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Impact assessment of an effluent discharge on benthic macroinvertebrates in a subtropical river using indexes

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ABSTRACT. Benthic macroinvertebrates are used as environmental bioindicators in the assessment of water quality in rivers and lakes, due to the sensitivity of some taxa to pollution. The objective of this research was to evaluate the consequences of industrial effluent discharge on the structure of the benthic community present in a river in the subtropical region of Brazil. The organisms were collected at three points of the Coutinho River, in 2013 (September and November) and 2014 (January and March). To characterize the community were calculated density, Shannon diversity index (H'), Pielou equitability (J), taxa richness, Biotic Indices (Biological Monitoring Working Party - BMWP, Average Score Per Taxon - BMWP-ASPT, Family Biotic Index - FBI) and Canonical Correspondence Analysis (CCA) between sampling points and biotic and abiotic variables. Fifteen taxa were identified and among the collected organisms, the family Chironomidae was the most representative, followed by Oligochaeta, Hirudinea, Bivalvia, Gastropoda. According to the results of the biological indices, point 1 indicated moderate pollution and the following points (2 and 3) showed severe pollution. These indices showed poor waters with a high degree of pollution. The results were efficient in detecting the environmental impacts suffered by the river and suggest the necessity of a continuous monitoring of the same.

Keywords: biotic index, pollution, zoobenthos.

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Introduction

Industrial effluent discharge comprises one of the most significant pollution sources in fresh waters because the release of chemicals in rivers is often done without previous treatment (Rajaram & Das, 2008). In between the discharge and the deposition into river sediments, many compounds can bind with other particles and undergo chemical changes that may, in turn, enhance or decrease their toxicity. Numerous chemicals are also incorporated into the aquatic food webs via benthic organisms (Araujo, Zagatto, & Bertolotti, 2006).

Benthic macroinvertebrates are organisms that offer useful information for water quality assessments, providing data on past and present environmental conditions (Pratt & Coler, 1976). This is possible because impacts can change invertebrate community structure and composition, and also modify their vital functions. The evaluation of the environmental quality of an ecosystem requires information on abiotic and biotic attributes related to ecosystem functioning (Silva, Galvêncio, & Almeida, 2010).

Aquatic insect larvae are the most abundant and diverse benthic macroinvertebrates in running waters (Hynes, 1970; Lake, 1990). Their distribution is related to habitat physical, chemical and structural characteristics, as well as to food resource availability and to the habits of each species (Resh & Rosenberg, 1984; Boltovskoy, Tell, & Dadon, 1995; Merritt & Cummins, 1996). Aquatic insects are used to detect environmental disturbance for presenting low mobility and high abundance, besides being relatively easy to sample and identify, features that make them good candidates to compose biotic indices for water quality assessments (Roque & Trivinho-Strixino, 2000; Queiroz, Trivinho-Strixino, & Nascimento, 2000).

Currently, aquatic environments are undergoing continuous change due to natural disasters, abusive degradation, and overexploitation by human activities. As a result, researchers and organizations have been pursuing strategies for their recovery (Lopes & Pacagnan, 2014). Thus, this study and identification of benthic macroinvertebrates in the Coutinho River will make possible to ascertain the environmental quality of this environment and to identify possible environmental problems caused by industrial effluent

discharges, since the river may be used in the future district (*Secretaria Estadual de Meio Ambiente* [Sema], 2008).

Material and methods

Study area

The Coutinho River is located in Guarapuava city, Paraná State, Brazil (Figure 1) and its source is placed in the Palmeirinha district. It presents alluvial soil and is affluent of the right margin of the Jordão basin, which is inserted in the Médio Iguaçu tributary hydrographic unit (Paraná, 2006). The riparian zone was largely replaced by agricultural areas, except for a few fragment remnants of native Mixed Ombrophilous Forest, and the river is also surrounded by an industrial hub near the urban area of Guarapuava (Sema, 2008).

The Paraná State is the fastest growing Brazilian state in industrial production (*Instituto Paranaense de Desenvolvimento Econômico e Social* [IpardeS], 2018). The Guarapuava city industrial hub includes timber exploitation, machinery, packages, and furniture production, the last with 40 industries (Grzeszczyszyn & Machado, 2010). The chemicals in effluents that industries launch into rivers can kill several organisms and can also be harmful to the local population when heavy rainfall and floods occur (Buss & Vitorino, 2010).

Samplings

Three sampling points (Figure 1) were established along the Coutinho River according to their position relative to the industrial effluent discharge site: one upstream (P1) 25° 19' 47" S and 51° 29' 41" W), by the PR 460 road, the other (P2) (25° 21' 5" S and 51° 30' 45" W) nearby, and the third (P3) (25° 22' 58" S and 51° 35' 5" W) downstream, by the BR 277 road (Figure 1).

The three points were sampled in September/2013, November/2013, January/2014, and March/2014. In each sampling occasion, water physical and chemical parameters measured included temperature, pH, turbidity, phosphate, and dissolved oxygen. Water analyses were performed at the Novatec Analysis Center of the *Universidade Estadual do Centro-Oeste* (Unicentro). Sediment and benthic macroinvertebrates were collected with three throws of a Petersen dredge (0.02 m² area) in each point. Sediment composition was classified according to the Wentworth (1922) granulometric scale.

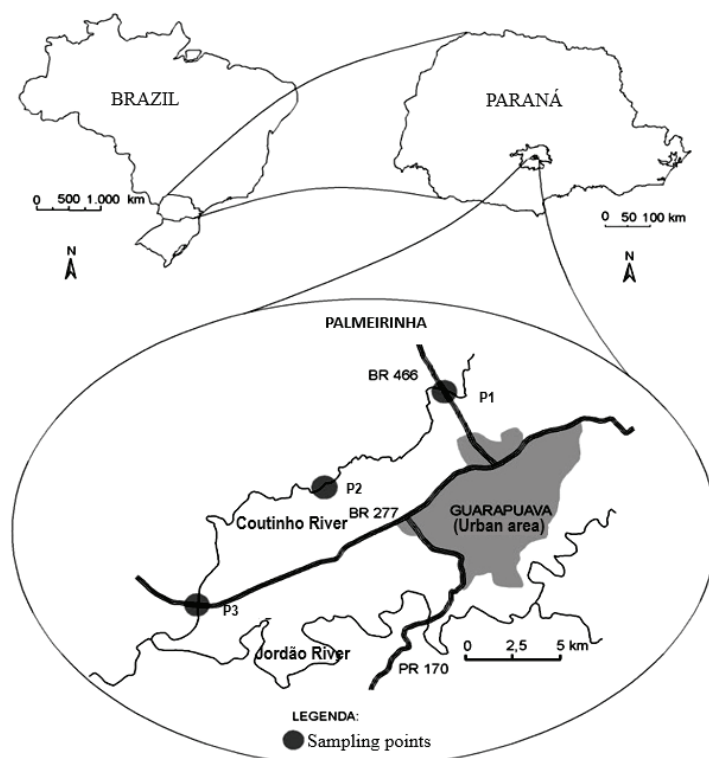


Figure 1. Location of the sampling points (black points – P1, P2, and P3) in the Coutinho River, Guarapuava, Paraná. Map by Divair José Fachi.

Samples were washed at the lab using sieves of 1 and 250 mm mesh size. Macroinvertebrates retained in the sieves were kept in 70% ethanol solution, sorted, and identified to the lowest taxonomic level possible with the specific keys: Merritt and Cummins (1984); Roldan-Pérez (1988); Trivinho-Strixino, and Strixino (1995); Epler (2001); Fernandez and Dominguez (2001); Costa, Souza, and Oldrini (2004); Lecci and Froehlich (2007).

Data analyses

The structure of the community of benthic macroinvertebrates was evaluated using density values (Welch, 1948) and the diversity indices of Shannon-Wiener (H') and equitability Pielou (J). These indices were calculated using the Dives 3.0 software (Rodrigues, 2014).

We applied two visual assessment protocols to characterize environmental and ecological attributes of river reaches, one by Hannaford, Barbour, and Resh (1997) and the other by Ohio Environmental Protection Agency (EPA, 1987), both modified by Callisto, Ferreira, Moreno, Goulart, and Petrucio (2002). We then applied the Biological Monitoring Working Party (BMWP) biotic index, adapted by Loyola (2000), to evaluate the water quality of the Coutinho River. This index attributes scores for each taxon based on their tolerance to organic impacts. The BMWP-ASPT (Average Score Per Taxon) was calculated by dividing the BMWP result by the number of scored families in the sample (Walley & Hawkes, 1997). Finally, we applied the Family Biotic Index (FBI), which attributes values of tolerance to organic pollution for macroinvertebrate families, to verify water pollution levels (Hilsenhoff, 1987).

A Canonical Correspondence Analysis (CCA) was performed in the PAST program (Hammer, Harper, & Ryan, 2001), to verify if there were links between the environmental variables and the macroinvertebrates sampled at each point.

Results and discussion

The application of habitat assessment protocols evidenced that the three Coutinho River reaches ($P1 = 45$ points; $P2 = 50$ points; $P3 = 46$ points) were altered by anthropogenic actions that led to habitat disruption along the river, such as deforestation by agricultural enterprises. Although the three reaches were classified accordingly, the $P2$ reach received the highest score (50 points) and evidenced local degradation. According to Dudgeon (1996), the suppression of the riparian forest decreases the reproductive success of aquatic and semi-aquatic species that need appropriate sites for mating and laying eggs.

The water quality results (Table 1) revealed that the dissolved oxygen, pH, and turbidity values were the lowest at the $P2$ reach, which is located near the effluent discharge site of the industrial area of Guarapuava. The lowest phosphate concentration (0.1 mg L^{-1}) was found in $P3$. Temperature varied little among sampling points, and turbidity was the highest at $P1$ (Table 1).

All pH values registered were below six, evidencing an acidified environment. According to Siqueira et al. (2012), pH can influence species distribution and biological interactions by hindering the performance of the physiology of aquatic organisms.

The National Council of Environment (*Conselho Nacional do Meio Ambiente* [Conama], 2005) establishes minimum Dissolved Oxygen (DO) values of 5 mg L^{-1} for Class II water bodies. However, only the $P1$ reach was within this limit (Table 1), being the $P2$ (1.85 mg L^{-1}) and the $P3$ (3.35 mg L^{-1}) below minimum quality. Sperling (2005) states that DO concentration can indicate pollution effects of organic wastes in freshwaters: when DO values range between 4 and 5 mg L^{-1} , sensitive fish species die out; when DO is 2 mg L^{-1} , nearly all fish species die out, and when DO drops to 0 mg L^{-1} , anaerobic conditions take place.

Phosphate values of $P2$ and $P3$ were within the range pre-established by Conama (2005) (i.e., $\leq 0.1 \text{ mg L}^{-1}$). Values of $P1$ were above this limit (0.16 mg L^{-1}), likely due to agricultural runoff from adjacent areas, which may include phosphate and organophosphate fertilizers.

Sediment evaluation revealed that the $P2$ presented, on average, the highest percentage of sand (85.1%), followed by $P3$ (83.7%) and $P1$ (81.9%). Finer sediment as clay and silt were less representative, being the highest average value registered at $P1$ (18.1%) (Figure 2). The sediment granulometry can be indicative of anthropic actions that cause siltation and change the physical nature of sediments in lotic ecosystems, consequently influencing the benthic fauna (Bryce, Lomnický, & Kaufmann, 2010).

Fifteen taxa were identified (Table 2), being Oligochaeta and Chironomidae the most abundant. These two taxa are considered resistant and tolerant to environmental impacts, likely because they

present morphological adaptations and generalist habits that allow their survival in oxygen-poor environments (Merrit & Cummins, 1996). Oligochaetes represented 100% of the benthic community assemblage of P3 (September/2013 and January/2014). The presence of Oligochaeta indicates the existence of organic matter in the environment and poor water quality (Bruno et al., 2012; Kamada, De-Lucca, & De-Lucca, 2012).

Table 1. Average values (\pm standard deviation) of physical and chemical parameters registered in the three sampling points of the Coutinho River.

	Phosphates (mg L^{-1})	Dissolved oxygen (mg L^{-1})	pH	Turbidity (NTU)	Temperature ($^{\circ}\text{C}$)
P1	0.16 \pm 0.01	5.65 \pm 0.09	5.85 \pm 0.05	17.8 \pm 1.09	19 \pm 0.71
P2	0.12 \pm 0.02	1.85 \pm 0.21	5.59 \pm 0.06	1.2 \pm 0.1	19 \pm 0.43
P3	0.1 \pm 0.01	3.35 \pm 0.11	5.54 \pm 0.04	6 \pm 0.15	18 \pm 0.43

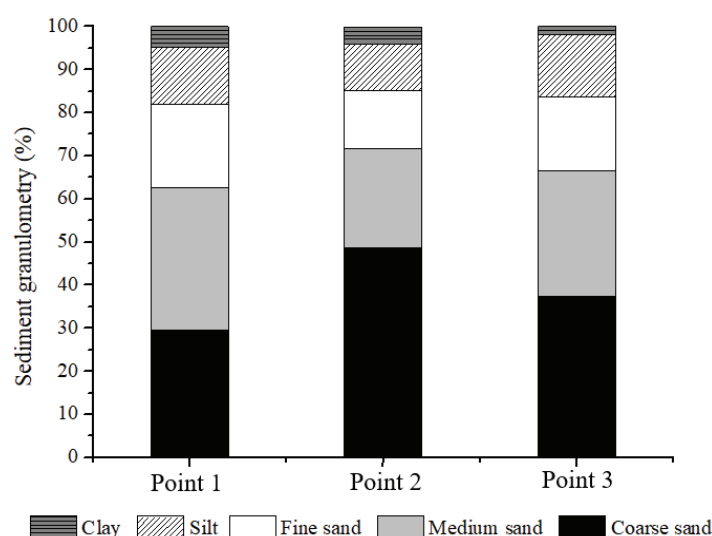


Figure 2. Average sediment granulometry in the three reaches of the Coutinho River during the study period.

Table 2. Relative abundance values (%) of benthic macroinvertebrates sampled with a Petersen dredge in three points (P1, P2, and P3) of the Coutinho River during the study period.

	Sept./2013			Nov./2013			Jan./2014			Mar./2014		
	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3
Phylum Annelida												
Class Hirudinea	-	60	-	32	60	-	3	10	-	-	23	14
Class Oligochaeta	40	40	100	51	-	67	12	-	100	20	-	72
Phylum Arthropoda												
Class Insecta												
Order Coleoptera												
Family Elmidae	3	-	-	-	-	-	-	-	-	-	-	-
Order Diptera												
Family Chironomidae												
<i>Chironomus</i> sp.	3	-	-	-	30	-	74	76	-	-	71	14
<i>Dicrotendipes</i> sp.	-	-	-	-	-	-	5	10	-	-	3	-
<i>Paracladius</i> sp.	6	-	-	-	-	-	-	-	-	-	-	-
<i>Paralauterborniella</i> sp.	9	-	-	-	-	-	-	-	-	-	-	-
<i>Polypedilum</i> sp.	3	-	-	7	-	-	-	-	-	-	-	-
<i>Stenochironomus</i> sp.	-	-	-	-	-	-	3	-	-	-	-	-
<i>Tanytarsus</i> sp.	-	-	-	-	-	33	-	-	-	-	-	-
Family Psychodidae	3	-	-	-	-	-	-	-	-	-	-	-
Order Ephemeroptera												
Family Ephemeridae	3	-	-	-	-	-	-	-	-	-	-	-
Order Trichoptera												
Family Hydroptilidae	3	-	-	-	-	-	-	-	-	-	-	-
Phylum Mollusca												
Class Bivalvia	27	-	-	10	-	-	3	-	-	80	-	-
Class Gastropoda	-	-	-	-	10	-	4	-	-	3	-	-

Chironomidae are generally found in sediments with decaying organic matter (Amorim & Castillo, 2009) and therefore have the characteristic of being tolerant to variations in the aquatic environment. The *Chironomus* midge represented 74% of the macroinvertebrate fauna of P1 in January/2014, 76% of the P2 fauna in January/2014, and 71% in March/2014. *Chironomus* is related to water degradation, as it is abundant in eutrophic places, besides supporting low values of dissolved oxygen in the environment (Trivinho-Strixino & Strixino, 1995; Ceretti & Nocentini, 1996; Marques, Ferreira, & Barbosa, 1999).

The P1 reach presented the highest taxonomic richness (10 taxa in September/2013) and the orders Ephemeroptera (3%) and Trichoptera (3%) were exclusive to P1. According to Rosenberg and Resh (1993), insects of these orders are ecologically important for environmental assessments in lotic ecosystems for their sensitivity to disturbances and occurrence in good-quality waters. In this context, their occurrence in P1 was likely associated with the higher levels of dissolved oxygen observed therein.

Hirudinea and Bivalvia also presented high relative abundance. The highest relative abundance of bivalve mollusks (80%) was found in P1 in March/2014, and that of Hirudinea (60%) was found in P2 in September and November/2013. The presence of these organisms is favored in environments with high levels of organic pollution (Barnes, 1984; Amorim & Castillo, 2009; Rodrigues, 2013; Bruno et al., 2012).

The high density of the few taxa observed in the Coutinho River (Figure 3), along with low overall richness, indicate degradation. In P1, the *Chironomus* presented the highest density observed, with 161 ind. m⁻² (January/2013), followed by Oligochaeta, with 89 ind. m⁻² (November/2013) and Bivalvia, with 50 ind. m⁻² (September/2013). In P2, *Chironomus* (128 ind. m⁻² in March/2014) and Hirudinea (39 ind. m⁻² in March/2014) were the most abundant, whereas in P3 the highest density registered was that of Oligochaeta, with 27 ind. m⁻² in March/2014.

The P1 reach presented the highest diversity ($H' = 0.78$), equitability ($J = 0.70$) and richness ($S = 13$ taxa), while the P3 presented the lowest values for these metrics. The equitability values differed in all sampling points, indicating taxa dominance. Moreover, these metrics tended to decrease along the river continuum, from P1 to P3 (Table 3), as observed for water physical and chemical parameters as well, indicating increased environmental degradation from P2 onwards.

Based on the FBI scores, the three sites of the Coutinho River were classified as presenting poor water quality and significant organic pollution. The BMWP and BMWP-ASP indices showed differences among reaches, being the P1 classified as polluted (BMWP) or with moderate pollution (BMWP-ASPT), and the P2 and P3 classified as strongly polluted (BMWP), or with severe pollution (BMWP-ASPT). Ruaro, Agustini, and Orssatto (2010) obtained similar values for the Clarito River, in the state of Paraná, which also receives pollution from industrial sources along its course. In São Paulo State, the Pequerê River of Cubatão city also underwent degradation and riparian forest removal, being classified as presenting very poor water quality (Amorim & Castillo, 2009). On the other hand, the preserved riparian cover of the Correntoso River (Aquidauana, State Mato Grosso do Sul) ensured all sampling points presented good water quality results of biotic indices (FBI, BMWP, and BMWP-ASPT) (Silva, Favero, Sabino, & Garnés, 2011).

The CCA between the physicochemical parameters of the water and the macroinvertebrates present in the Coutinho River (Figure 4, axis 1 - 79.8 and axis 2 - 20.2%) at three sampling points showed a possible association of Oligochaeta with increased turbidity levels. This group usually lives in environments with high electrical conductivity and turbidity (Alves, Marchese, & Escarpinati, 2006; Gorni & Alves, 2015).

Table 3. Shannon-Wiener diversity, Pielou equitability, and species richness registered in three points of the Coutinho River (P1, P2 and P3).

	Shannon-Wiener (H')	Equitability (J)	Richness (S)
P1	0.78	0.70	13
P2	0.44	0.63	5
P3	0.31	0.52	4

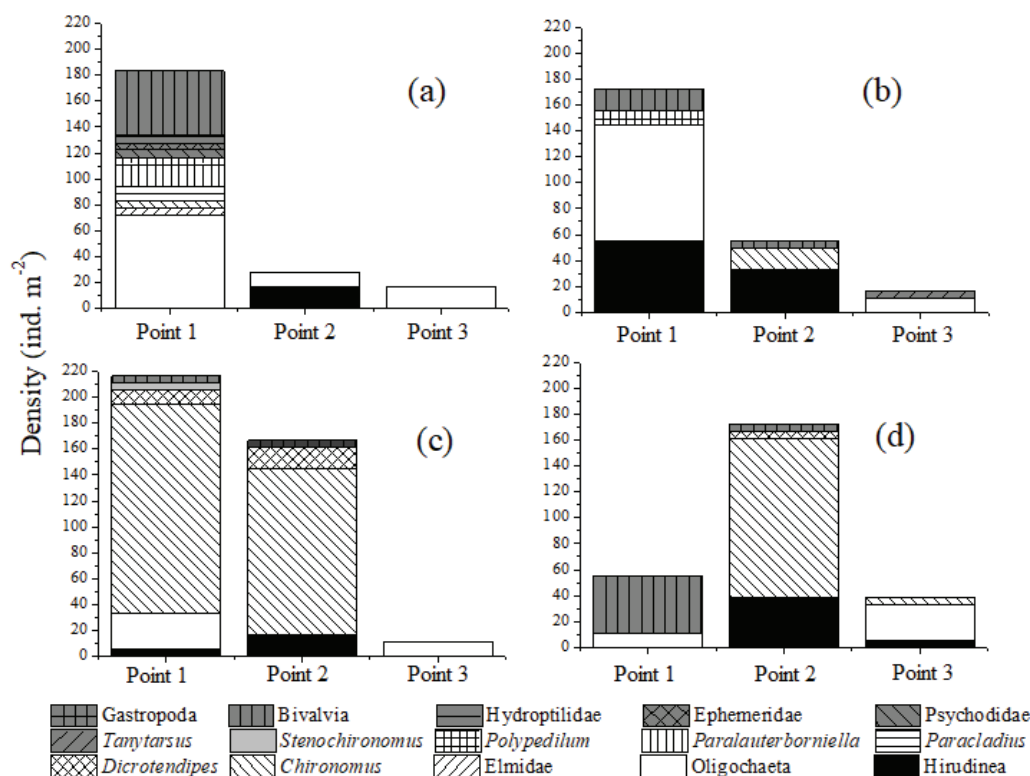


Figure 3. Density values (ind. m⁻²) of benthic macroinvertebrates sampled at three points of the Coutinho River in (a) September/2013, (b) November/2013, (c) January/2014, and (d) March/2014.

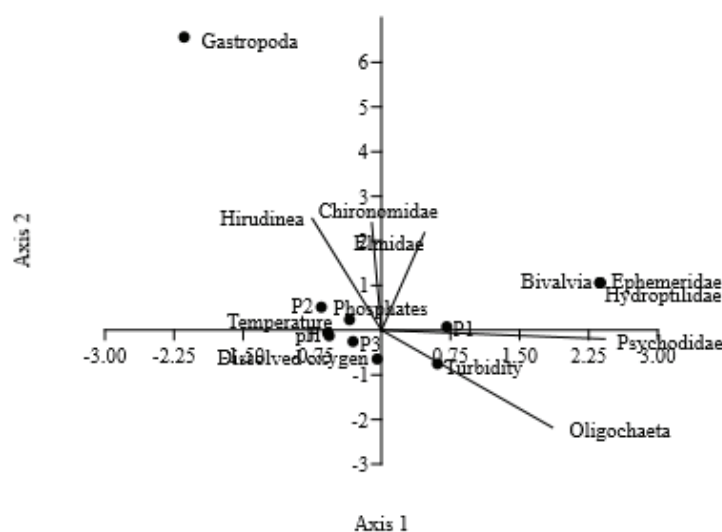


Figure 4. Sorting axes produced by CCA between the physicochemical parameters present in water (temperature, pH, dissolved oxygen, phosphates and turbidity) and the taxa sampled in the Coutinho River at three sampling points (P1, P2 and P3).

Conclusion

The use of benthic macroinvertebrates for the Coutinho River environmental quality assessment was efficient and enabled the diagnostic of local limnological variations. Our results indicate that the sampled reaches are impacted by both agricultural runoff from adjacent areas and industrial effluent discharges. Evidence includes the higher taxonomic richness found upstream from the industrial area together with the high density of tolerant taxa (as Oligochaeta and *Chironomus*) downstream from it.

All biotic indices (FBI, BMWP, and BMWP-ASPT) point to moderate-towards-severe pollution along the Coutinho River. Thus, our results should serve as an environmental degradation warning and a call for continuous monitoring of the Coutinho River water quality and impact mitigation actions.

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