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Research paper

Does the influence of anthropic impacts reflect on the predator-prey relationship?

Influência de impactos antrópicos refletem na relação predador-presa?

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ABSTRACT: The predator-prey interactions present in communities influence their composition and structure, acting as a controlling force in the spatial and temporal dynamics of populations. In this context, we aimed to evaluate the influence of environmental impacts on the interaction dynamics between predators and prey in environments with different qualitative characteristics. To this end, we collected macroinvertebrates (prey) and fish (predator) in four sampling sites with distinct seasonal periods. Correlation analyses were performed between predators and prey in different scenarios and, afterwards, the type of relationship, positive or negative, was evaluated. However, in our results more positive relationships were found than negative, which may indicate that predation directly affects other types of ecological relationships between prey groups. More significant relationships were exhibited in the upstream versus downstream regions. This fact may be linked to the anthropic impacts observed downstream. In summary, the relationship between predator-prey interactions and environmental quality, predicted in the initial hypothesis, was corroborated, in which upstream regions (with better qualitative characteristics) exhibited this relationship more stable than downstream regions.

Keywords: Uberaba river basin; ecology of communities; human impacts; predation; ecological relationships.

RESUMO: *As interações predador-presa presentes nas comunidades influenciam sua composição e estrutura, atuando como força controladora na dinâmica espacial e temporal das populações. Nesse contexto, objetivamos avaliar a influência dos impactos ambientais na dinâmica interacional entre predadores e presas em ambientes com distintas características qualitativas. Para isso, foram realizadas coletas de macroinvertebrados (presa) e peixes (predadores) em quatro pontos amostrais com distintos períodos sazonais. Foram realizadas análises de correlação entre predadores e presas em diferentes cenários e, posteriormente, avaliado o tipo de relação, positiva ou negativa. Contudo, em nossos resultados foram encontradas mais relações positivas do que negativas, que pode indicar que a predação diretamente afeta outros tipos relações ecológicas entre os grupos de presas. Foram exibidas maiores relações significativas nas regiões a montante em relação a jusante. Este fato pode estar ligado aos impactos antrópicos observados a jusante. Em síntese, a relação entre as interações predador-presa e a qualidade ambiental, prevista na hipótese inicial, foi corroborada, na qual as regiões a montante (com características qualitativas melhores) exibiram esta relação mais estável do que as regiões a jusante.*

Palavras-chave: *Bacia do rio Uberaba; ecologia de comunidades; impactos humanos; predação; relações ecológicas.*

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INTRODUCTION

Populations live and interact with each other in a given area or habitat. Relyea and Ricklefs (2021) define this coexistence between populations as a biotic community, which can interact in various ways (e.g., transfer of energy and matter). This ecological dynamic means that interactions within this community can lead to competition that can influence the number of individuals in the population, even leading to extinction within the community (ODUM, 2010).

This oscillation can be generated by some factors and these can be explained by interactions within a community. According to Cain; Bowman and Hacker (2017) the authors explain that the action of one population can affect the growth rate of another population. Thus, populations can interrelate with each other in a reciprocal manner.

For Chaves and Alves (2010), the survival and reproduction of animals are possible thanks to the availability of energy, that is, the greater the consumption, the greater the energy gain. Predators, for example, have developed various strategies to capture the largest possible number of prey during their foraging actions. In this sense, the theory of optimal foraging proposed by MacArthur and Pianka (1966) stipulates that the energy costs involved in the search for, capture, and manipulation of prey should not be greater than the energy obtained from food items.

According to , Relyea and Ricklefs (2021) populations can interact in several ways: harmonic, with neither population harmed (e. g., neutralism); with one species benefiting while the other is unaffected (e. g., commensalism) and with both populations being favored (e. g., protocooperation or mutualism); and disharmonic, with the two populations vying with each other for a resource (e. g., competition), with one population inhibited while the other is unaffected (e. g., amensalism), with one parasitic species using the other as a host (e. g., parasitism) and with one population feeding on the other (e. g., predation).

Disharmonic interactions can occur in communities, determining, at least in part, their composition and structure. In this context, predation can act as a controlling force in the spatial and temporal dynamics of species. Its effect can assist in the synchrony of population cycles in the predator-prey relationship (CAIN; BOWMAN; HACKER, 2017).

This perspective was experimentally verified by Paine (1966), who observed that removal of predators on tidal rocks drastically reduced herbivore diversity. This reduction occurred primarily by intensifying interspecific competition among herbivores (PAINE, 1966; ODUM, 2010; MORENO; ROCHA, 2012; RELYEA; RICKLEFS, 2021).

It is worth noting that the negative interaction in many cases becomes a mechanism of natural selection, because some populations that do not self-regulate are controlled and prevented from having an overpopulation resulting in the decrease of their abundance (ODUM, 2010, RELYEA; RICKLEFS, 2021).

Mendonça et al. (2015) verified the spatial overlap of densities between fish larvae (e. g., predators) and zooplankton (prey). With this, they evidenced that the daily vertical migration of *H. edentatus* and *P. squamosissimus* larvae is used as an anti-predatory strategy between the larvae and other fish.

Predator-prey interactions have been addressed in different aspects in ecology. In an attempt to understand what determines the diet of a predator, ecologists have focused their special attention on the theory of optimal foraging. This theory is based on developing predictions of how prey and predators adjust their behavior and strategies in response to changes under specific conditions (BEGON; HARPER; TOWSEND, 2007).

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Although predators exhibit wide variability in foraging tactics, in general, they exert strong selection pressure on their prey, influencing escape behavior, this being a response developed over the evolutionary history of predator-prey relationships (CAIN; BOWMAN; HACKER, 2017). The habitat directly influences the relationships, since heterogeneity/complexity exerts a decisive factor in the supply of resources, as well as in the creation of refuge areas. A good example of this relationship is the presence of macrophyte banks that can provide, climate stability, food resources and refugia for several species (AGOSTINHO et al., 2007).

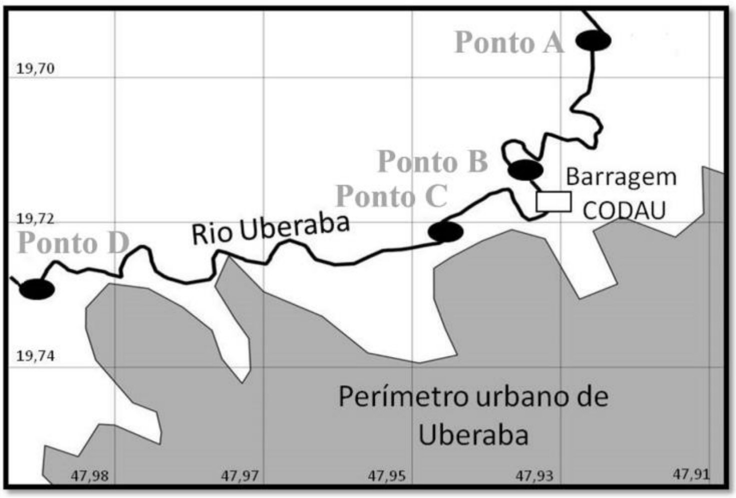
Consistent with these ideas we hypothesize that environmental impacts and changes in the characteristics of the environment influence predator-prey relationships in affected regions. To this end, we aimed to evaluate the influence of environmental impacts on the ecological dynamics of predator-prey at different sites with distinct qualitative characteristics in the Uberaba River, lower Rio Grande basin.

MATERIAIS E METHODS

Study area

The collections were carried out at four different points (Points A; B; C and D), divided into two groups, points A and B located upstream of the dam and points C and D located downstream of the dam, in an established longitudinal length of 100 meters for each point sampled from the Uberaba River, in the municipality of Uberaba-MG (**Figure 1**).

Figure 1. location of the study area in the municipality of Uberaba-MG



Point A is the most upstream region in relation to the other points, with rural area characteristics, located at coordinates 19°38'26.77" S/47°53'12.70" W. According to Souza et al. (2016) and Camargo, Souza, and Buranello (2019), this stretch presents dense riparian forest on both sides, the bed is composed of little fine sediment with abundant rocks of different sizes; the water flow alternates in rapids and pools.

Point B is a region also with rural zone characteristics, located at coordinates 19°42'48.35" S/47°56'17.94" W. Also according to the same authors, this environment has dense riparian forest on the right bank, while on the left bank it shows regions covered with

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grass and others with no forest, its bed is composed of few rocks and fine sediment; its flow is predominantly lentic; it has a strong odor; fixed and free submerged macrophytes occur.

Point C, is a region with greater proximity to the urban perimeter of Uberaba, even so, the environment presents characteristics of rural area regions, located at coordinates 19°43'17.28" S/47°56'51.95" O. According to Souza et al. (2016) and Camargo, Souza, and Buranello (2019), this point displays on its left bank a dense riparian forest and, on its right bank area for grazing activities with the presence of cattle; its bed is composed mainly of large rocks, often exposed out of the water slide, and fine sediment in a few regions; its flow is alternated between rapids and shallow pools; it presents strong odor and oil threads; presence of submerged macrophytes in large quantity.

Point D is the most downstream region among the points, located in the urban perimeter of Uberaba, more specifically in the Alfredo Freire district, near the sewage treatment plant, at coordinates 19°43'45.18" S / 47°59'55.57" W. The same authors report that this stretch has dense riparian forest on both banks; bed composed of rocks and pebbles of different sizes, water flow composed mostly of rapids, but has some backwaters near its edge; has an extremely strong odor; at certain times of the year there is a high concentration of algae.

Sampling

Sampling was carried out in the period from October, December 2014 to March and June 2015, with authorization from SISBIO No. 33448-1. We used sieves of 1.0 x 0.50m, with mesh of 0.3 mm between adjacent nodes for both taxonomic groups (macroinvertebrates and fish) being employed by two employees and 50 minutes of sampling for each point. Additionally, for macroinvertebrates, sediment was collected in a 1 liter PVC pipe. In the laboratory the material was sorted in 25 cm diameter x 10 cm high sieves with apertures of 2, 1 and 0.5 mm. The collected specimens were fixed in 10% formalin and conserved in 70% alcohol. In the laboratory, macroinvertebrates were identified according to Costa, Ide and Simonka (2006) and Mugnai, Nessimian and Baptista (2010), and fish according to Graça and Pavanelli (2007) and Ota et al. (2018).

Data analysis

Interpretations of the related data on predatory interactions were confronted according to Ota et al. (2018). In possession of the data, the relative abundance of all potential predators and prey were tabulated according to their time scale at each point.
After tabulation, a correlation analysis was performed between predators (fish) and prey (macroinvertebrates) following the following analytical blocks: a) relationship between all predators and all prey; b) relationship between all predators and each taxa; c) relationship between each predator and all taxa; d) relationship between each taxonomic category and each taxa. Then, the type of relationship was evaluated, positive or negative, and tested for significance using Spearman correlations, because the data did not meet the necessary assumptions of normality and homoscedasticity. All analyses were performed using the Statistica 7 software (STATSOFT, 2005).

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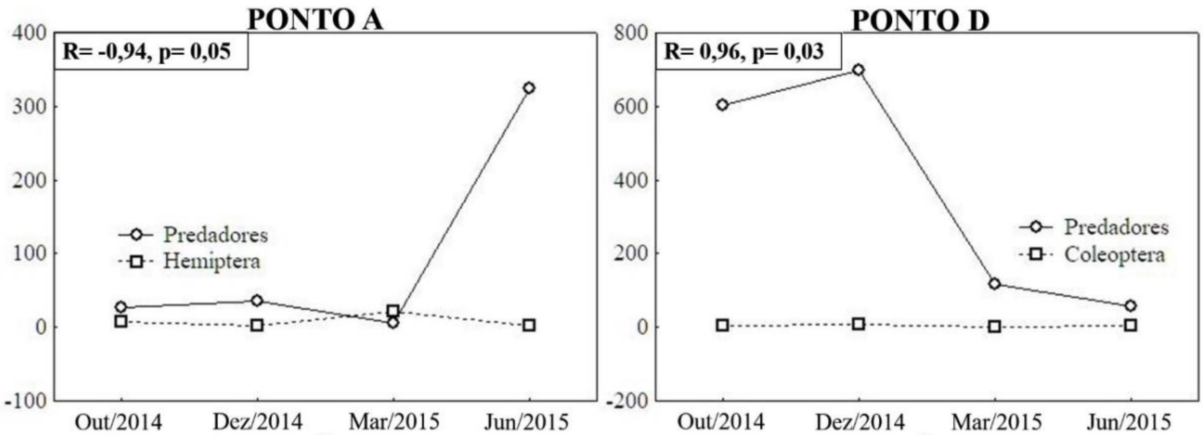
Revista Brasileira de Ciência, Tecnologia e Inovação

RESULTS AND DISCUSSION

Thirty-five taxa were listed, of these, 7 belong to Hexapoda and 28 to the fish taxonomic group. Of these last taxa, 21 species were analyzed in the predator/prey relationship, due to the reports of this interaction found in specialized bibliography (see OTA et al., 2018). Thus, only the species that presented this foraging characteristic or reports of these items in their diet were left (**Table 1**).

In the predator/prey relationship analyses, the analytical block of spatial relationships between predators and orders, those that were significant were at point A, with a negative relationship for predators and Hemiptera, and point D, with a positive relationship for predators and Coleoptera (**Figure 2**).

Figure 2. Spearman's correlation analysis between predators (fish) in general versus prey orders (macroinvertebrates). Negative correlation at point A (upstream) and positive at point D (downstream)



In the analytical block of relationships between predator species and prey orders, significant relationships were found in the following points: point A, between *A. lacustris* and Trichoptera, *P. harpagos* and Trichoptera (negative relationships), *P. harpagos* and Coleoptera, and *G. inaequilabiatus* and Plecoptera (positive relationships) (**Figure 3**); point B, between A. lacustris and Trichoptera (negative relationship), *S. marmoratus* and Diptera, and *P. reticulata* and Odonata, and *P. r*eticulata and Hemiptera (positive relationships) (**Figure 4**).

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Revista Brasileira de Ciência, Tecnologia e Inovação

Table 1. List of taxonomic categories related to the collection points in Uberaba River, municipality of Uberaba/MG, from October to December 2014 and March to June 2015

Order	Point A				Point B				Point C				Point D			
	Oct	Dec	Mar	Jun	Oct	Dec	Mar	Jun	Oct	Dec	Mar	Jun	Oct	Dec	Mar	Jun
ARTHROPODA																
Hexapoda																
Coleoptera	36	16	5	6	0	0	0	0	0	0	6	7	6	7	2	3
Diptera	0	0	1	0	0	34	4	0	0	15	109	423	0	118	3753	633
Ephemeroptera	0	2	19	0	0	0	0	0	0	0	0	0	0	0	0	0
Hemiptera	8	2	22	2	3	12	21	0	2	1	3	9	0	1	3	2
Odonata	12	12	11	9	19	53	136	0	101	113	5	23	0	2	0	0
Plecoptera	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Trichoptera	0	0	1	1	0	0	2	0	0	0	0	0	0	0	0	0
PEIXES																
Characiformes																
Astyanax aff. *paranae*	20	25	0	8	0	0	0	0	0	0	0	0	0	0	0	0
Astyanax lacustris	0	0	2	11	21	14	0	20	0	0	0	0	0	0	0	0
Astyanax bockmanni	0	0	0	32	0	0	0	0	0	0	0	0	0	0	0	0
Astyanax fasciatus	0	0	0	11	0	0	0	0	0	0	0	0	0	0	0	0
Astyanax fuscoguttatus	0	3	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Cichlasoma paranaense	0	1	0	0	2	2	2	0	0	0	0	0	0	0	0	0
Characidium sp.	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Oligosarcus pintoi	0	0	0	0	7	9	10	15	0	0	0	38	0	0	0	0
Siluriformes																
Hypostomus cf. *ancistroides*	1	5	2	132	3	2	0	14	12	0	0	1	0	0	0	1
Hypostomus sp.	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Hypostomus paulinus	0	0	0	12	0	0	0	0	0	0	0	0	0	0	0	0
Hypostomus nigromaculatus	0	0	0	67	0	0	0	0	0	0	0	0	0	0	0	0
Hypostomus Iheringi	0	0	0	17	0	0	0	0	0	0	0	0	0	0	0	0
Rhamdia quelen	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0
Rhamdia pentamaculata	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0
Perciformes																
Geophagus brasiliensis	0	0	0	0	0	6	6	15	1	0	0	0	0	0	0	0
Oreochromis niloticus	0	0	0	0	0	0	0	0	9	0	0	0	289	2	1	0
Cyprinodontiformes																
Poecilia harpagos	5	1	0	0	36	53	55	115	2	0	0	0	0	0	0	0
Poecilia reticulata	0	0	0	0	2	2	14	0	858	37	109	1574	314	696	116	57
Gymnotiformes																
Gymnotus inaequilabiatus	1	0	0	4	2	0	0	1	1	0	0	1	0	0	0	0
Symbranchiformes																
Synbranchus marmoratus	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0

Prey macroinvertebrates: Coleoptera, Diptera, Ephemeroptera, Odonata, Plecoptera, Tricopetera; Predatory fish: Characiformes: *Astyanax aff. Paranae*; *Astyanax lacustris*; *Astyanax bockmanni; Astyanax fasciatus; Astyanax fuscoguttatus; Cichlasoma paranaense. Characidium sp.; Oligosarcus pintoi*. Siluriformes: *Hypostomus cf. ancistroides; Hypostomus sp.; Hypostomus paulinus; Hypostomus nigromaculatus; Hypostomus Iheringi; Rhamdia quelen; Rhamdia pentamaculata.* Perciformes: *Geophagus brasiliensis*; *Oreochromis niloticus.* Cyprinodontiformes: *Poecilia harpagos; Poecilia reticulata*. Gymnotiformes: *Gymnotus inaequilabiatus*, Symbranchiformes: *Synbranchus marmoratus*.

Figure 3. Spearman's correlation analysis between predator species versus prey orders at point A (upstream). A. lacustris and Trichoptera, *P. harpagos* and Trichoptera (negative relationships), *P. harpagos* and Coleptera, and *G. inaequilabiatus* and Plecoptera (positive relationships)

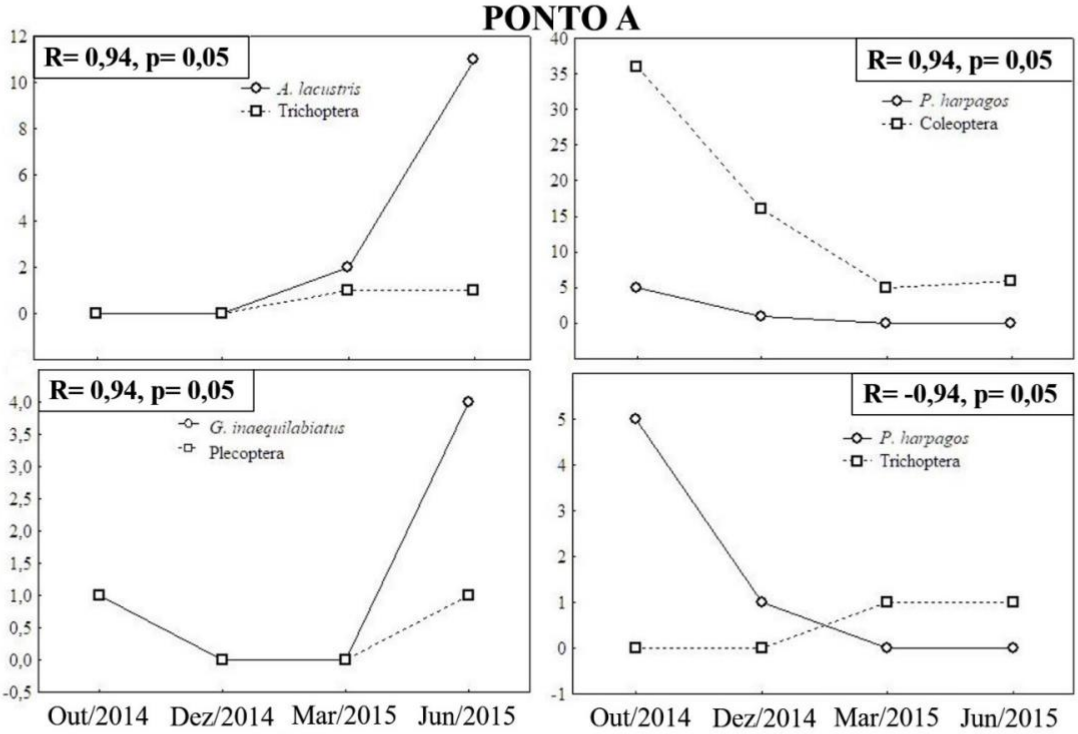
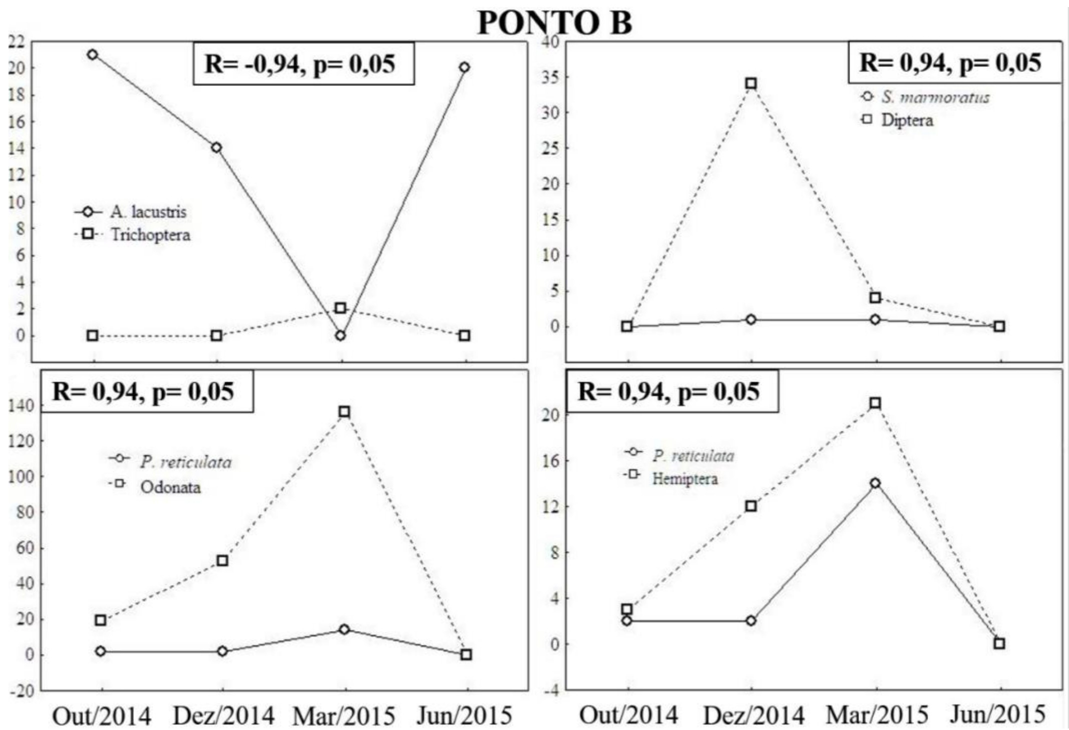


Figure 4. Spearman's correlation analysis between predator species versus prey orders at point B (upstream). *A. lacustris* and Trichoptera (negative relationship), *S. marmoratus* and Diptera, and *P. reticulata* and Odonata, and *P. reticulata* and Hemiptera (positive relationships)



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Significant relationships were not found in the post-dam regions (except for predator relationships in a general context), thus the regions above the dam exhibited these ecological relationships more clearly. This fact may be linked to the anthropogenic impacts observed downstream of the dam, which according to Souza et al. (2016) and Camargo, Souza, and Buranello (2019) negatively affected the composition of aquatic communities. The break in longitudinal flow in the downstream regions of a dam directly affects water dynamics and nutrient concentration, and consequently affects the structure of trophic networks (AGOSTINHO; JÚLIO JR.; BORGHETTI,1992).

Elton (1958) points out that the disruption of a trophic network forces new ecological connections of predation and consequently the dynamics of this interaction. In addition, the detritus chain, more effective in aquatic environments, is directly affected by the decrease in nutrients, which are the trophic basis of these communities (ODUM, 2010).

In environments with community control based on a bottom-up dynamic (*botton up*), reveals the composition of species and their relationships found in downstream regions, the decrease in population abundance of the food base (e.g. macroinvertebrate prey) negatively influences the upper trophic levels (e.g. predatory fish), the interactional connections and, consequently, the trophic behavior of the community (RICKLEFS, 2021). However, in regions upstream of the dam in which they exhibited significant interactions between predators and their prey the community control approximates more closely to a top-down relationship.

In this context, inverse relationships, i.e. negative relationships are theoretically predicted in predator-prey relationships, following the logic of the Lotka-Volterra model (RICKLEFS, 2009; ODUM, 2010). However, in our results more positive relationships were found than negative ones, which may indicate that predation directly affects other types of ecological relationships between prey species. Noteworthy is the effect of predation on species competition. Predation can act as a controller of community structure in certain environments, so predation on organisms that are good competitors can aid in the recovery of other groups with less competitive ability (STILLING, 2002).

This effect is observed in classic work on rocky shores, in which foraging *Pisaster* spp. (starfish) provides a lower rate of competition among mussels (RICKLEFS, 2009; RELEYA, RICKLEFS, 2021). Thus, the action of predators in order to suppress the abundance of some prey enables the population increase of others, facts that can be observed in the relationships between *P. harpagos* and Coleoptera, *A. lacustris* and Trichoptera, *G. inaequilabiatus* and Plecoptera (all at point A), *S. marmoratus* and Diptera, *P. reticulata* and Odonata/Hemiptera (all at point B) (**Figures 2-4**).

If predators are negatively impacted, the absence of predation or elimination of predators can dramatically change the community structuring model from structural control by predation to competition-mediated control (STILLING, 2002). This change may favor species with greater ability/strategies for competition and consequently drastically decrease species not adapted to this structural configuration, or even lead them to local extinction, following the competitive exclusion model (ODUM, 1988).

Moreover, in the most common prey relationships found and their location in the water column, benthic prey, represented by Coleoptera and Trichoptera, as well as bento/pelagic prey, represented by Hemiptera (ESTEVES, 2011), exhibited predators from more superficial regions such as P. harpagos and A. lacustris (GRAÇA; PAVANELLI, 2007; OTA et al., 2018). However, despite the common static definition for predator species, this fact can be explained by the ecomorphological capacity of predator species, which when

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subjected to environmental pressures (e.g. resource availability) can occupy other regions of the water column during the search for food resources, mainly, due to their active foraging characteristics (SOUZA; TOZZO, 2013; SOUZA et al., 2015; CANO et al., 2020).

Similarly, the predators that were found to have the most significant relationships were *A. lacustris*, *P. reticulata* and *P. harpagos*. This can be explained by the dynamic foraging form (SOUZA; TOZZO, 2013; SOUZA et al., 2015; CANO et al., 2020), already previously reported, occupying several regions of the water column and by having a generalist diet (LIEM, 1980; ABELHA et al., 2006).

Another interesting point found in the results is that the relationships are found mainly in the upstream points A and B (only one relationship was found in point D), these facts can also be related to the environmental quality of their banks and their surroundings. Points A and B are located in more rural regions with less contact from urban activities and with the presence of more dense riparian forest in relation to the downstream points (SOUZA et al., 2016; CAMARGO; SOUZA; BURANELLO, 2019).

Thus, urban impacts can generate amplified negative effects in the river channel of the downstream regions (Points C and D), due to the most harmful actions in this environment such as domestic and industrial waste disposal, soil compaction, deforestation of the riparian forest, soil leaching and higher siltation rate (GALDEAN, 2000; JESUS; CAVALHEIRO, 2004; SOUZA et al., 2016). These factors influence abiotic water dynamics that generate damaging effects on community structure (WARD, 1992; GALDEAN, 2000; SOUZA et al., 2014) and consequently their behavioral relationships (LIEM, 1980; CANO et al., 2020).

CONCLUSION

In summary, the relationship between predator-prey interactions and environmental quality, predicted in the initial hypothesis, was corroborated, in which upstream regions (with better qualitative characteristics) exhibited this relationship more stable than downstream regions. Furthermore, based on the results the structural control of these communities is more similar to top-down control mediated by predation. Since, the most found interactional relationships were positive and with the decrease of predators in the downstream collection stations may be related to the lack of correlation of these interactions.

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REFERENCES

ABELHA, M. C. F.; GOULART, E.; KASHIWAQUI, E. A. L.; SILVA, M. R. *Astyanax paranae* Eigenmann, 1914 (Characiformes: Characidae) in the Alagados Reservoir,

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Revista Brasileira de Ciência, Tecnologia e Inovação

Paraná, Brazil: diet composition and variation. **Neotropical ichthyology**, v. 4, n. 3, p. 349-356, 2006. DOI: https://doi.org/10.1590/S1679-62252006000300006

AGOSTINHO, A. A.; JÚLIO JR., H. F.; BORGHETTI, J. R. Considerações sobre os impactos dos represamentos na ictiofauna e medidas para sua atenuação. Um estudo de caso: reservatório de Itaipu. **Revista Unimar**, v. 14, p. 89-107, 1992.

AGOSTINHO, A. A; THOMAZ, S. M; GOMES, L. C; BALTAR, S. L. S. M. A. Influence of the macrophyte *Eichhornia azurea* on fish assemblage of the Upper Paraná River floodplain (Brazil). **Aquatic Ecology**, v. 41, n. 4, p. 611-619, 2007. DOI: https://doi.org/10.1007/s10452-007-9122-2

BEGON, M; HARPER, J. L.; TOWNSEND, C. R. **Ecologia: de indivíduos a ecossistemas**. 4° ed. Porto Alegre: Artmed, 2007.

CAIN, M. L.; BOWMAN, W. D.; HACKER, S. D. **Ecologia**. Artmed Editora, 2017.

CAMARGO, P. R. S.; SOUZA, F.; BURANELLO, P. A. A. Influência de impactos antrópicos na comunidade de macroinvertebrados na bacia do baixo rio Grande. **Revista em Agronegócio e Meio Ambiente**, v. 12, n. 2, p. 643-662, 2019. DOI: https://doi.org/10.17765/2176-9168.2019v12n2p643-662

CANO, A. C. S. S.; HIROKI, K. A. N.; PELLI, A.; SOUZA, F. Variação ecomorfológica em populações de *Astyanax* aff. *paranae* Eigenmann, 1914, de diferentes sub-bacias no Alto Rio Paraná. **Biota Amazônia**, v. 10, n. 2, p. 6-10, 2020. DOI: http://dx.doi.org/10.18561/2179-5746/biotaamazonia.v5n3p44-49

CHAVES, F. G.; ALVES, M. A. S. Teoria do forrageamento ótimo: premissas e críticas. **Oecologia Australis,** v.14, n.2, p. 369-380, 2010. DOI: http://dx.doi.org/10.4257/oeco.2010.1402.03

COSTA, C.; IDE, S.; SIMONKA, C. E. **Insetos imaturos: metamorfose e identificação**. Ribeirão Preto: Holos, 2006.

ELTON, C. S. **The Ecology of Invasions by Animals and Plants**. London: Methuen, 1958.

ESTEVES, F. A. **Fundamnetos de limnologia**. 3. ed. Rio de Janeiro: Interciência. 2011.

GALDEAN, N.; CALLISTO, M.; BARBOSA, F. A. R.; ROCHA, L. A. Lotic ecosystems of Serra do Cipó, southeast Brazil: water quality and a tentative classifications based on the benthic macroinvertebrate community. **Journal of Aquatic Ecosystem Health and Management**, v.3, p. 545-552, 2000. DOI: https://doi.org/10.1080/14634980008650691

GRAÇA, W. J.; PAVANELLI, C. S. **Peixes da planície de inundação do alto rio Paraná e áreas adjacentes.** Maringá: EDUEM, 2007.

JESUS, N.; CAVALHEIRO, F. **Aspectos antrópicos, legais e conservacionistas na Serra do Japi, SP**. In: SANTOS, J. E. (Org.). Faces da polissemia da paisagem: ecologia, planejamento e percepção. São Carlos: Rima, 2004.

LIEM, K. F. Adaptive significance of intraspecific and interspecific differences in the feeding repertoires of cichlid fishes. **American Zoologist**, v.20, p.295-314, 1980. DOI: https://doi.org/10.1093/icb/20.1.295

MACARTHUR, R. H.; PIANKA, E. R. On optimal use of a patchy environment. **American Naturalist**, v.100, n.916, p. 603-609, 1966.

MENDONÇA, M. M; PICAPEDRA, P. H. S; FERRONATO, M. C; SANTOS, P. V. Diel vertical migration of predators (planktivorous fish larvae) and prey (zooplankton) in a tropical lagoon. **Iheringia, Série Zoologia**, v.105, n.2, p.174-183, 2015. DOI: https://doi.org/10.1590/1678-476620151052174183

MORENO, T. R.; ROCHA, R. M. Ecologia de costões rochosos. **Estudos de Biologia: Ambiente e Diversidade**, v. 34, n. 83, p. 191-201, 2012.

MUGNAI, R.; NESSIMIAN, J. L.; BAPTISTA, D. F. **Manual de identificação de macroinvertebrados aquáticos do Estado do Rio de Janeiro**. Rio de Janeiro: Technical Books, 2010.

ODUM, E. P. **Ecologia**. Rio de Janeiro: Guanabara Koogan, 2010.

OTA, R. R.; DEPRÁ, G. D. C.; GRAÇA, W. J. D.; PAVANELLI, C. S. Peixes da planície de inundação do alto rio Paraná e áreas adjacentes: revised, annotated and updated. **Neotropical Ichthyology**, v. 16, n. 2, 2018. DOI: https://doi.org/10.1590/1982-0224-20170094

PAINE, R. T. Food web complexity and species diversity. **The American Naturalist**, v. 100, n. 910, p. 65-75, 1966.

RELYEA, R.; RICKLEFS, R. E. **A Economia da Natureza**. 8ª ed. Rio de Janeiro: Guanabara Koogan, 2021.

RICKLEFS, R. E. **A economia da natureza**. 5° ed. Rio de Janeiro: Guanabara Koogan, 2009.

SOUZA, F. LEITÃO, M. L. C.; ROCHA, B. G. A.; HIROKI, K. A. N.; PELLI, A. Estrutura ictiofaunística do rio Uberaba: a influência dos barramentos na dinâmica ecológica das comunidades de peixes. **Biota Amazônia,** v. 6, n. 4, p. 87-93, 2016. DOI: http://dx.doi.org/10.18561/2179-5746/biotaamazonia.v6n4p87-93

SOUZA, F.; SANTOS, C. J.; TRAMONTE, R. P.; KLEPKA, V. Estrutura da comunidade de macroinvertebrados em três córregos na bacia do alto rio Paraná: uma relação entre qualidade ambiental e parâmetros ecológicos. **Revista em Agronegócios e Meio**

Ambiente, v. 7, n. 2, p. 413-427, 2014. DOI: https://doi.org/10.17765/2176-9168.2014v7n2p%25p

SOUZA, F.; TOZZO, R. A. *Poecilia reticulata* Peters 1859 (Cyprinodontiformes, Poeciliidae) como possível bioindicador de ambientes degradados. **Revista Meio Ambiente e Sustentabilidade,** v. 3, n. 2, p. 163-175, 2013. DOI: https://doi.org/10.22292/mas.v3i2.164

SOUZA, F.; ZUANON, L. A.; FROTA, A.; PESENTI JUNIOR, L. F.; SILVA, H. P. Variação ecomorfológica em populações de *Astyanax* aff. *paranae* Eigenmann, 1914, na bacia do alto Rio Paraná. **Biota Amazônia**, v.5, n.3, p.44-49, 2015. DOI: http://dx.doi.org/10.18561/2179-5746/biotaamazonia.v5n3p44-49

STATSOFT. Statistica (data analysis software system). Version 7.1. 2005.

STILLING, P. **Ecology: Theories and Applications.** New Jersey: Upper Sanddle River; 2002.

WARD, J. V. **Aquatic Insect Ecology I: biology and habitat**. New York: John Wiley & Sons Inc. 1992.

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