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LANDFILL LEACHATE THREATENS TROPICAL FISH IN THE CENTRAL AMAZON

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ABSTRACT:
A primary concern associated with landfill operations pertains to the generation of leachate, defined as a liquid that emerges as a consequence of the decomposition of organic materials. The leachate generated poses a significant threat to the aquatic environment where it is discharged. This phenomenon is not confined to the active phase of the landfill, as leachate production persists even many years after the landfill has been closed. The present study evaluated the composition of the fish community, as well as the concentrations of metals in the water and in the tissues of the fish, in a small stream that received leachate from a landfill in the city of Manaus, Amazonas, Brazil. The headwaters of the small stream are located within the confines of the Adolpho Ducke Forest Reserve, a significant natural conservation area and a research hub for environmental studies in the Amazonian region. The concentrations of heavy metals in the leachate and in the tissues of fish did not exceed the limits established by CONAMA Resolution 357/2005. However, fluctuations in water quality parameters, including pH (6.42 ± 0.72), dissolved oxygen levels (0.3 to 5.02 mgO2/L), and electric conductivity, were observed during both the wet and dry seasons. A total of six fish species were documented in the area contaminated by leachate, while a significantly higher number of 19 species were recorded in the area that was not contaminated by leachate. Consequently, the composition of the fish community was significantly impacted by the landfill leachate. Furthermore, the study area has been identified as a site for the emergence of invasive species.

Key words: biodiversity, freshwater pollution, fish communities, urban pollution

CHORUME DE ATERRO SANITÁRIO AMEAÇA PEIXES TROPICAIS NA AMAZÔNIA CENTRAL

RESUMO:
Um dos principais problemas relacionados à operação de aterros sanitários é a formação de chorume, um líquido resultante da decomposição de matéria orgânica. O chorume gerado representa uma ameaça significativa ao ambiente aquático onde é descartado. Esse problema não se limita à fase ativa do aterro, pois a produção de chorume ainda pode ser observada mesmo muitos anos após o fechamento do aterro. O presente estudo avaliou a composição da comunidade de peixes, bem como as concentrações de metais na água e nos tecidos dos peixes, em um pequeno riacho que recebeu chorume de um aterro sanitário na cidade de Manaus, Amazonas, Brasil. O pequeno riacho começa dentro da Reserva Florestal Adolpho Ducke, uma importante região de conservação natural e área para estudos ambientais na Amazônia. As concentrações de metais pesados no chorume, e nos tecidos dos peixes, não ultrapassaram os limites estabelecidos pela Resolução CONAMA 357/2005. No entanto, mudanças nos parâmetros de qualidade da água, como pH (6.42 ± 0.72), níveis de oxigênio dissolvido (0.3 a 5.02 mgO_2/L) e condutividade elétrica foram afetados, tanto nas estações chuvosa quanto na seca. Seis espécies de peixes foram registradas na área impactada pelo chorume, enquanto 19 espécies foram encontradas em uma área não impactada. Dessa forma, a composição da comunidade de peixes foi bastante afetada pelo chorume do aterro sanitário. Além disso, a área de estudo tem sido um local para o surgimento de espécies invasoras.

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INTRODUCTION

The increasing concentration of human populations in major urban centers is closely linked to the generation of large volumes of waste. Therefore, effective waste management is one of the most critical issues in environmental protection. The leachate generated for landfill poses a significant threat to the aquatic environment where it is discharged (Qian et al 2024). Urbanization is a global component in land use and effluent production, and it represents one of the main sources of issues on the natural environment. According to the International Solid Waste Association (ISWA), uncontrolled dumpsites hold 40% of the world's waste and the 50 largest dumpsites affect the daily lives of 64 million people. Direct disposal of solid waste in landfills or dumpsites is the most common practice in majority of the countries. However, inadequate disposal of large amounts of residues causes several issues, including soil pollution, air pollution, superficial and underground water pollution, visual and noise pollution, disease spread, real estate devaluation, and irreversible ecological damages (Wilby and Perry, 2006).

Pollution and constant pressure from the urban areas harm the natural environment at different intensities (Mavakala et al. 2016; Wilby and Perry, 2006). Due to the increased disposal of potentially harmful waste, both to the environment and to human health, several environmental risk assessment study methods have been developed including quantitative and qualitative parameters, either chemical, physical or biological (Abunama et al., 2021). In this way, there is increasing interest in promoting a better understanding on how the individuals, groups, communities, and populations of the different organisms are affected by xenobiotic substances (Fauziah, 2013).

Notably, the Amazon plays an extremely important role in the global carbon balance, climate regulation and many processes in the water cycle. The Amazon Forest is fundamental for such dynamics, but over the last decades it has been suffering from intense irregular deforestation to make space for agriculture and animal grazing, and for irregular urban use (Ferrante and Fearnside, 2018).

In the Western Amazon, particularly in Manaus, capital of the Amazonas state, there has been a rapid population growth in the last 30 years. Between the early 1950's and the creation of the Free Economic Zone of Manaus in 1967, the population was quite stable at about 200,000. However, intense growth followed and in 1980 the population had grown to 611,763 and subsequently in 2021 to more than 2 million. The rural flight and migratory influx from the Northeast and South of the country were motivated by better economic conditions in the region. Unfortunately, urban infrastructure services did not follow suit the demand, which caused serious social, economic and environmental problems, especially in public health and sanitation.

Continuous and disorderly mineral exploitation (oil, gas, and gold), implementation of industries from all economic sectors, disorderly population growth, deforestation, among others, are activities that significantly affect the biota, especially fishes, which directly affect fisheries, livelihood, and overall quality of life of the Amazonian people (Oliveira de Souza et al. 2016).

According to ABRELPE – Brazilian Association of Waste Management Companies (2014), between 2013 and 2014 urban solid residues in the state of Amazonas increased around 4,103 to 4,145 tonnes per day, 45% of which are sent to controlled dumpsites or landfills. The controlled landfill in the city of Manaus is built by the highway AM-10 connecting to the cities of Rio Preto da Eva and Itacoatiara, and the nearby areas have already started to be occupied. In addition to the environmental impact, such settings are prone to waterborne diseases, in turn posing pressure on the sanitary and health systems. Another issue is the type of soil that is easy for the rainwater to percolate and leach to the ground water.

The product of the decomposition of the organic matter, known as leachate, presents different physical and chemical characteristics depending on the composition of the waste and the time for decomposition (Vaccari et al., 2019). The leachate derives mainly from chemical and microbiological decomposition processes of the residues disposed in the landfill. The decomposition of solid waste disposed in dumpsites or landfills goes through aerobic and anaerobic stages. The aerobic phase of the decomposition starts soon after the residue is disposed, and the aerobic bacteria utilize the oxygen available. Once the oxygen is depleted, the anaerobic phase begins with anaerobic organisms hydrolysing and fermenting cellulose and other organic matter. The chemical composition of the leachate varies widely, as it depends on the type of waste, the way it was disposed, age and management of the landfill, and it is easily affect by climatic factors, especially precipitation and temperature. Leachate presents highly soluble substances and may contaminate groundwater and surface waters near the landfill, becoming extremely harmful to the environment and surrounding communities (Costa et al. 2019).

Therefore, the disposal of solid wastes without selective collection may include several polluting chemical substances, such as heavy metals, antibiotics, pesticides, hormones, and highly pathogenic bacteria. In areas of high precipitation index such as the Amazon, the volume of leachate produced is clearly higher than in other arid or semi-arid areas, and the leachate that is usually runs off to a receiving water body, causes several environmental impacts in different groups, be them fish (Noaksson et al. 2005), macroinvertebrates or rodents (Bloor et al. 2005).

The Amazon is a region of remarkable biodiversity, and any environmental alteration can result in serious damage. For instance, the ichthyofauna comprises more than 3,000 fish species from various orders, exhibiting a wide range of adaptations, including behavioral, physiological, biochemical, genetic, and molecular strategies (Junk et al., 2007). Consequently, even minor changes in the physical and chemical characteristics of the water can lead to irreversible environmental impacts. In this context, the objective of the present study was to evaluate the environmental pollution caused by leachate from the controlled landfill in Manaus and its effects on the fish fauna of the impacted stream.

MATERIALS AND METHODS

Study area

The study was conducted between 2006 and 2007 at the controlled landfill of Manaus (S 02°57'17.96"; W 60°00'45.67"). At that time, the landfill had been in operation for 22 years, receiving all types of urban and hospital waste (Lollobrigida de Souza et al., 2012). The landfill is located along the AM-10 highway (Manaus/Itacoatiara), approximately 19 km from the city center and adjacent to the Adolfo Ducke Forest Reserve. The reserve covers an area of 100 km², and by the year 2000, urban expansion in Manaus had reached its southern boundary. The west of the reserve, some streams drain toward the Rio Negro, while to the east, other streams flow toward the Amazon River. Additionally, forest cover to the east, north, and particularly the west had already undergone significant fragmentation and degradation. As a result, the reserve has been increasingly transitioning into an urban park (Lima et al. 2008; Ribeiro et al. 1999).

Water analysis

To estimate the depuration profile of the leachate from the controlled landfill, six fixed leachate sampling points were selected (Figure 1) in two periods, i.e., dry season (September/2006) and wet season (April/2007). The sampling point 1 corresponds to pure leachate collected directed by the stabilization tank. The samplings 2 to 6 corresponds to leachate diluted by the Matrinxã stream´s water. The sampling was carried out in accordance with the procedures and work instructions of the ECOLABOR Quality System (SQE), based on the Water Sample Collection and Preservation Guide – 1st Edition – CETESB.

Figure 1. Map of the Manaus controlled landfill, showing the contaminated water sampling points (● 1 to 6) and the fish sampling points (I to IV).

For each sampling point (2 to 6) three 350 mL samples were collected and acidified with 2 mL of 1N H_2SO_4, and filtered through 0.45 µm cellulose acetate filters. Filtered samples were analysed for heavy metals (Cu^{2+}, Cd^{2+}, Pb^{2+} and Ni^{2+}) by atomic absorption spectrometer graphite furnace mode (Perkin Elmer Analyst^{TM} 800). Wavelength, pre-treatment temperature and atomization temperature were, respectively: Cadmium: 228.8 nm, 700 °C and 1400 °C; Copper: 324.8 nm, 1200 °C and 1900 °C; Lead: 283.3nm, 850 °C and 1500 °C; Nickel: 232.2 nm, 1100 °C and 2300 °C (APHA- Method 3113).

Water flow, temperature, conductivity (Jenway 470), pH (Jenway 350) and dissolved oxygen (YSI 550) were measured *in loco*. Each parameter was measured in triplicate. The water flow was estimated according to Tucci (2002), in which the flow measurement is performed using floaters. This method consists of determining the surface velocity of the water and estimating the average velocity by applying a correction factor, which is then multiplied by the cross-sectional area of the channel.

In addition, about 1L of leachate (sampling point 1) was sent to a specialized laboratory (Ecolabor Comercial Consultoria e Análise Ltda.) for analysis of benzene, toluene, xylene (USEPA SW 846 4ª Rev. - 8015D) and mercury (APHA-Method 3113B).

Fish fauna study

Fish were sampled in four locations (Figure 1). The first location (Figure 1-I) was in Matrinxã stream`s, 50 m upstream to the second location (Figure 1-II), a small reservoir with a concrete dam. The third location (Figure 1-III) was 20 m downstream to the dam. The water flow was also measure in the third location. Fish captured outside the impacted area by the leachate was approximately 2 km upstream from the landfill (Figure 1-IV).

Fish were collected in the morning using 30 m tangle nets with a 30 mm mesh size, hand nets, and a 2 m × 2 m dragnet with a 5 mm mesh size. At each sampling site, a total fishing effort of one hour was applied, equally divided among the three capture methods. Sampling was conducted once per season.

All captured fish were transported dead to the laboratory for identification. Fish management and euthanasia was according to the ethics of animal use by the Brazilian Society of Laboratory Animal Science (COBEA). For large (> 7 cm) size fish species (*Hoplosternum littorale* and *Pterygoplichthys punctatus*) dorsal muscle and liver samples were collected for later acid digestion and heavy metal analysis. For small (< 2 cm) fish species (*P. reticulata*) with more than 9 individuals were digested in acid. Samples were placed in glass tubes, weighed, and digested with 1N HNO_3 at 60 - 70 °C for at least 24 h (Baldisseroto *et al*., 2004; APHA-Method 3030D). After digestion, samples were analyzed for heavy metals. All graphs were prepared using Origin (Pro) 7.5 software.

RESULTS

For heavy metal analysis, all water samples presented similar debug profiles, except for Cu^{2+} (Fig 2A). Downstream to the Matrinxã stream´s (sampling point 3), Ni^{2+}, Cd^{2+} and Pb^{2+}concentrations were highly debugged (Fig 2B, C and D).

The Cu^{2+} concentration in the leachate in the stabilization tank during the dry season (Abril to September) was 10±1.39 μg Cu^{2+}/L, with gradual dilution until reaching Matrinxã stream´s (sampling point 3), at about 1.05 ± 0.11 μg Cu^{2+}/L. During the wet season (October to March), Cu^{2+} concentration in the stabilization tank was 5.87 ± 1.17 μg Cu^{2+}/L. In the other sampling points, Cu^{2+} concentrations remained at 4.06 ± 0.47 μg Cu^{2+}/L (Figure 2A). According to the CONAMA Framework Resolution 357/2005 (National Environment Council – Conselho Nacional do Meio Ambiente), the maximum permissible concentration is of 9 μg Cu^{2+}/L.

The highest nickel concentration was in the leachate in the stabilization tank (170.48 ± 14.22 μg Ni^{2+}/L) in the dry season. After the debugging in sampling point 3, values during the wet and dry seasons were very similar at 1.23 ± 0.38 μg Ni^{2+}/L (Figure 2B). The maximum permissible concentration under CONAMA 357/2005 is 0.025 mg Ni^{2+}/L.

Cadmium debugging was similar to nickel and lead. The highest concentration was in the leachate in the stabilization tank during the dry season (2.98 ± 0.75 μg Cd^{2+}/L), higher than the acceptable concentration under CONAMA 357/2005 of 1 μg Cd^{2+}/L. In the other sampling points, either in the wet or dry season, concentrations remained low at 0.021±0.01 μg Cd^{2+}/L (Figure 2C).

The highest concentration of lead was also in the leachate in the stabilization tank (9.34 ± 0.79 μg Pb^{2+}/L) during the dry season. From the debugging in sampling point 3, concentration is reduced to 0.24 ± 0.08 μg Pb^{2+}/L. During the wet season lead was not detected in any of the sampling points (Figure 2D). According to CONAMA 357/2005, 10 μg Pb^{2+}/L is the permissible level. Fish tissue analysis did not show high heavy metal accumulation (Table 1).

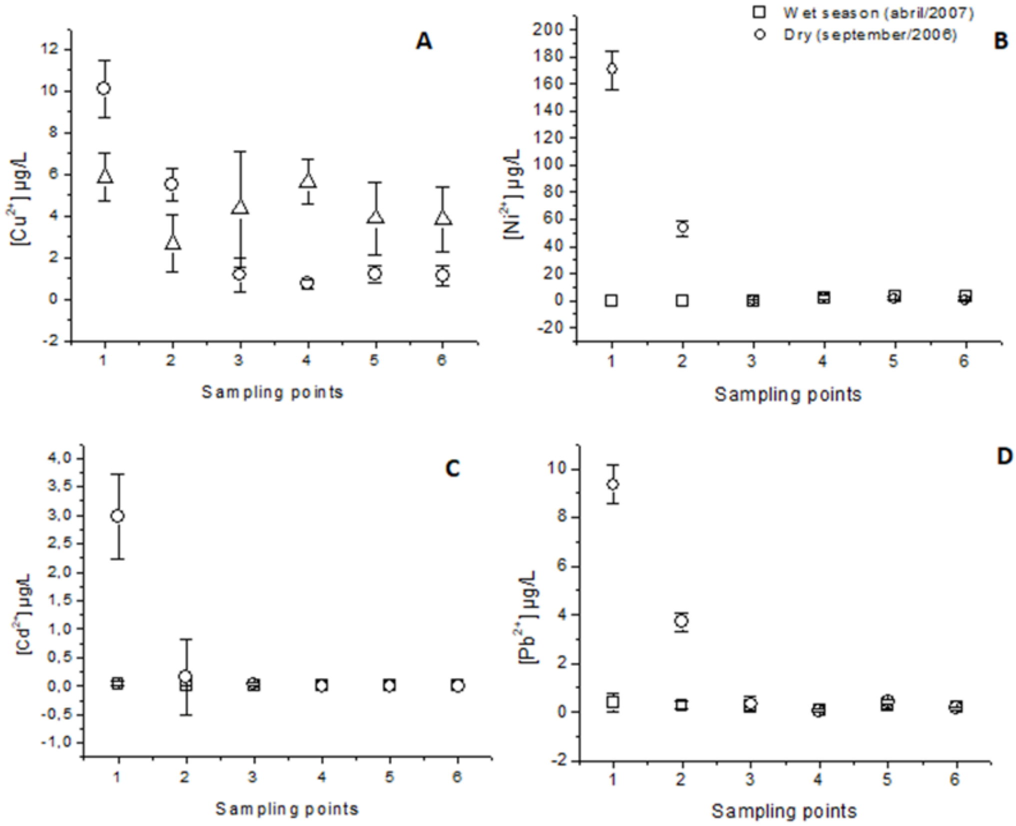

Figure 2. (A) Dilution profile of copper (Cu^{2+}), (B) nickel (Ni^{2+}), (C) cadmium (Cd^{2+}) and lead (Pb^{2+}) (D) in wet season (April/2007) and dry season (September/2006) from the leachate produced by the Manaus controlled landfill.

Table 1. Analysis of metals (µg/L) in fish body and fish tissues (muscle and liver).

Species	Samples	Cd^{2+}	Cu^{2+}	Ni^{2+}	Pb^{2+}
P. reticulata	Female (27)	0.008±0.005	1.81±0.22	0.01±0.01	0,04±0,01
	Male (24)	0.002±0.001	1.68±0.44	0.02±0.02	0,02±0,01
H. littorale	Muscle (6)	0.005±0.003	0.33±0.27	nd	0,009±0,009
	Liver (6)	0.005±0.005	10.85±5.09	nd	0,001±0,001
P. punctatus	Muscle (4)	nd	0.04±0.01	nd	nd
	Liver (4)	0.04±0.03	1.18±1.15	nd	0,11±0,10

nd= not detected

The leachate flow in sampling point 4 during wet and dry seasons were of 0.207 ± 0.064 m/s (n=4). Temperature and pH of the leachate during the same periods were of 26.5 ± 1.03 °C and 6.42 ± 0.72, respectively. Oxygen concentration varied most in sampling point 4, from 0.30 mg O_2/L in the dry season to 5.02 mg O_2/L in the wet season, averaging 2.91 ± 1.73 mg O_2/L.

Electric conductivity between sampling points 2, 3, and 4 presented unusual values. In wet season conductivity (µS cm^{-1}) was expected to be reduced in sampling point 4 in the stream, but that did not occur (Figure 3).

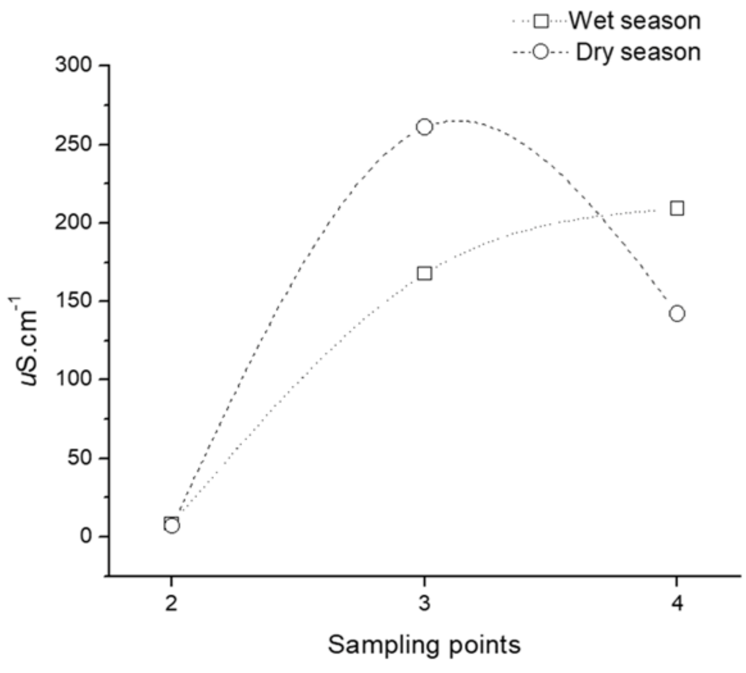

Figure 3. Leachete conductivity (µS.cm^{-1}) profile in a stretch of the Matrinxã.

The analysis of hydrocarbons and mercury in the leachate sample revealed undetectable concentration of benzene, toluene, xylene (< 5 µg/L) and mercury (< 0.0002 mg Hg/L).

Fish fauna

In the area affected by the leachate (points I, II and III), six fish species were captured (Figure 4), of which only *Apistogramma* cf. *steindachneri* (1) is commonly seen in small stream in Central Amazon. The other five species, *Cichlasoma amazonarum* (47), *Poecilia reticulata* (224), *Aequidens tetramerus* (1), *Hoplosternum littorale* (8) and *Pterygoplichthys punctatus* (10) are exotic to the study area. *Poecila reticulata* is not native to the Amazon, but it was the most abundant species with 224 individuals, which represented 76.98% of total abundance. The other species are typically found in the Solimões River Basin, not naturally occurring in the Negro River Basin (study area), that have blackwater rivers with low conductivity, and low pH. Those fish most likely migrated due to changes in biotic and abiotic parameters.

In the area outside the impacted of the landfill, approximately 2 km upstream from the landfill, 267 individuals from 19 fish species were caught (Figure 5). None of the species were found in the impacted area of the landfill (Figure 4). The most abundant species were *Copella nattereri* and *Poecilia* sp. with 138 and 29 individuals, respectively.

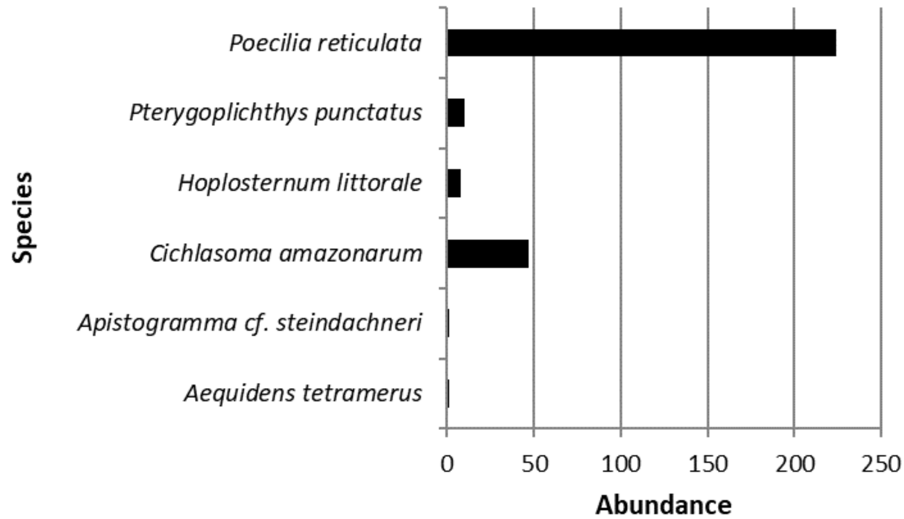

Figure 4. Abundance profile of fish sampled at the impacted site of the Manaus controlled landfill.

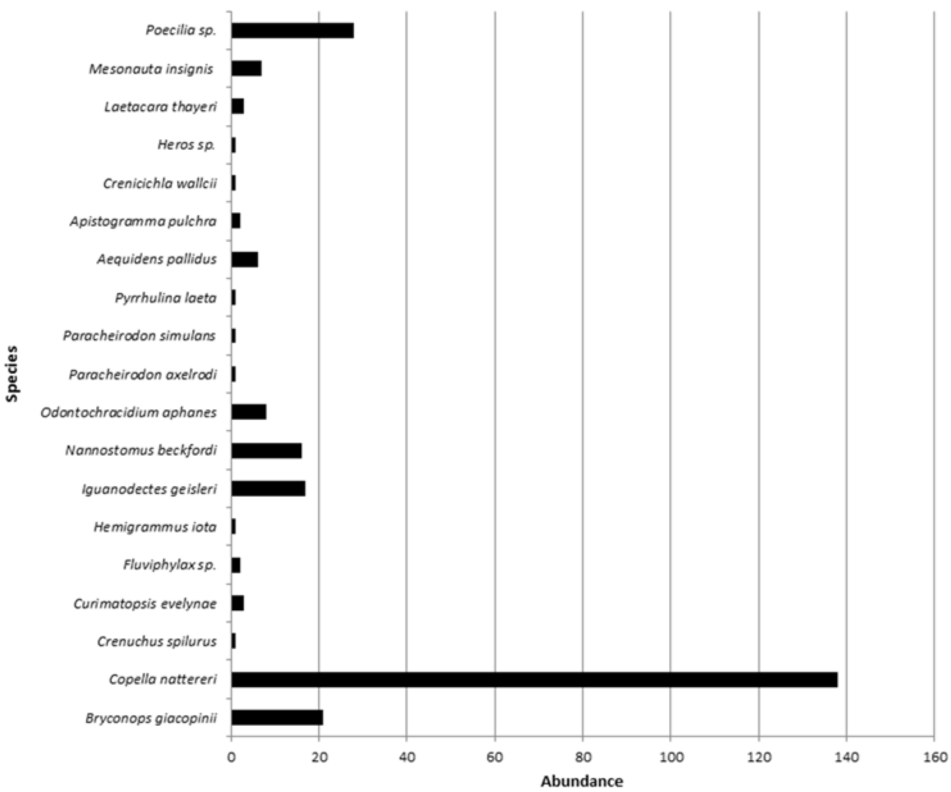

Figure 5. Abundance profile of fish sampled outside the Manaus controlled landfill impacted site.

DISCUSSION

Leachate pollution

The most common waste disposal method worldwide has been disposal in non-sanitary landfills (dumpsites and uncontrolled landfills) and this is mainly due to low cost of implementation and maintenance when compared to more sophisticated methods such as incineration or sanitary landfill. However, the disposal of waste in non-sanitary landfills leads to the production of a large amount of leachate that will inevitably pollute a river or lake (Abunama, 2021).

In this work the heavy metal concentration in leachate stabilization tanks were low during the dry season, except for Cu^{2+} (10 ± 1.39 µg/L) and Cd^{2+} (2.98 ± 0.75 µg/L). This may be due to the variation in the leachate pH values according to the waste decomposition stage. In the early stages, usually in the first three years, pH is low because of the fermentation of the organic matter, which helps dilute the metal concentration. Following this period, the organic matter stabilizes, and pH gradually increases, and divalent metals become less soluble (Wdowczyk and Szymańska-Pulikowska, 2021; Kulikowska and Klimiuk, 2008).

Water flow in the stream did not vary much (0.207 ± 0.064 m/s), which results in a quite constant dilution rate. The pH value (6.42 ± 0.72) was slightly high, suggesting chemical changes in the water, as blackwater pH values are usually low 4.0 to 5.0 according Junk et al. (2007) due of the large amounts of dissolved humic substances (blackwater). Variation in dissolved oxygen concentration was noteworthy, from 0.30 to 5.02 mg O_2/L, which may be the strong effect of high organic load of the leachate on the stream during dry season and weaker during wet season, respectively.

The highest conductivity value observed in sampling point 3 during the dry season may be due to percolation of concentrate leachate through the soil, as the waste deposition in the landfill is at an elevation 40-m higher than point 3. The leachate is diluted downstream by small water sources in point 4. During the wet season, more leachate percolates through to the stream resulting in similar conductivity values at points 3 and 4 (Figure 3). According to Junk et al. (2007) the natural conductivity of river draining like Matrinxã stream´s usually is low (5-20 µS cm^{-1}) due to the limited content of dissolved minerals. In this case, we see a great change in the environmental electrical conductivity.

Changes in the fish community structure

The most common causes of biodiversity loss in rivers in Brazil following human occupation are pollution, silting, eutrophication, physical barriers to control flow, overfishing, and introduction of species (Fauziah et al. 2013).

In the streams surrounding of Manaus, the most obvious environmental impacts are deforestation, road construction, conversion of forest area into agriculture use and pastures. In the limits of the urban area of Manaus, the main causes of environmental impacts are forest fragmentation, pollution and eutrophication from dumping of domestic effluents (Anjos, 2007). Such environmental alterations have negatively affected water quality, the structure of the environment and the aquatic living resources (Silva, 1995). Indeed, Amazonian igarapés have waters with low concentrations of mineral salts and are extremely sensitive to physico-chemical changes, which can significantly impact aquatic communities (Borghezan et al., 2021).

In streams in the Central Amazon, the fish community is usually composed mainly of small fish species, such as Characiformes and Siluriformes (Silva, 1995; Sabino and Zuanon, 1998; Bührnheim, 2002; Mendonça *et al*., 2005; Anjos, 2007). Nevertheless, in the stream near the controlled landfill, Perciformes were most dominant, followed by Siluriformes, and no Characiformes, particularly from the Characidae family, were observed. In a previous study assessing the integrity of the streams north of Manaus, the Characidae family was the most representative in number of species and highly sensitive to environmental changes, with drastic reduction in the population. It follows that the absence of characids confirms the hypothesis that they are a highly sensitive group of fish to anthropogenic environmental changes (Silva, 1995; Mendonça *et al*., 2005; Anjos, 2007).

The dominance in terms of abundance was determined by an exotic species, *Poecilia reticulata*, with 76.98% of the total abundance sampled in the leachate impacted stream (Figure 4). This result is similar to those reported previously for Anjos (2007), in streams in forest fragments within of Manaus. Where the same species represented 85% of the total abundance. Dominance of *P. reticulata* has also been reported in impacted streams in Southern Brazil (Cunico et al., 2009). Besides *P. reticulata*, *Cichlasoma amazonarum* was also found in all samplings, and represented 16.15% of total abundance. The *C. amazonarum* is a species typically found in floodplains and considered as an invading species in inland streams, also confirms the previous findings by Anjos (2007), who reported this species as highly frequent in impacted streams in the Manaus. *Pterygoplichthys punctatus* was the third fish species in terms of abundance (3.44%), also an invading species in inland streams. Anjos (2007) also reported *P. punctatus* as the third species in abundance and only captured in impacted streams.

A drastic change in the composition of fish species was observed in the stream of the landfill. Among the collected fish species, only *Aequidens tetramerus* and *Apistogramma* cf. *steindachneri* are common to inland streams. The other species were either introduced (*P. reticulata*) or invaded the environment (*C. amazonarum, P. punctatus* and *H. littorale*). The invading species are physiologically and biochemically adapted to low water oxygen concentrations. *P. punctatus*, for example, has modified stomach for gas exchange, and *H. littorale* has modified intestine for the same purpose, which may explain their resilience in water with high variation (0.30 to 5.02 mg O_2/L) in oxygen concentration (Almeida-Val, 1999). Furthermore, the low number of species does not follow the numbers as high as 19 species usually found in streams of same size and no impacted of landfill leachate, as we found in this study.

Changes in biotic and abiotic parameters of the environment may induce the extinction of some local species and be favourable to new invading species. Escalante-Mañe et al. (2022) found strong evidence of the deleterious effects of leachate on the embryonic development of *Danio rerio*. On the other hand, some of the adaptations of *P. reticulata* to low oxygen concentrations are ovoviviparity, i.e., the females retain the eggs inside the body and give birth to live, free-swimming fry, who have better chance of survival; and detritivory, i.e., feeding on decomposing organic matter, which increases the capacity to utilize food sources (Almeida-Val, 1999).

In an area away from the impacted of the landfill (*ca.* 1 km upstream), species diversity was higher (19), which indicates the strong pressure of the landfill on the fish fauna. Most of the species collected in this study was also reported in previous studies in the Central Amazon, for example, Silva (1995) in Carandiru stream´s (currently affected by the growth of the city of Manaus), Anjos (2007) in streams in forest fragments in the city of Manaus, Mendonça et al., (2005) in the Adolfo Ducke Forest Reserve (surrounded by Manaus city on the Sourth and West sectors), and by Sabino and Zuanon (1998) and Bührnheim (2002). Among the 19 species, *Paracheirodon axelrodi* (cardinal tetra) and *P. simulans* (green neon tetra), are common to Amazon streams but they are not native to the study area. These two species are native to the Negro and Orinoco River basins. They may have been introduced by ornamental fish traders based in Manaus or even by aquarists who gave up on the fish and released them in the nature.

Currently, in 2025, the small stream assessed in this study is highly silted due to infrastructure works in the controlled landfill and the progress of road construction.

CONCLUSION

The environment in the impacted area of the landfill has been extremely affected, drastically reducing the abundance and richness of fish species, due to changes in water quality parameters. The area outside the impacted of the landfill also presents some signs of alteration due to the human introduction of exotic species. In this case, we suggest continuously monitoring the impacts of the landfill on the aquatic environment, detecting changes in water quality and biota, as well as tracking the dispersion of exotic species in this environment.

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