação entre indivíduos maiores e menores. Além disso, em área de criação de peixes em tanques-rede (CF), não há diferença na alimentação entre indivíduos menores e maiores por causa do consumo de ração peletizada. Para isso, avaliamos o conteúdo estomacal de indivíduos de diferentes tamanhos corporais amostrados em uma área CT e em uma área CF. Observamos diferenças significativas na dieta entre indivíduos maiores e menores apenas na área de CT, corroboradas por relações positivas e negativas entre os itens alimentares e o comprimento padrão nessa área. Na área CF, observamos o consumo de ração peletizada por indivíduos de diferentes tamanhos e apenas relações positivas entre os itens alimentares e o comprimento padrão. Assim, a piscicultura em tanques-rede interferiu no consumo dos recursos alimentares naturais, promovendo uma dieta mais homogênea entre os indivíduos menores e maiores. Nesse contexto, em razão da importância da segregação trófica entre os indivíduos para a coexistência intrapopulacional e estabilidade populacional, essa homogeneização pode promover um desequilíbrio na dinâmica populacional.

Palavras-chave: Água doce; Aquicultura; Dieta; *Geophagus sveni*; Influência antrópica.

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INTRODUCTION

Cage fish farms have been extensively implemented in coastal and continental areas due to their efficiency in intensive cultivation and ease of implementation in these environments (Agostinho et al., 2007; Frisso et al., 2020). The cages of cage fish farms are made up of nets that allow water to circulate, carrying uneaten pelleted feed, scales, feces, and remains of dead fish to the adjacent aquatic environment (Barrett et al., 2018; Cacho et al., 2020; Nobile et al., 2020). Thus, this cultivation system could interfere with the trophic status of the surrounding environment (Cacho et al., 2020), particularly the foraging behavior of wild aquatic organisms (Ramos et al., 2013; Nobile et al., 2020; Kliemann et al., 2022), along with various with physiological (i.e., liver steatosis and histopathology) and health effects (i.e., infection by parasites) (Barrett et al., 2018; Kliemann et al., 2018; Nobile et al., 2020). Several studies have reported how cage fish farms affect the diet of wild fish in marine (Barrett et al., 2018; Tičina et al., 2020) and freshwater environments (Barrett et al., 2018; Nobile et al., 2020; Brandão et al., 2021; Kliemann et al., 2022). However, resource use has been evaluated at the population level and did not account for variation in the feeding of individuals with different body sizes.

Feeding changes of the wild fish during growth tend to be related to body morphology, as well as mouth size, which restricts the size range of the prey (Mittelbach & Persson, 1998; Cuthbert et al., 2020). Fish can consume phytoplankton, zooplankton, and small invertebrates when young, and large invertebrates, fish, and plants when adults (Neves et al., 2015; Kliemann et al., 2019; Sánchez-Hernández et al., 2019). In addition to body and mouth size, vision and swimming performance also limit foraging ability and habitat use (Nunn et al., 2012; Sánchez-Hernández et al., 2019). Thus, adult and juvenile fish exhibit different feeding habits (Kliemann et al., 2019). This difference can also be associated with changes to energy requirements during development (Gerking, 1994) and the availability of food guiding the foraging strategy of individuals (Sánchez-Hernández & Cobo, 2018; Sánchez-Hernández et al., 2019). Thus, cage fish farms that alter the environment's resource availability could interfere with fish's dietary intraspecific variation.

Among the neotropical wild fish species influenced by cage fish farms (see Kliemann et al., 2018; Nobile et al., 2018; Brandão et al., 2021; Kliemann et al., 2022), *Geophagus sveni* Lucinda, Lucena, & Assis, 2010 (Cichlidae: Cichlinae) is strongly influenced by the cage fish farm because of its trophic opportunism. *Geophagus sveni* is a wild and nonnative species, abundant in the Paraná river basin (traversing Brazil, Paraguay,

and Argentina in South America) (Ota et al., 2018). This species has omnivorous feeding habits and trophic plasticity, consuming food items available in the environment [Moretto et al., 2008 (*Geophagus proximus* = *G. sveni*); Kliemann et al., 2018 (*G. proximus* = *G. sveni*), Kliemann et al., 2022; Ota et al., 2018]. Given this characteristic, in areas influenced by cage fish farms, this wild species has directly consumed excess pelleted feed from tilapia (*Oreochromis niloticus* (Linnaeus, 1758)) farming cages (Kliemann et al., 2018, 2022). In this context, considering that trophic segregation during growth favors intraspecific coexistence (Sánchez-Hernández et al., 2019), evaluating the diet of individuals of different size classes is important to understanding the influences of cage fish farms on the wild fish population.

Here, we evaluated how cage fish farm affects the diet of *G. sveni* individuals at different body sizes. Based on previous studies showing that body and mouth size, vision, and swimming performance limit foraging ability and habitat use (Nunn et al., 2012; Sánchez-Hernández et al., 2019), we hypothesized that, in areas where there is no cage fish farm, differences in feeding occur between larger and smaller individuals. However, in cage fish farm areas, where pelleted feed is available in the environment (Kliemann et al., 2018, 2022; Ramos et al., 2022), there are no differences in feeding between smaller and larger individuals due to the consumption of pelleted feed. We expect that in the cage fish farm area, all evaluated individuals consume pelleted feed, influencing the consumption of natural food resources, and promoting a more homogeneous diet among smaller and larger individuals.

MATERIALS AND METHODS

Study area

Collections were carried out in two areas with similar physiographic characteristics (Kliemann et al., 2022) in the Ilha Solteira reservoir, São Paulo state, Brazil. One sampling area contained the cage fish farm (CF) (20°2'33.62"S; 50°55'57.60"W). The other area was approximately 10 km upstream and had no effects from any cage fish farm, representing the control (CT) (20°0'13.71"S; 50°51'58.94"W).

The Ilha Solteira reservoir was formed in 1965 and is an accumulation reservoir located at the confluence of the Grande, Paranaíba, and Paraná rivers. This reservoir has an average depth of 17.6 m, a maximum volume of 21.060×10^6 m³, a basin area of 1.195 km², an average flow of 5.206 m³·s⁻¹, and a residence time of 46.7 days (Garcia et al., 2014). Approximately 70 CF enterprises were operating in this reservoir (Carmo et al., 2021).



The cage fish farm used in this study was in the Grande River, Can-Can Arm (Fig. 1). This CF farmed Nile tilapia (*O. niloticus*) and had approximately 230 cages with 18 m³ and 18 cages with 144 m³. Pelleted feed was supplied at a rate of approximately 4,500 kg/day, according to the personal communication with the owner of the fish farm.

Fish sampling

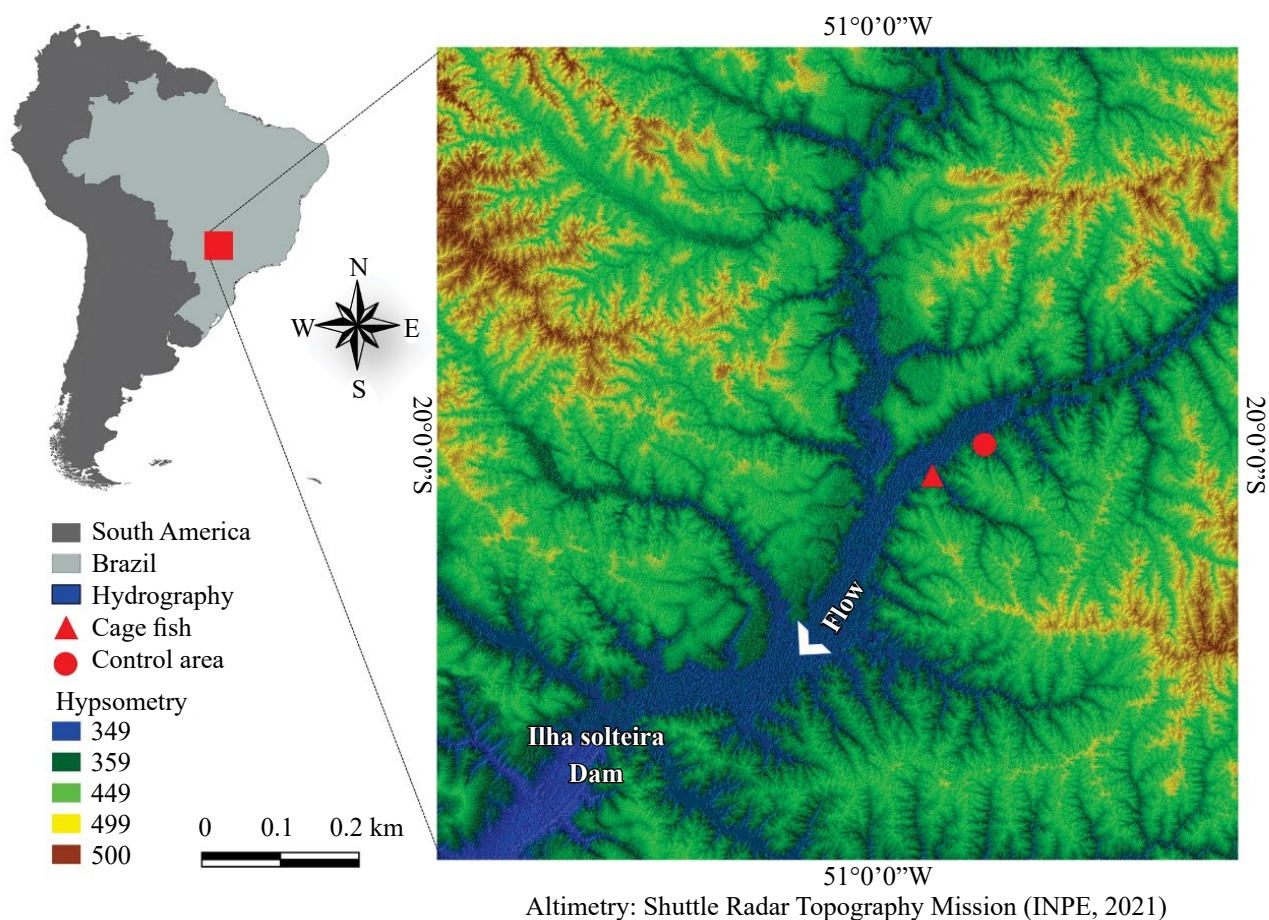
Geophagus sveni individuals were collected bimonthly during 2014, 2016, and 2019 with gillnets of different mesh sizes (two lots with meshes 3–7 cm and one lot with meshes 7–16 cm in both areas and in all collection years). In the cage farm area, the gillnets were installed between the cages perpendicular to the riverbank (certificate Sistema Nacional de Gestão do Patrimônio Genético e do Conhecimento Tradicional Associado no. A278D23 and no. A908D5F; Sistema de Autorização e

Informação em Biodiversidade authorization no. 42229-5 and no. 64763-1). Comitê de Ética em Experimentação Animal da Universidade Estadual Paulista “Júlio de Mesquita Filho” authorization number 001/2014 and 006/2019.

Laboratory procedures

The individuals were identified, and their standard length (cm) and total weight (g) were measured. Vouchers were deposited in the fish collection belonging to the Instituto de Biociências, Letras e Ciências Exatas of the Universidade Estadual Paulista “Júlio de Mesquita Filho”, Campus São José do Rio Preto, São Paulo state, Brazil (*G. sveni* DZSJRP-Pisces 8898).

The stomachs of the individuals were removed, fixed in a 4% formaldehyde solution, preserved in 70% alcohol, and examined under an optical stereomicroscope. Food items were separated and identified to the lowest possible taxonomic level based on



Altimetry: Shuttle Radar Topography Mission (INPE, 2021)

Source: Inpe (2022).

Figure 1. Sampling areas in the Ilha Solteira reservoir, Upper Paraná river, São Paulo state, Brazil.

existing studies, namely, Bicudo & Bicudo (1970) for algae, Mugnai et al. (2010) for invertebrates, and Ota et al. (2018) for fish. Detritus was identified in three categories: sediment (river sediment), plant material (remains of plant material that could not be identified), and organic material (organic material that could not be identified). We quantified stomach contents using the volumetric method (Hyslop, 1980), in which the displacement of each food item was measured using a graduated Petri dish for small foods and a graduated beaker for large foods (Hellawell & Abel, 1971).

Data analyses

Data were analyzed comparing two groups: smaller and larger individuals. For this aggragation, once the size of the first maturity of *G. sveni* is not known, we used the standard-length point threshold for dietary change indicated in the threshold rate indicator analysis (TITAN) to classify the smaller and larger groups. This analysis is based on the principles of indicator species analysis (IndVal) and change-point analysis (nCPA) identifying indicator taxa (food items) between levels of a continuous variable (standard length) (Baker & King, 2010). The threshold for change in CT was 10 cm, and in CF, it was 12.5 cm. Thus, in the CT area, individuals with a standard length < 10 cm were grouped into smaller (SM) group, and individuals > 10 cm were grouped into larger (LG) group. However, in the CF area, individuals with a standard length < 12.5 cm were grouped into SM groups, and individuals > 12.5 cm were grouped into LG groups.

To compare the significance of differences in the food composition of *G. sveni* between SM and LG groups in each sampling area, we adopted one-way multivariate permutation analysis of variance (PERMANOVA) using the Bray-Curtis distance with 999 random permutations (Anderson, 2001). To verify whether the observed differences were related to the differences in the diet composition between groups ($p > 0.05$) or only the dispersion or heterogeneity of the samples ($p < 0.05$) (Anderson, 2006), a permutation analysis of multivariate dispersions (PERMDISP) was applied to the same dataset. This analysis measures the distance of the multivariate average of the group to the centroid through a principal coordinate analysis (PCoA) (Silva et al., 2017). The calculation of the group average was performed using the Bray-Curtis dissimilarity measure. In addition, a permutation test was calculated to compare the average distance of each individual to the group average. The permutation test is a pseudo-F-ratio test, like the F-ratio in analysis of variance. The p-value was obtained through 999 permutations of least squares residuals (Anderson, 2006).

To verify which food items contributed to the difference in diet composition between SM and LG groups, the overall pool similarity analysis SIMPER was applied (Clarke, 1993) with the same data matrix and Bray-Curtis distance (Hammer et al., 2001).

To evaluate the trophic niche breadth between SM and LG groups in each sampling area, the PERMDISP was also used. In this case, the differences in the distance between the individuals indicate that some individuals have more restricted or broader diets than others (Correa & Winemiller, 2014; Silva et al., 2017). In addition, the average distance to the centroid indicates the average niche breadth. The comparison was tested using a permutation test through 999 permutations of least squares residuals (Anderson, 2006).

To check for changes in the diet of individuals of different sizes, the TITAN analysis was also applied in each sampling area. The direction of the response was negative (z-) when values above the threshold caused consumption to decrease and positive (z+) when consumption increased. Uncertainty in change points and consistency in the response direction of each food item were estimated by the purity and reliability. Purity and reliability were obtained by resampling and measuring the robustness of the indicator response using 250 permutations and 500 resamplings. Purity and reliability equal to or greater than 0.95 were defined as robust indicators (Baker et al., 2020).

All statistical analyses were performed using the RStudio programming environment (RStudio Team, 2022), with a significance set to $p < 0.05$. PERMANOVA, SIMPER, PERMDISP, and permutation test were performed using the vegan package (Oksanen et al., 2020) and the *adonis*, *simper*, *betadisper*, and *permutest.betadisper* functions, respectively. The TITAN analysis was performed using the TITAN2 package and *titan* function (Baker et al., 2020).

RESULTS

The diet of *G. sveni* in both sampling areas consisted of various food items of animal, vegetable, and artificial origin (pelleted feed). We analyzed the stomachs of 505 individuals (CT-175; CF-329) of 6.2 to 28 cm (CT) and 4.8 to 19 cm (CF) (Table 1). In the CT, the SM group mainly consumed (volumetric percentage greater than 10%) sediment detritus, Gastropoda, and Cladocera. In addition, the LG group mainly consumed Gastropoda, Bivalvia, sediment detritus, and terrestrial plants (Table 1). In the CF, the SM group mainly consumed pelleted feed and sediment detritus; and the LG group mainly consumed pelleted feed, Bivalvia, Gastropoda, and aquatic plants (Table 1).

Table 1. Food items consumed by *Geophagus sveni* in each group with smaller individuals (SM) and group with larger individuals (LG) in the control and cage fish farm area, Ilha Solteira reservoir, Upper Paraná river basin, São Paulo state, Brazil¹.

Site	Control area		Cage fish farm area	
Group	SM	LG	SM	LG
Standard length (min–max cm)	6.2–9.9	10.0–28.0	4.8–12.4	12.5–19.0
Number of individuals	43	132	236	93
Food items	Volumetric percentage (%)			
Cyanophyta		0.26		
Rhodophyta		0.07	0.01	0.08
Algae	1.13	0.10	0.04	*
Aquatic plants		2.92	2.07	10.05
Cladocera	14.78	1.07	0.01	*
Copepoda	0.28	0.03		
Ostracoda	0.73	0.30		
Crustacea			0.61	0.34
Bivalvia	2.35	15.37	8.55	19.80
Gastropoda	15.06	26.94	9.44	11.50
Diptera larvae	2.97	3.89	0.53	3.22
Ephemeroptera	1.47	1.09		
Aquatic insect	8.74	6.91	2.07	1.43
Aquatic invertebrate	9.46	0.60	0.01	*
Fish fragments	0.78	5.11		
Scale			4.65	0.60
Terrestrial insects	0.29	0.10	0.22	0.02
Seed			0.06	6.96
Monocotyledons	6.33	2.48		0.43
Terrestrial plants	1.19	10.08	4.02	2.11
Pelleted feed		0.08	46.46	35.71
Sediment detritus	24.36	13.99	18.37	7.75
Organic detritus	4.20	1.72	1.67	0.03
Plant detritus	5.88	6.96	1.81	0.30

¹Values are based on percentage data for the volume food items. Values in bold represent most important items (volumetric percentage > 10%); *values < 0.01.

We observed significant differences in diet composition between SM and LG groups only in the CT (PERMANOVA CT - DF = 1, F = 4.75, $p = 0.001$; CF - DF = 1, F = 1.66, $p = 0.11$). This significant difference was related to differences in diet composition rather than diet variation between individuals (PERMDISP DF = 1, F = 1.78, $p = 0.18$). The food items that contributed to the difference in CT were Gastropoda, sediment detritus, Bivalvia, terrestrial plants, and aquatic insects, with greater abundance consumption by the LG group (Table 2).

In the CT, the threshold of change in food item consumption was 10 cm. Below 10 cm (smaller individuals), the related food items (z-) were aquatic invertebrates, algae, and Cladocera, indicating that smaller individuals consumed mainly these food items. On the other hand, above 10 cm (larger individuals), the related food items (z+) were aquatic plants, Bivalvia, terrestrial plants, and Gastropoda, indicating that larger individuals consumed mainly these food items (Fig. 2a, Kliemann et al., 2024).

There were no significant differences in the trophic niche breadth between SM and LG groups in each sampling area

Table 2. Results of the dissimilarity analysis (SIMPER) for the proportion of food items consumed by *Geophagus sveni* between the group with smaller individuals (SM) and group with larger individuals (LG) in the control area, Ilha Solteira reservoir, Upper Paraná river basin, São Paulo state, Brazil.

Food items	Overall average dissimilarity	Average dissimilarity	Contribution %	Cumulative %	Average abundance	
					SM	LG
Gastropoda	92.08	17.27	18.8	18.8	0.008	0.026
Sediment detritus		15.36	16.7	35.4	0.010	0.014
Bivalvia		8.31	9.0	44.5	0.003	0.015
Terrestrial plants		7.18	7.8	52.3	0.000	0.010
Aquatic insects		6.81	7.4	59.7	0.004	0.006

(PERMDISP CT - DF = 1, $F = 1.78$, $p = 0.18$; CF - DF = 1, $F = 1.31$, $p = 0.25$). The average distance to the centroid was 0.62 and 0.64 in the CT; and 0.60 and 0.62 in the CF for the SM and LG groups, respectively.

In the CF, the threshold for change in consumption according to the standard length was 12.5 cm. Monocotyledons, Rhodophyta, seeds, Bivalvia, and aquatic plants had positive relationships (z^+) with the standard length and were primarily consumed by individuals > 12.5 cm (Fig. 2b, Kliemann et al. 2024). No items were related to individuals smaller than 12.5 cm.

DISCUSSION

The population of *G. sveni* exhibited differences in feeding between SM and LG individuals in the CT, with smaller individuals consuming smaller prey and larger individuals consuming larger prey. The differences in feeding due to body size have been observed in studies evaluating the ontogeny of other species of the *Geophagus* genus (Meschiatti & Arcifa, 2002; Mazzoni & Da Costa, 2007). Studies demonstrated that juveniles consumed fish scales, whereas adults consumed detritus, plants,

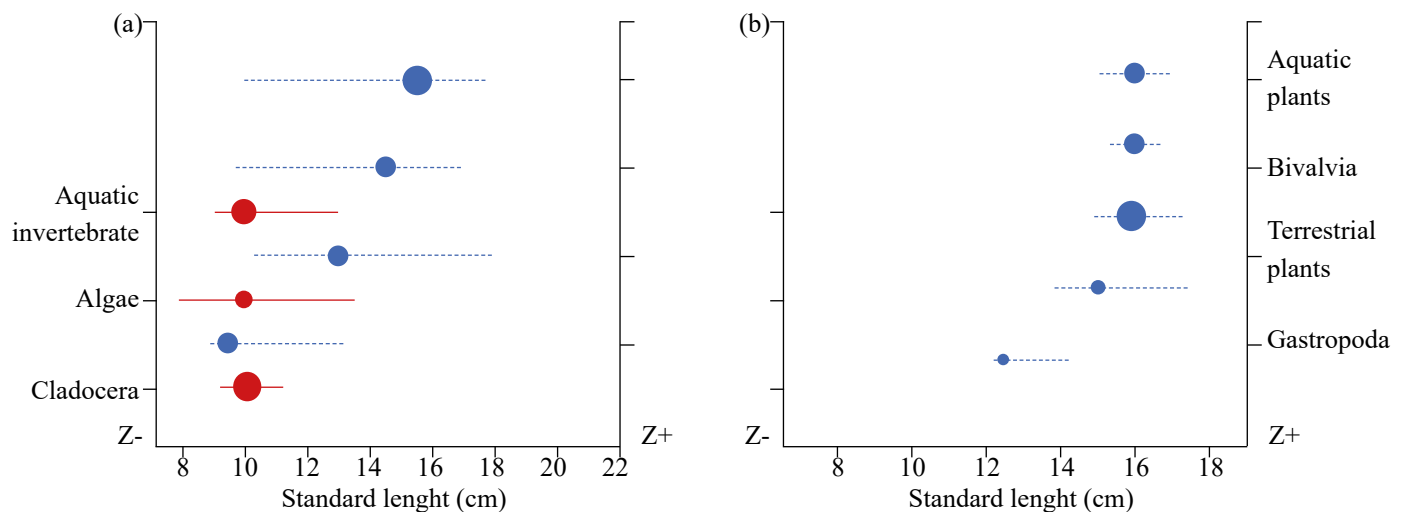


Figure 2. Threshold indicator rate analysis representing changes in the consumption of food items of *Geophagus sveni* in (a) control and (b) cage fish farm area, Ilha Solteira reservoir, Upper Paraná river basin, São Paulo state, Brazil, according to the standard length. The circles represent change points, and their sizes are relative to their z-score values. The bars correspond to confidence intervals ranging from 5 to 95% of 500 bootstrap resamplings. The red points represent food items with negative scores (z^-) and blue points for items with positive scores (z^+) according to the standard length. For additional information, see Kliemann et al. 2024.

aquatic insects, and microcrustaceans (Meschiatti & Arcifa, 2002). In addition, omnivorous feeding habits with carnivorous tendencies were also documented for juveniles, while adults were only omnivorous (Mazzoni & Da Costa, 2007). Here, we observed trophic segregation in this change in diet in the control area. In the cage fish farm area, there were no differences in diet composition and the relationship between standard length and food item sizes, demonstrating that the diet was influenced by pelleted feed availability.

In general, the foraging capacity and food selectivity change during the growth of fish, mainly due to changes in morphological traits (Keppeler et al., 2015; Kliemann et al., 2021). Positive relationships between consumer size and prey size are expected and are commonly reported because mouth size increases during development (Ornelas-García et al., 2018; Baldasso et al., 2019; Manna et al., 2019; Sánchez-Hernández et al., 2019). Thus, fish tend to consume phytoplankton, zooplankton, and small invertebrates during the early stages of life, whereas adults consume large invertebrates and fish (Neves et al., 2015; Kliemann et al., 2019; Sánchez-Hernández et al., 2019). In the control area, this relationship was demonstrated by smaller individuals consuming aquatic invertebrates, microcrustaceans, and algae, whereas larger individuals consumed Gastropoda and plants. The consumption of larger prey meets the cost-benefit ratio of foraging. Based on this ratio, the energy expenditure of capture is lower, and the energy gain in absorption is greater, as predicted by the optimal foraging theory (Schoener, 1974; Montanini et al., 2017; Manna et al., 2019).

The differences in diet between SM and LG groups and the relationship between the size of food items and the size of individuals observed in the control area indicate intraspecific variations in diet. This variation favors growth, population stability, and intraspecific coexistence, all of which are important for the colonization of new environments (De La Torre Zavala et al., 2018; Britton, 2019). Based on the classical niche theory, differentiation in the trophic niche promotes coexistence, which is fundamental for population stability as it reduces intraspecific competition (Hutchinson, 1961; Leray et al., 2019). Therefore, the variation in diet according to the standard length observed might have contributed to the successful colonization of *G. sveni* in the study area since it is an introduced species and one of the most abundant in the study areas evaluated here (see Orlandi-Neto et al., 2022 for abundance).

In the cage fish farm area, the pelleted feed consumption can interfere with the consumption of natural food resources, promoting a more homogeneous diet among individuals. We observed no differences in the diet between the LG and SM groups,

and in the TITAN a higher frequency of consumption of some food items was observed only for larger individuals. In addition, there was no significant relationship between pelleted feed and the standard length of fish, indicating that pelleted feed was consumed by all individuals evaluated. Since the TITAN analysis detects the food item that shows a change in frequency and volume over the standard length (Baker et al., 2020), food items that are not indicated are consumed by all individuals. The opportunism and trophic plasticity of *G. sveni* favored the consumption of pelleted feed, which is abundant and easily obtained in the area surrounding the farm (Nobile et al., 2020; Kliemann et al., 2022), with individuals of all sizes exploring this area.

Specifically, Kliemann et al. (2018, 2022) observed changes in the feeding habits of *G. sveni* due to the consumption of pelleted feed in fish farm areas. Additionally, in the cage farm area, smaller individuals mainly consumed pelleted feed, and larger individuals pelleted feed and other food resources. We suggest that the greater competitive capacity of larger individuals favors the consumption of other food sources. The size-structured dominance hierarchy explains that for territorial fish, such as species in the genus *Geophagus* (Kadry & Barreto, 2010; Oliveira et al., 2016; Souza et al., 2018), larger and more dominant individuals consume the more advantageous food resources (Sánchez-Hernández et al., 2019). Thus, the large competitors access more food, including Bivalvia, aquatic plants, and Rhodophyta (algae), and the pelleted feed, which is easily accessible, was consumed by all individuals.

Another explanation for the results observed in the cage fish farm area might be related to predation pressure. This predation pressure is likely to be higher for small wild fish if feeding opportunities at cage fish farms attract high densities of predators (Barrett et al., 2018). Orlandi-Neto et al. (2022) evaluated the same study area as the one evaluated here and observed a high abundance of *Plagioscion squamosissimus* (Heckel 1840), a carnivorous species, around the rearing cages compared to the control area, reinforcing this inference of greater predation in these areas. Brown (1985) observed that smaller individuals are more prone to predation and adopt different foraging behaviors to avoid it. Consequently, smaller individuals tend to be less dispersed through the water column (Lukoschek & McCormick, 2001) and might consume fewer bivalves and other items attached to cage structures. However, in the control area, where the abundance and pressure of predators tend to be lower due to the lower fish abundance (Barrett et al., 2018), food items such as bivalves could be consumed, explaining the size-based trophic segregation observed in this area.

CONCLUSION

Our study showed that cage fish farms interfered with the consumption of natural food resources, promoting a more homogeneous diet among smaller and larger individuals. We did not observe significant variation in diet between smaller and larger individuals, and we suggest that this is due to the consumption of pelleted feed. Thus, due to the importance of trophic segregation for intrapopulation coexistence and population stability, this homogenization can promote an imbalance in population dynamics. As this is an economically important species, the impacts that these imbalances may have on the fish stock are uncertain. In the short term, pelleted feed consumption has favored the population stock (Orlandi-Neto et al., 2022), but, due to the biological impacts of pelleted feed consumption already reported for *G. sveni* (Kliemann et al., 2018), the long-term response is unknown.

Despite the spatial limitation of our study, several studies reported pelleted feed consumption by wild fish in different reservoirs and marine environments (Barrett et al., 2018; Nobile et al., 2018; Nobile et al., 2020; Tičina et al., 2020; Kliemann et al., 2022), which corroborates our findings. Another important point is the physiological alterations due to pelleted feed consumption (Kliemann et al., 2018; Nobile et al., 2020). The consumption by individuals of different sizes can also indicate possible influences on aspects of reproductively of the immature fish. Therefore, future studies should evaluate whether the physiology of fish is affected by cage fish farms throughout development.

CONFLICT OF INTEREST

Nothing to declare.

DATA AVAILABILITY STATEMENT


The data are available at <https://zenodo.org/records/12551974>.

AUTHORS' CONTRIBUTIONS


Conceptualization: Kliemann, B.C.K., Delariva, R.L., Ramos, I.P.; **Methodology:** Kliemann, B.C.K., Garves, J.D.S., Delariva, R.L., Veríssimo-Silveira, R., Ramos, I.P.; **Investigation:** Garves, J.D.S., Pagliarini, C.D., Ramos, I.P.; **Data curation:** Kliemann, B.C.K., Pagliarini, C.D., Delariva, R.L., Ramos, I.P.; **Formal analysis:** Kliemann, B.C.K.; **Visualization:** Kliemann, B.C.K., Garves, J.D.S., Pagliarini, C.D., Delariva, R.L., Ramos, I.P.; **Resources:** Veríssimo-Silveira, R., Ramos, I.P.; **Funding acquisition:** Veríssimo-Silveira, R., Ramos, I.P.; **Project administration:** Ramos, I.P.; **Supervision:** Ramos, I.P.;

Writing – original draft: Kliemann, B.C.K.; **Writing – review & editing:** Garves, J.D.S., Pagliarini, C.D., Delariva, R.L., Veríssimo-Silveira, R., Ramos, I.P.

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