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Extreme events and ichthyofauna: case report of a neotropical river

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ABSTRACT

The increasing frequency and intensity of extreme weather events and their impact on aquatic ecosystems and fish species is concerning. This manuscript reports and analyzes two events, a drought in 2019 and a flood in 2024, providing valuable insights into the consequences of these events. The rescue of 269 individuals of 19 fish species during the 2019 drought highlights the significant impact of the extreme conditions on the ichthyofauna. Rising temperatures, isolation, and habitat fragmentation must have posed severe challenges for the fish species during this period. On the other hand, the observation of 53 dead individuals of 5 species during the 2024 flood indicates the detrimental effects of this event on the fish population. The association of mortality and dispersal of several species with the existing dam further underscores the complexity of the challenges faced by fish during extreme flood events. The correlation between rainfall, river regime, and the impact of land use and occupation provides an important context for understanding the dynamics of these extreme events. The low rainfall during the 2019 drought and the gradual increase in rainfall between 2022 and 2024 leading to the flood demonstrate the significant role of precipitation patterns in shaping the outcomes for fish species. Additionally, the analysis of land use and occupation, particularly the substantial increase in urbanization in the drainage basin over the last 30 years, highlights the human-induced factors contributing to the stress on aquatic ecosystems. Both extreme floods and droughts have significant implications for fish species. Extreme floods can alter riverbeds, cause direct mortality, and disrupt isolated populations, while extreme droughts can lead to fish kills, and habitat fragmentation, and exacerbate environmental stressors. This analysis emphasizes the urgent need for comprehensive measures to mitigate the impact of extreme weather events on aquatic ecosystems and fish species. Addressing factors such as land use and occupation, water management, and climate change adaptation strategies is crucial for promoting the resilience of fish populations in the face of ongoing environmental challenges.

Keywords: drought, Ipanema National Forest, rainfall.

Eventos extremos e a ictiofauna: relato de caso de um rio neotropical

RESUMO

É preocupante ver a frequência e intensidade crescentes de eventos climáticos extremos e seu impacto nos ecossistemas aquáticos e espécies de peixes. Este manuscrito relata e analisa dois eventos, um de seca em 2019 e de enchente em 2024 fornecendo insights valiosos sobre as consequências desses eventos. O resgate de 269 indivíduos de 19 espécies de peixes durante a seca de 2019 destaca o impacto significativo das condições extremas na ictiofauna. O aumento das temperaturas, o isolamento e a fragmentação do habitat devem ter representado desafios severos para as espécies de peixes durante esse período. Por outro lado, a observação de 53 indivíduos mortos de 5 espécies durante a enchente de 2024 indica os efeitos prejudiciais desse evento na população de peixes. A associação da mortalidade e dispersão de várias espécies com a barragem existente ressalta ainda mais a complexidade dos desafios enfrentados pelos peixes durante eventos extremos de enchentes. A correlação entre precipitação, regime fluvial e o impacto do uso e ocupação da terra fornece um contexto importante para a compreensão da dinâmica desses eventos extremos. A baixa precipitação durante a seca de 2019 e o aumento gradual da precipitação entre 2022 e 2024, levando à enchente, demonstram o papel significativo dos padrões de precipitação na formação dos resultados para as espécies de peixes. Além disso, a análise do uso e ocupação da terra, particularmente o aumento substancial da urbanização na bacia de drenagem nos últimos 30 anos, destaca os fatores induzidos pelo homem que contribuem para o estresse nos ecossistemas aquáticos. É evidente que tanto as enchentes quanto as secas extremas têm implicações significativas para as espécies de peixes. As enchentes extremas podem alterar os leitos dos rios, causar mortalidade direta e interromper populações isoladas, enquanto as secas extremas podem levar à morte de peixes, fragmentação do habitat e exacerbação de estressores ambientais. Esta análise enfatiza a necessidade urgente de medidas abrangentes para mitigar o impacto de eventos climáticos extremos nos ecossistemas aquáticos e nas espécies de peixes. Abordar fatores como uso e ocupação da terra, gestão da água e estratégias de adaptação às mudanças climáticas é crucial para promover a resiliência das populações de peixes diante dos desafios ambientais contínuos.

Palavras-chave: Floresta Nacional de Ipanema, pluviosidade, seca.

1. INTRODUCTION

It's interesting to note that extreme climatic events are responses to changes that occur in the hydrological cycle, which is regulated by climatic characteristics (Tejadas *et al.*, 2016). These events can manifest as prolonged droughts, heat waves, or precipitation events associated with huge, infrequent storms and floods (Tonkin, 2022). The impact of these events can be observed in the spatial and temporal distribution of hydrological variables, such as precipitation and flow, as well as the intensity and frequency of events (Adam *et al.*, 2015). Changes in precipitation patterns can cause noticeable effects on ecosystems, particularly in aquatic systems and associated biota (Santos *et al.*, 2017). Extreme rainfall, with its irregular temporal and spatial distribution, can cause soil erosion, flooding, and damage to drainage systems (Araújo *et al.*, 2008). Conversely, drought is a complex natural phenomenon that affects several global regions, resulting in low rainfall levels and inducing social, economic, and environmental impacts (Macedo *et al.*, 2010).

Events beyond natural limits can greatly impact water quality, river elevation, hydrodynamics, and biological communities (Tejadas *et al.*, 2016). The disruptions caused by climate change are expected to increase significantly over the next 100 years (IPCC, 2021), with human occupation and development in urban and rural areas contributing to environmental degradation and floods (Lorenzon *et al.*, 2015).

Hydrological changes affect the entire ecosystem, especially impacting fish, a group that is highly vulnerable to regional climate change (Mooij *et al.*, 2009; Santos *et al.*, 2017; Andrade *et al.*, 2018). In the Ipanema National Forest, 89 fish species have been catalogued in its drainage (Smith *et al.*, 2021), while in the Ipanema River, approximately 52 fish species have been recorded (Oliveira *et al.*, 2013), which may be directly or indirectly affected by the events described in this article. Fish are sensitive to environmental variations, such as rising temperatures and falling oxygen levels, and not all are adapted to these transformations, which can generate profound changes at the individual, population, and ecosystem levels (Andrade *et al.*, 2018; Silva *et al.*, 2018).

The consequences of these changes include changes in the air-water interface, with increased incidence of ultraviolet radiation, salt leaching, silting, reduction of feeding and nursery areas, in addition to a decrease in available oxygen and an increase in temperature (Val and Almeida-Val, 2008). In addition, delays or inefficiencies in fish reproductive strategies and changes in their habitats, such as expansion or contraction, may occur (Lima *et al.*, 2021; Portella *et al.*, 2021). In addition, there may be a reduction in the genetic variability of species, a decrease in population growth rates and an increase in the risk of local extinction due to the loss of feeding and refuge areas, combined with oxygen scarcity and increased temperature (Letcher *et al.*, 2007).

Consequently, these changes lead to the loss of endemic species, the spread of exotic species and changes in habitats, causing deregulation throughout the ecosystem. However, there is still little information on the specific impacts of these changes on fish species in the Ipanema River. In view of the above, this work, which is the first of its kind in the Sorocaba River Basin, presents a report on two extreme events that occurred in the Ipanema River, in the section located in the Ipanema National Forest, highlighting their effects on the fish community and the influence of the use and occupation of the drainage network in the intensification of these events.

2. MATERIALS AND METHODS

2.1. Study area

The Ipanema National Forest is a Federal Conservation Unit located in the municipalities of Iperó, Araçoiaba da Serra and Capela do Alto in São Paulo, Brazil. It covers an area of 5.400 hectares and has the Ipanema River in its hydrography, in addition to the Ribeirão do Ferro and the Rio Verde, belonging to the Sorocaba Hydrographic Basin, the Ipanema River being one of the main tributaries of the Sorocaba River. At the junction of the Ipanema River and the Verde River, a dam called the Hedberg Dam was built in 1808 and is considered the oldest in Brazil. Despite the dam, there is no regulation of the water flow, as it no longer has the functions for which it was intended at the time of its construction. The study was conducted on the Ipanema River and the Hedberg Dam (Figure 1).

2.2. Extreme events of 2019 and 2024

In November of 2019, there was a reduction in the water level in the Ipanema River downstream of the Hedberg Dam and nearby lakes, causing fish death, isolation, and stranding of specimens. In January 2024, due to increased rainfall, the level of the Ipanema River rose by 1.5m in the same places as in the 2019 drought. A long period of torrential rain caused an increase in the volume of the Ipanema River and its tributaries, resulting in a great flood (Figure 2).

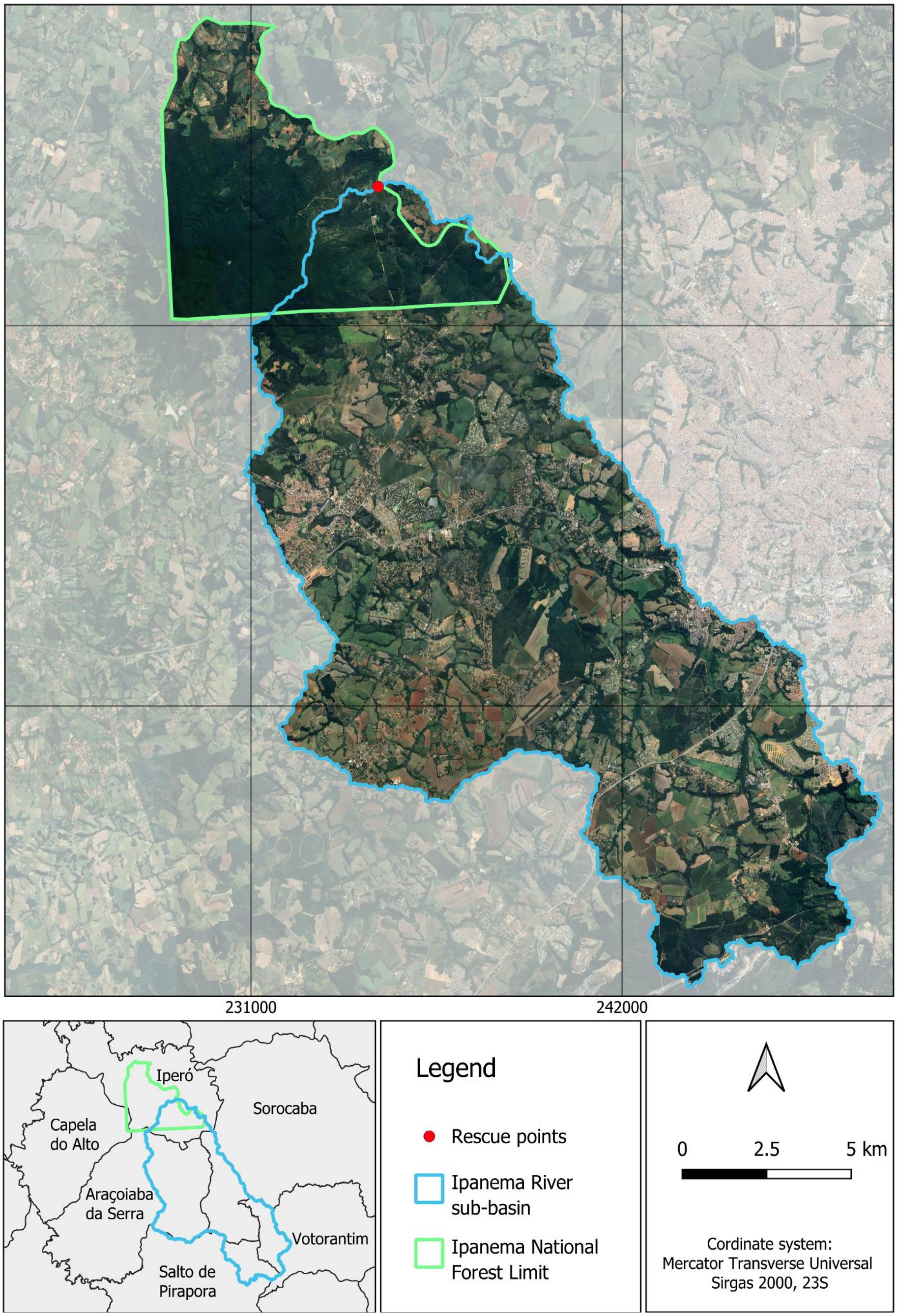

Figure 1. Study area presenting the hydrographic system of the Ipanema National Forest, Iperó, São Paulo, Brazil, and the point where the rescue was carried out.

Figure 2. Ipanema River, Hedberg Dam, Ipanema National Forest, in the events of November 2019 (a, b, c) and January 2024 (d, e, f).

2.3. Ichthyofauna Rescue

Wildlife rescue, by definition, consists of the specialized action of capturing or relocating animals found outside their natural habitat, putting at risk their lives and/or the safety of people (França *et al.*, 2021). In this study, fish rescue involved capturing and relocating fish from areas impacted by environmental changes, such as droughts and floods, to locations where safer conditions for their survival were identified. However, despite the rescue efforts, some individuals were found dead. These were collected and included in the study's database.

In both events, ICMBio/Ipanema National Forest requested and authorized the monitoring of ichthyofauna in the downstream section of the Hedberg Dam and the flooded areas on the banks of the dam. The rescue of fish fauna during the drought event was carried out between November 5 and 6, 2019, while in January 2024, fish were rescued during the flood. Fish rescue and collection were performed under different environmental conditions. During the drought, fish were collected from isolated lakes due to reduced water levels, which caused the isolation of fish. During the flood, collection was necessary due to habitat loss, population displacement caused by rising water levels, and subsequent isolation of fish when water levels returned to normal. Fish were rescued and sampled using 5.0 mm multifilament mesh trawls, pans, sieves, buckets, and transport boxes (Figure 3A), in addition to manual procedures.

The specimens were identified, weighed (g), and measured (standard length in cm). After this procedure, they were released, always in locations close to where the fish were captured. There was no need to move the fish long distances. The ichthyofauna rescue activity was carried out under authorization issued by IBAMA, Process N°. 02009.000127/200830. Both dead and live fish (Figure 3B), when captured during the rain event, were also identified, weighed, and measured. Only the dead specimens were sent to the Laboratory of Structural and Functional Ecology (LEEF), fixed in 10% formalin, and stored in 70% alcohol.

Figure 3. Carrying out rescue work in bodies of water in the Ipanema National Forest (A) and specimens were killed because of the reduction in levels of the Ipanema River downstream of the Hedberg Dam (B), Ipanema River, Ipanema National Forest.

To complement the study, raw precipitation data from 2010 to 2024 and also monthly data from the last 3 years were obtained from the National Institute of Meteorology (INMET). Additional precipitation and river regime data from the Hedberg Dam were provided by the

Urban Drainage and Hydrometeorological Monitoring Laboratory of the Hydraulics Technology Center Foundation (FCTH) of the University of São Paulo. However, the data collection station at the dam, installed in 2016, presented discontinuous data in some periods. Information for the year 2019 was not available due to a failure in the installed equipment, and data for 2024 have not been released.

In addition, the drainage network whose outlet is the Ipanema National Forest Dam was obtained using geoprocessing tools, delimiting the limits of the responsible river basin. For the temporal analysis of the characterization of land use and occupation in the study area, the land use base map for the years 1992, 2002, 2012, and 2022 was used, obtained through the MapBiomas Project database, from the v.8.0 collection and processed in the QGis 3.30.2 geoprocessing software.

3. RESULTS

Both extreme events mentioned in this paper refer to two distinct moments that occurred in the Ipanema River, a larger river located in the Ipanema National Forest, which directly affected the ichthyofauna. In 2019, low precipitation led to an extreme drought event, resulting in a decrease in water levels, leaving hundreds of fish trapped in puddles. On 5 and 6 November, rescue operations were carried out, during which individuals of different species were relocated to more favorable environments, upstream of the rescue section. A total of 269 individuals of 19 species were recorded (Table 1 and Figure 4), one of which was invasive, and none were endangered. Most of the rescued species were medium and large in size, many presenting abrasions and scale displacement due to the efforts made in areas with low water levels. Small and juvenile species were scarce in the rescue, probably due to their greater ease of escape in shallower waters. Even so, many dead individuals were observed at the site.

Table 1. Rescued fish species and their respective abundances, lengths, and standard deviations. Classification as Migrant (M) and Non-Migratory (NM) and threat status according to MMA Ordinance No. 148, of June 7, 2022 (Brazil) and Decree 63.853/2018 of the State of São Paulo (SP). LC: Least Concern.

Order/Family	Abundance drought event	Abundance rain event	M/NM	Threat status SP/Brazil
CHARACIFORMES				
Acestrorhynchidae				
Acestrorhynchus lacustris (Lütken 1875)	3		NM	LC/LC
Anostomidae				
Schizodon nasutus Kner 1858	2		M	LC/LC
Bryconidae				
Salminus hilarii Valenciennes 1850	16		M	LC/LC
Characidae				
Aphyocharax dentatus Eigenmann & Kennedy 1903	15		NM	LC/LC
Astyanax lacustris (Lütken 1875)	21		NM	LC/LC
Hemigrammus marginatus Ellis 1911	12		NM	LC/LC
Psalidodon anisitsi (Eigenmann 1907)	4		NM	LC/LC
Psalidodon fasciatus (Cuvier 1819)	23	14	NM	LC/LC
Piabina argentea Reinhardt 1867	7		NM	LC/LC
Serrapinnus notomelas (Eigenmann 1915)	9		NM	LC/LC

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Curimatidae				
Cyphocharax modestus (Fernández-Yépez 1948)	4		NM	LC/LC
Steindachnerina insculpta (Fernández-Yépez 1948)	1	18	NM	LC/LC
Erythrinidae				
Hoplias malabaricus (Bloch 1794)	3		NM	LC/LC
Parodontidae				
Parodon nasus Kner 1859	9		M	LC/LC
Prochilodontidae				
Prochilodus lineatus (Valenciennes 1837)	53		M	LC/LC
Serrasalmidae				
Serrasalmus maculatus Kner 1858	6		NM	LC/LC
SILURIFORMES				
Loricariidae				
Hypostomus ancistroides (Ihering 1911)	12		NM	LC/LC
Rineloricaria latirostris (Boulenger 1900)		7	NM	LC/LC
Heptapteridae				
Pimelodella sp.		11	NM	LC/LC
GYMNOTIFORMES				
Gymnotidae				
Gymnotus carapo Linnaeus 1758		3	NM	LC/LC
PERCIFORMES				
Cichlidae				
Geophagus iporangensis Haseman 1911	46		NM	LC/LC
Oreochromis niloticus (Linnaeus 1758)*	23		NM	LC/LC
Total	**269**	**53**		

*Invasive species.

In January 2024, high levels of precipitation resulted in a major flood in the Ipanema River, affecting fish to the point that many specimens were transported to areas far from the river channel, becoming stranded and dying. The inventoried species (53 individuals belonging to 5 species) are indicated in Table 1 and Figure 5. In addition, it was possible to observe many specimens going upstream, overcoming the existing waterfall, including *Prochilodus lineatus*, *Salminus hilarii* and numerous small species, such as *Astyanax lacustris* and *Palidodon fasciatus*.

The Ipanema River has a dam that separates the lentic (upstream of the dam) and lotic (downstream of the dam) sections. Therefore, the increase in water volume caused it to invade historical sites and other structures in the conservation unit. In a way, some migratory species benefited, with a greater volume of water and, consequently, greater ease in moving upstream; however, other species, such as small non-migratory species, or those with short migrations, were seriously affected. Most of the specimens found dead were small and medium-sized.

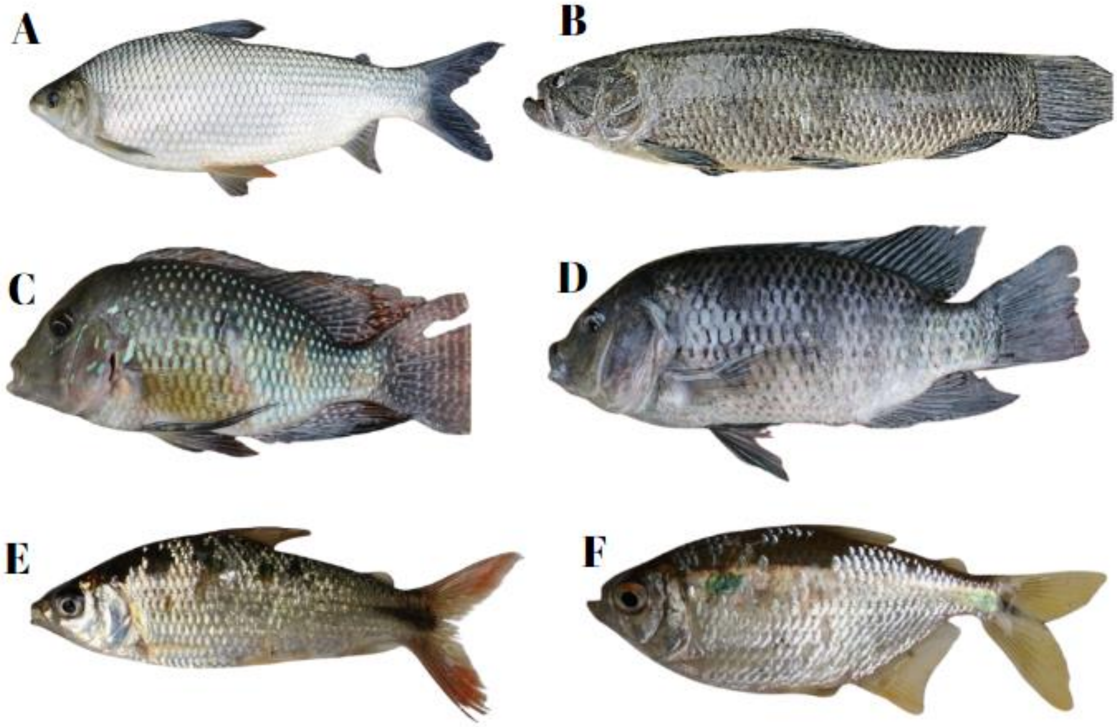

Figure 4. Species rescued during the drought in the water bodies of the Ipanema National Forest, in 2019. A - *Prochilodus lineatus*; B - *Hoplias malabaricus;* C - *Geophagus iporangensis*; D - *Oreochromis niloticus;* E - *Cyphocharax modestus;* F - *Astyanax lacustris.*

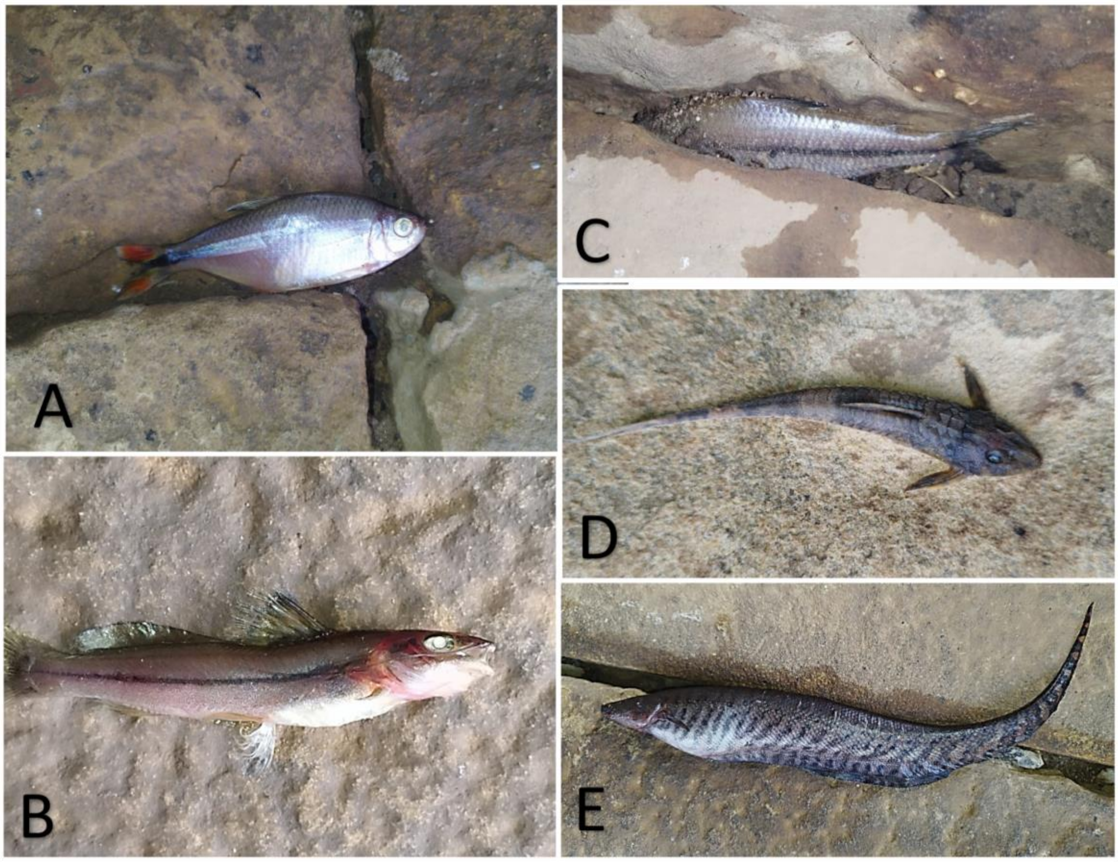

Figure 5. Specimens rescued during the extreme flood of January 2024. A – *Psalidodon fasciatus*; B – *Pimelodella* sp.*;* C – *Steindachnerina insculpta*; D – *Rineloricaria latirostris*; E – *Gymnotus carapo.*

Based on the above report, an investigation was carried out on precipitation, fluvial regime and use and occupation of the Ipanema River drainage basin with the aim of understanding these events, the possibility of new occurrences and what could aggravate the effects on the ichthyofauna. According to data obtained from the Inmet website, it is possible to observe that annual precipitation is inconsistent, especially between the years 2017 and 2024 (Figure 6A).

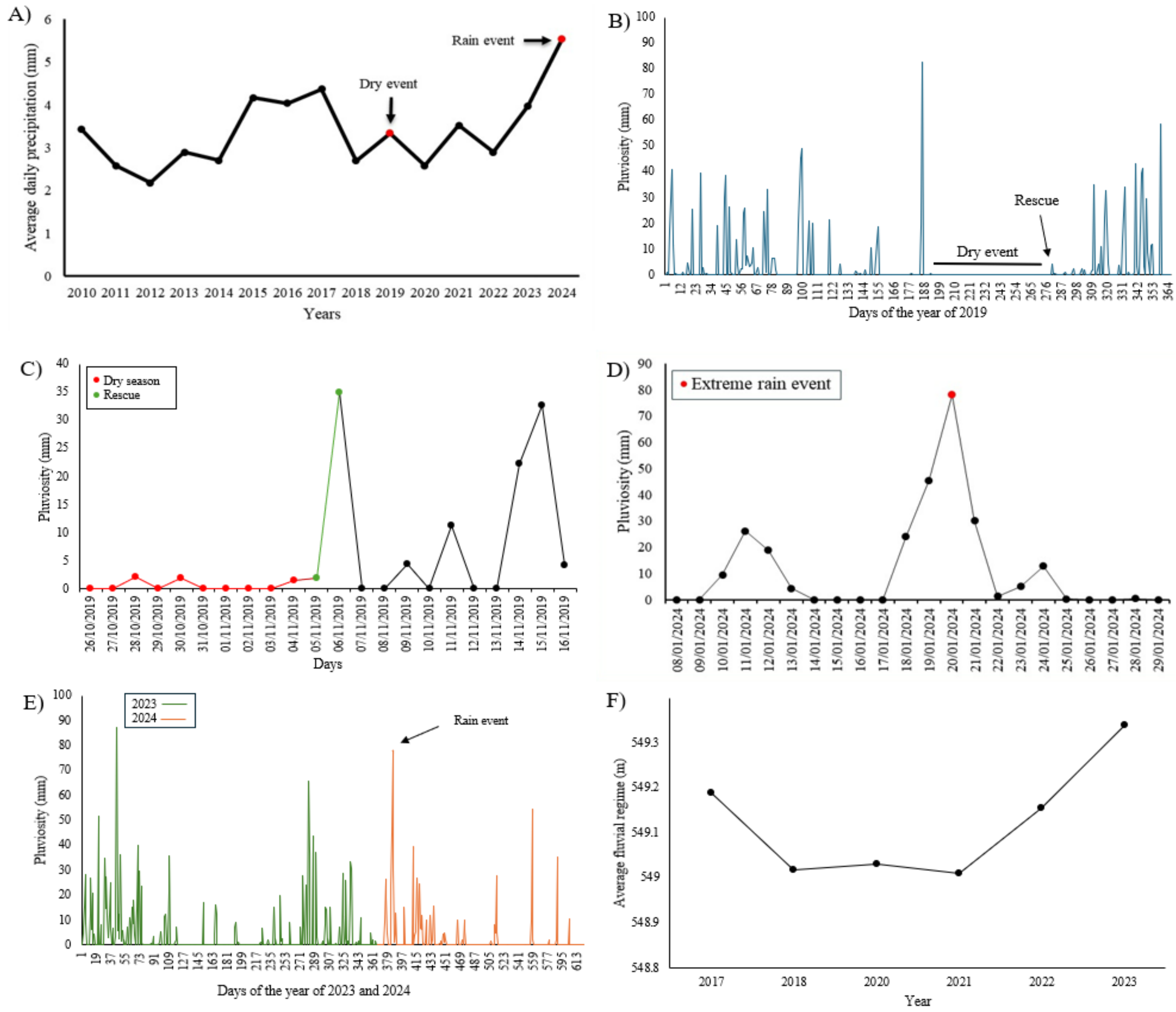

Figure 6. Rainfall and river regime data. A - Average annual precipitation from 2010 to 2024 (data from 2024 to March). B - Daily precipitation index (mm) in 2019 (extreme drought event). C - Precipitation index (mm) from October 26, 2019 to November 16, 2019. D - Precipitation index from January 8, 2019 to January 29, 2019. E - Precipitation index for the years 2023 and 2024 (data from 2024 to September). F - Average river regime at the Hedberg Dam, Flona de Ipanema, Iperó/SP from 2017 to 2023 (absence of the year 2019 and 2024), data provided by the Urban Drainage Area and Hydrometeorological Monitoring laboratory (FCTH-USP/SP).

Regarding the 2019 drought event, some considerations should be made. On July 5, 2019, the sixth highest rainfall in the last 24 years was recorded, being the highest in 2019 (82.6 mm). This precipitation rate is only surpassed by: November 23, 2010, with 87 mm, February 13, 2023 with 87.4 mm, February 15, 2014 with 88.8 mm, March 11, 2016 with 98.2 mm and June 6, 2017, with 112.4 mm (Figure 6B). It is strange that this high precipitation occurs during the dry period, demonstrating a serious change in climate events, leading us to believe that this anomaly may be the main factor for the absence of rain between July 5, 2019 and November 6, 2019. Therefore, the year 2019, marked by one of the highest precipitation rates of the decade, is also the year of an extreme drought event. This is the reason why the year 2019 has a higher annual average rainfall than some years that did not experience an extreme drought event, such as 2018 and 2020.

Analyzing the precipitation in the period close to the rescue (October and November 2019) helps to understand the main reason that led to the extreme drought event. There was a representative return of rain only on November 6 (second day of the rescue) with 35 mm. There were 125 days with little or no precipitation. It is also possible to observe that, after the rescue, rains became more frequent again, returning to normal for the rainy season (Figure 6C).

In the flood event that occurred at the beginning of 2024, it is possible to observe an increase in precipitation on January 18 (24 mm), increasing considerably until January 20, when the highest precipitation of the month occurred (78 mm), affecting the entire river basin. 177.4 mm of rain was recorded in just 4 days (January 18 to 21) (Figure 6D). When observed together with the year 2023, it is understood that large peaks of rainfall are not abnormal, with February 13 having 87.4 mm of rain. However, the sequence of rainfall in a short period in 2024 (4 days) makes this event extreme. Just for comparison, the same value of 177.4 mm of rain was obtained in both years at their peak rainfall. The big difference is that in 2023 it took 9 days (February 12 to 20) (Figure 6E). The average river regime at the Hedberg Dam between 2018 and 2021 was lower, with an increase only in 2022. The year 2023 had the highest river regime recorded in the last 7 years (Figure 6F). This information reinforces the relationship between precipitation and river regime, which is expected, but may also represent a worsening due to the way in which land use is being carried out.

Spatial and temporal analysis of the study area over 30 years allowed us to identify major changes in land use and coverage during this period. The pasture area showed a 66% reduction, becoming predominantly an urbanized soybean production area, where, represented by the physiognomies “Urban Area” and “Soybean”, they were the ones that increased the most in their areas, with this increase being 2447% and 586%, respectively. This scenario demonstrates a negative aspect for the studied drainage basin, due to the consequences of the loss of vegetation cover, increased soil sealing, reduction of the water infiltration rate, surface runoff, and maximum flow rates. On the other hand, there was a 39% increase in forest vegetation cover; however, this phenomenon is observed exclusively in the forest massif already established in the south of the basin and located in the Ipanema National Forest. However, it is worth highlighting that the riparian forest, whose preservation is extremely important to cushion the impacts of rainfall events, remained predominantly degraded (Figure 7 and Table 2).

4. DISCUSSION

The Southeast of Brazil is in an area with a high chance of extreme weather events (Marengo, 2016), as occurred in the Ipanema River in 2019 and 2024 and in Rio Grande do Sul in the first half of 2024 (Rizzati and Batista, 2024). Naumann *et al.* (2022), warn that in drought events, fish can end up isolated, on sandbanks, without the possibility of escape, and in several cases, without reproduction sites, as many species carry out part of this cycle using marginal lagoons, and due to the absence of water, these important ecosystems cease to exist. According to the same authors, the main causes for the drought events from 2019 to 2021 were the phenomenon of El Niño Southern Oscillation (ENSO) and changes in land use and deforestation. According to Bonfim *et al.* (2021), drought events are more common than rainy events.

Climate change affects the movement of fish between habitats, in addition to the loss of structural and functional connectivity of aquatic ecosystems, being one of the main causes of loss of fish diversity (Franklin *et al.*, 2024). In addition to the community in rivers and streams, these impacts can affect the fauna of birds, mammals, and other animals that have fish in their diet (Morais, 2008; Giuliani *et al.*, 2022). In the studied area, the main migratory species are *Prochilodus lineatus* (Valenciennes, 1837) and *Salminus hilarii* Valenciennes, 1837 (Portella *et al.*, 2021). However, it is clear that, of mortality in the two extreme events, a large part is small- and medium-sized species, such as *Psalidodon fasciatus*, *Astyanax lacustris*, and *Geophagus iporangensis*, species of which little is known about their movement patterns and locomotion (Mazzoni and Barros, 2021). Being the most abundant rescued species, *P. lineatus* is an important species for the Sorocaba River Basin, being one of the main migrants, while *O. niloticus* is one of the most widely distributed invasive species in the world (Smith *et al.*, 2003) and very common in the studied basin.

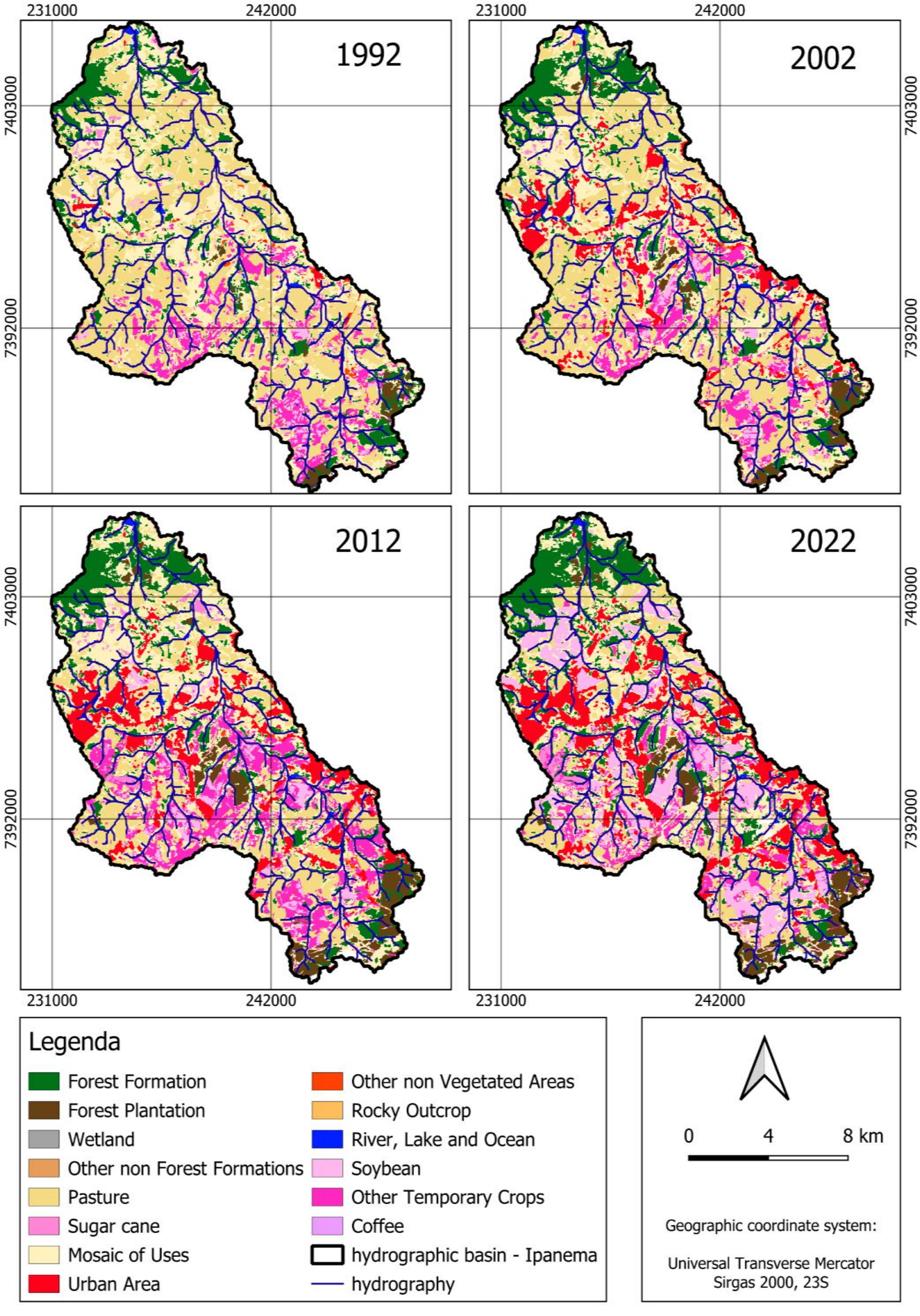

Figure 7. Land Use and Occupation of the Ipanema River drainage basin, in the years 1992, 2002, 2012, and 2022.

Table 2. Percentage (%) of the physiognomic characteristics present in the Land Use and Occupation of the Ipanema River drainage basin in the years 1992, 2002, 2012, and 2022.

Class (%)	1992	2002	2012	2022
Forest Formation	12.4361	13.5887	14.4077	17.3974
Forest Plantation	1.5117	2.9817	4.9078	5.3810
Wetland	<0.01	<0.01	<0.01	<0.01
Pasture	37.8664	33.2691	17.7661	12.5568
Sugar cane	0	0	0.9549	0.5962
Mosaic of uses	35.0346	32.2557	32.5866	29.1928
Urban Area	0.5524	7.6203	11.3596	14.1279
Other non Vegetated Areas	0.6229	<0.01	<0.01	0.6506
Mining	<0.01	<0.01	<0.01	<0.01
Hypersaline Tidal Flat	<0.01	<0.01	<0.01	<0.01
River, Lake and Ocean	1.3660	0.9558	0.8236	0.7037
Soybean	1.6774	1.5114	3.1258	11.5553
Other Temporary Crops	8.9324	7.8173	14.0680	7.8382
Coffee	<0.01	<0.01	<0.01	<0.01
Other Perennial Crops	<0.01	<0.01	<0.01	<0.01
TOTAL (%)	100	100	100	100

Rain is essential for fish migration (Leira *et al.*, 2018); however, events such as sudden floods and changes in water temperature end up impacting the life cycle of these species, and the entire fish community (Costa and Oliveira, 2024). Strong heat waves drastically affect the community of freshwater organisms, altering the metabolism and body formation of ectothermic organisms (Polazzo *et al.*, 2022). Camacho Guerreiro *et al.* (2016) carried out work in the Amazon, where they demonstrated that some fishermen are already aware that climate change alters ecosystems and affects fish communities.

Based on the data presented, the intensification of events and their consequences already reported in many studies and also in this manuscript, we dare to indicate the most common changes observed in Neotropical aquatic ecosystems (Andrade *et al.*, 2018), which can contribute positively and/or negatively to the ecosystem and the fish community present (Figure 8a). In addition, the ichthyofauna directly affected (Figure 8b) suffers damage to its movements, loss of spawning areas, or expansion of the same, leading to changes in the reproductive strategies of fish, especially in migratory species, in addition to high mortality rates in both types of events (Letcher *et al.*, 2007; Lima *et al.*, 2021; Portella *et al.*, 2021). It is worth highlighting the worsening of the situation in flood events, due to how the land is being used and occupied.

Data on land use and occupation in the context of extreme events help to understand the correlation between local landscape and erosion or water runoff (Santos *et al.*, 2021). With the decrease in the appearance of forest formation, there is greater soil sealing (Campioli and Vieira, 2019). As a consequence, Portela *et al.* (2023), demonstrate that forest soil and non-forest natural formation result in less vulnerability to flooding, while the landscape of urban infrastructure and watercourses have greater vulnerability.

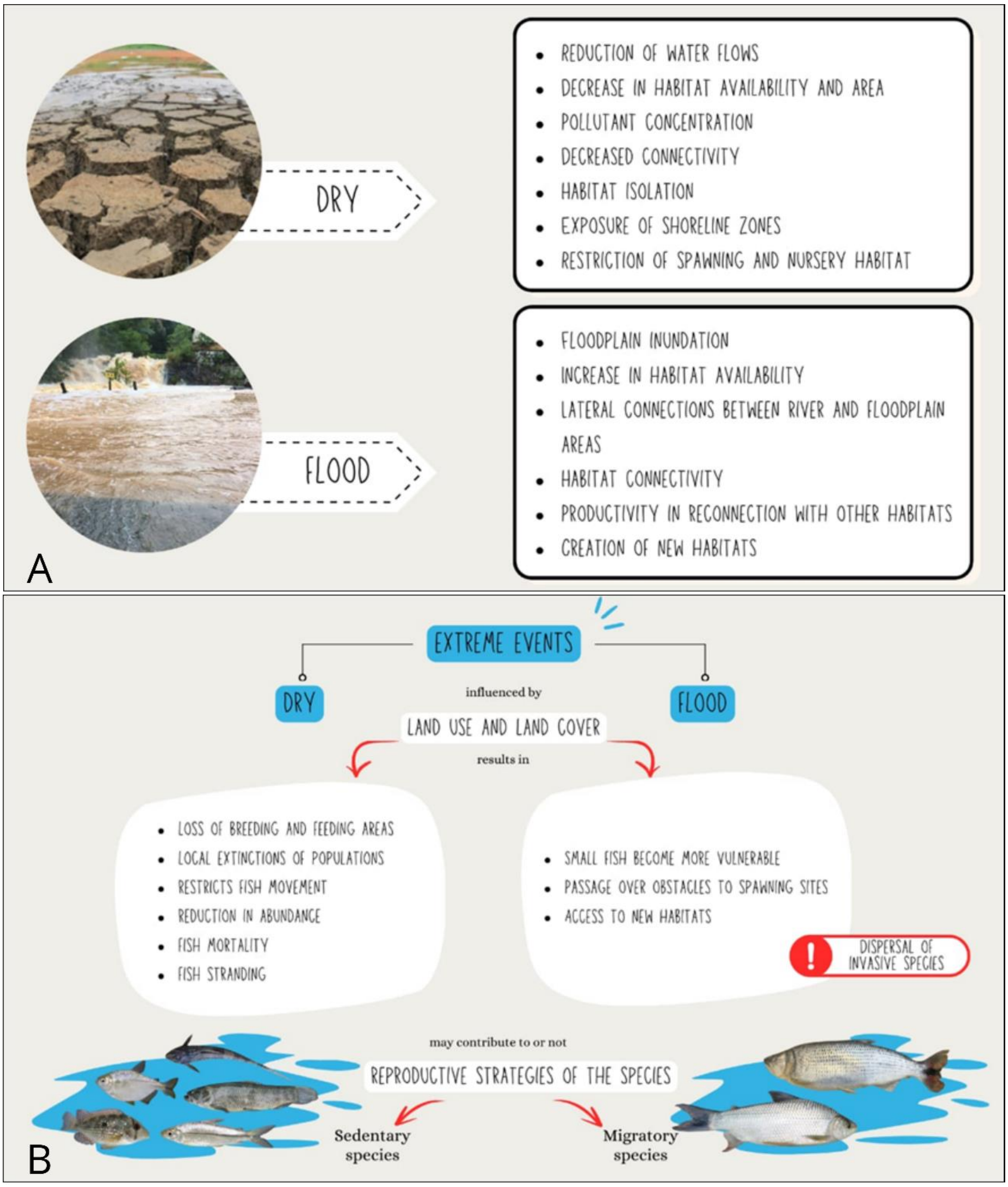

Figure 8. Effects of extreme events on aquatic ecosystems (a) and ichthyofauna (b) due to land use and occupation during dry and rainy seasons.

The effects of extreme events can increase the vulnerability of ichthyofauna due to the degradation of feeding and breeding sites, loss of habitats, and limitation of large areas for locomotion – especially in the case of migratory fish. As a result, the structure and composition of the community can be altered, as less tolerant species seek areas with better conditions, while only a few more tolerant species remain, which affects interspecific ecological relationships (Andrade *et al.*, 2018). This process favors the persistence of more resistant species, resulting in a community with less diversity (Chase, 2007).

Therefore, although this manuscript only portrays two events, presenting only descriptive data, the information presented here has the potential to support research that evaluates the influence of extreme events on fish fauna, as well as establishing guidelines for monitoring, evaluation, and decision-making. Furthermore, initiatives that precede such events, such as climate monitoring (rainfall and fluviosity) in areas more prone to such events, as is the case of the river studied, can avoid large mortalities by reducing the effect on the ichthyofauna.

5. CONCLUSION

Extreme events cause major impacts on fish communities and are highly influenced by land use and occupation. The amplification of these events leads to the disruption of aquatic ecosystems and ecological imbalance, resulting in habitat loss, changes in water quality, and declines in fish populations. The main causes of these events are linked to human activities, such as deforestation, urbanization, intensive agriculture, and climate change. Understanding the causes and consequences of these effects is, therefore, of paramount importance for implementing management and conservation measures that aim to protect and ensure the sustainability of aquatic ecosystems.

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