Topics of limnological research in Mexico

Coordinator
Alfredo Pérez Morales

UNIVERSIDAD DE COLIMA

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This book is dedicated to
Dr. Singaraju Sri Subrahmanya Sarma,
in gratitude for all his teachings in the world of limnology.

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Fishing Among Socioecological Challenges: The Case of the Zimapán Dam

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Abstract

The Global Climate change crisis urgently demands a deeper and more comprehensive understanding of aquatic systems. In this study, we analyzed the Zimapán Dam, a relatively recently created ecosystem distinguished by its high complexity and distinct anthropization, where fishing is intricately connected with ecological, environmental, and social factors. We updated the list of fish species present in the dam and analyzed daily registers of the "13 de Junio" Fishing Cooperative, aiming to comprehend the dynamics of fishing activity. Additionally, semi-structured interviews were conducted with fishers to capture their perceptions of the situation, identify underlying causes, and explore potential solutions. The fish community is composed of eight species and two subspecies identified as exotics. On average, during the study period, the catch per unit effort of tilapia was 10 kg per fisher per day. The fishing activity has experienced notable variations over time, lacking evident consistency and was influenced by various factors. Several causes for the decrease in fishing and the gradual abandonment of the activity due to lack of profitability were pointed out by the interviewees, primarily the presence of black bass. This study underscores the need for integrated approaches and collaborative solutions addressing both the ecological problems and social dimensions of fishing. Ecosystems like the Zimapán Dam will become increasingly important in the context of global change; therefore, understanding them as key ecosystems on which we will depend in the near future is essential.

Keywords

Anthropization; Black Bass; Exotic species; Hydroelectric Dam; Tilapia.

Introduction

Throughout the Anthropocene, human activities have caused impacts on the environment, altering atmospheric, geological, hydrological, and ecosystem processes at multiple scales, ranging from local to planetary (Ruddiman, 2013). Nowadays, we are witnesses of the ecosystem disruptions resulting from the transformation of natural and social processes, such as land use change, transformation and degradation of the ecosystems, and alterations in biogeochemical cycles. In fact, ecosystems are no longer conceivable without human influences (Schmitz, 2016). There is a growing concern about the capacity of ecosystems to maintain their function in the context of global change. According to the Global Risks Report (World Economic Forum, 2019), water bodies are acknowledged as one of the systems experiencing the most significant social, political, and economic pressure globally, as nearly all human activities are intimately linked with water. For instance, estimates indicate that humanity expropriates more than half of the accessible drinking water (Gleick & Palaniappan, 2010).

Aquatic ecosystems are particularly affected, and it is estimated that aquatic populations have decreased by 76 % in epicontinental bodies of water since 1970 (WWF, 2014). Epicontinental water bodies are key to ensuring the water supply for human population and the sustainable development of nations (Bunn, 2016). The viability of these water bodies in the future is crucial and depends on the control that can be exerted over the sources impacting them, which, in turn, relies on an adequate understanding of their functioning (Sage, 2019). This situation is particularly concerning in Mexican aquatic ecosystems.

In our country, 77 % of the human population resides in areas where only 33 % of renewable water is found (Arreguín-Cortés et al., 2020). According to the Atlas of Water Vulnerability to Climate Change (Arreguín-Cortés et al., 2015), the most critical basins and aquifers in terms of population and economic activities are over-conceded and overexploited respectively. Besides the scarcity of availability, pollution represents another limiting factor; in Mexico, 70 % of bodies of water show some degree of contamination (Conagua, 2018). For example, 49 % of rivers and streams are categorized with a high or very high degree of ecohydrological alteration (Garrido et al., 2010). According to Sánchez (2017), in Mexico, more than 80 % of municipal wastewater generated by public-urban use is discharged into water bodies without any treatment. Likewise, 82 % of industrial wastewater is discharged untreated (Bunge, 2010). This, coupled with the expected impact of climate change on precipitation patterns, contributes to the challenges. The country's situation is projected to become critical by 2025 (Ávila, 2008).

Additionally, introduced species are among the main effects of human alteration of aquatic systems. Exotic species can reduce native fish populations (Rahel, 2000), modify community dynamics (Minns & Cooley, 1999), alter trophic structure stability (Vander Zanden & Rasmussen, 1999), and even lead to the extinction of native species (Lodge, 1993). The potential consequences on native fauna and ecosystems are severe, especially in areas of high diversity (Zambrano et al., 2006). In Mexico, exotic fish species are established in virtually all bodies of water in the central region of the country and are one of the most significant factors contributing to the loss of native species (Zambrano & Hinojosa, 1999; Contreras-MacBeath et al., 2014). Numerous effects generated by exotic species have been identified, such as changes in community structure, competition for food resources (Zambrano et al., 2010), modification of native species populations, trophic cascades, and algal blooms (Figueredo & Giani, 2005), increased turbidity (Miller & Crowl, 2006), and reduction of trophic pathways (Córdova-Tapia, 2011). Currently, some negative effects of these species are known, but many details about how they integrate into food webs and their ecological implications remain unclear. Both pollution and the introduction of exotic species act synergistically on epicontinental water bodies, generating direct and indirect changes in the quantity and quality of existing resources, which in turn can lead to changes in community structure and ecosystem functioning (McCormick et al., 2009).

Water-related issues in Mexico are becoming increasingly problematic. Climate change, water scarcity, exotic species, and poor water quality are persistent and worsening problems. Major cities will have less water, water quality will deteriorate, and conflicts over water will increase. Moreover, poverty and social inequality will rise, making the situation even more complex (Ávila, 2008). In summary, it is expected that in the coming years, Mexico will experience a loss of water security, affecting many people and exacerbating poverty and inequality, while also endangering the country's ecosystems. We are facing a water crisis, both nationally and globally, posing a significant challenge for limnology. Therefore, in recent years, research efforts have been directed towards understanding how ecosystems can continue to provide goods and services under different anthropization scenarios (Naeem et al., 2012). In summary, this crisis urgently demands a deeper and more comprehensive understanding of aquatic systems. In this regard, limnology plays a crucial role in identifying solutions for sustainable water management in a context of scarcity and global change.

Zimapán as an Example of a Highly Anthropized Complex System

The Fernando Hiriart Balderrama "Zimapán" hydroelectric dam is situated in the "El Infiernillo" Canyon, marking the conclusion of a complex system comprising twelve dams along the Moctezuma River sub-basin in the Pánuco River region (Fig. 1). Its primary tributaries are the Tula River, carrying wastewater from the metropolitan area and traversing the Mezquital Valley, known for its intense agricultural activity. This river also passes through the Miguel Hidalgo Refinery "Tula" and the Tula Thermal Power Plant. The other main tributary is the San Juan River, collecting wastewater from the industrial zone of San Juan del Río, as well as from the wine and cheese industry in Querétaro, and the community of Tequisquiapan, known for its goldsmithing. Thus, this dam is strongly influenced by human activities throughout the basin.

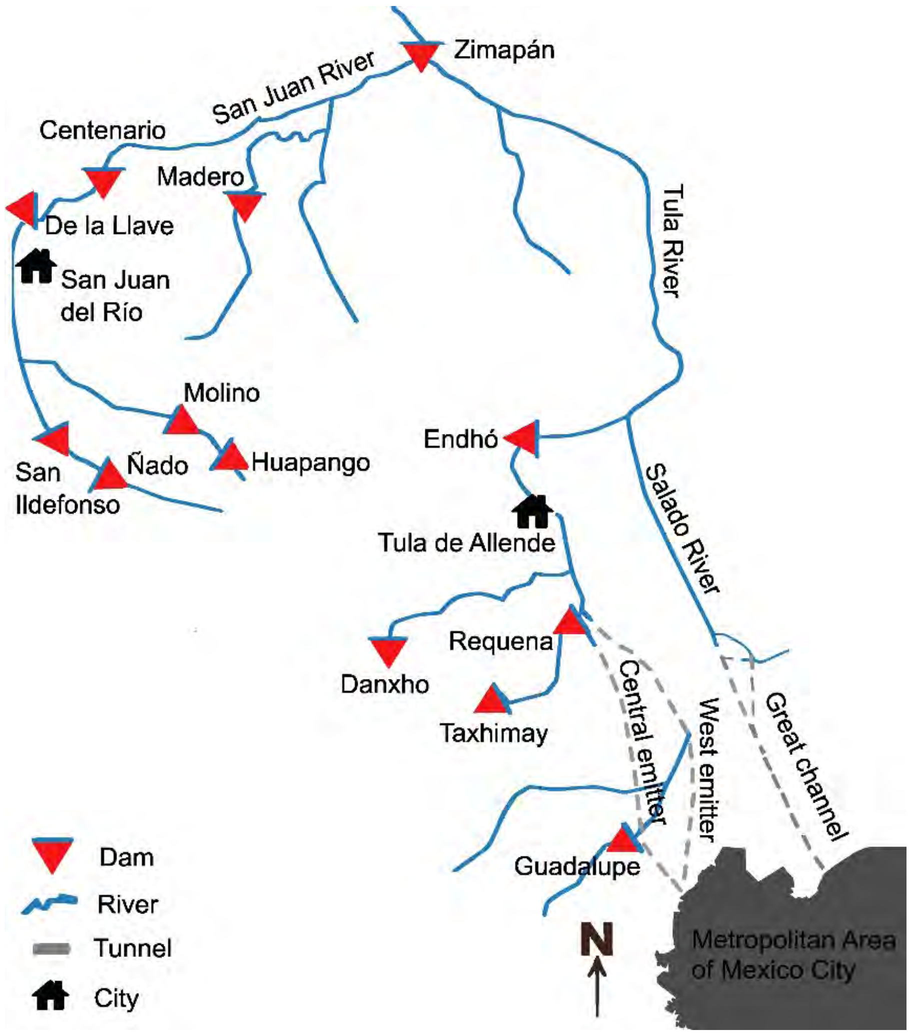

Figure 1. Hydrological System of Rivers and Dams that Converge in the Zimapán Dam. Based on Cortes-Silva et al., 2006.

Zimapán was built between 1990 and 1995 by the National Commission of Electricity (CFE) with the goal of generating electricity, featuring a 200 m high curtain dam forming a reservoir of 1,500 million m^3 of water in 2,300 ha. The dam's construction impacted the lives of twelve Otomi ejidos (community-owned lands) residing along the riverbanks, as well as 2,290 ha of cultivated and fruit-bearing lands (López-Hernández et al., 2021). The relocation of families living on the dam's edges, such as Vista Hermosa and Rancho Viejo, led to a radical shift from traditional agriculture to fishing, a new activity posing a challenge for these communities (López-Hernández et al., 2007). Despite the challenges, fishing cooperatives were formed in Hidalgo and Querétaro, initiating fishing activities in 1998, which has since become the primary source of income in the area. To this end, two exotic species, tilapia (*Oreochromis* sp.) and carp *(Cyprinus carpio*), were introduced. The dam has been subjected to multiple introductions of exotic species over the years; for instance, according to personal communications the fishermen, in 2005, largemouth bass (*Micropterus salmoides*) were illegally introduced to promote sport fishing. Since 2013, fishing efforts were organized within 13 associative groups, comprising 192 fishermen from Querétaro and 455 from Hidalgo. Fishing is conducted using gill nets in accordance with established regulations, and an annual closed season is implemented from April 21 to June 20 (SAGARPA, 2011).

A recurring environmental problem affecting fishing activity is the entry of wastewater from the Tula and San Juan rivers due to improper hydrological management and extraordinary floodings of untreated wastewater. In 2002 and 2021, extraordinary floods of untreated water were recorded due to the retention incapacity of the Requena and Endhó dams, which resulted in massive fish deaths in 2002; and a few months after the entry of water in 2021, there was a massive proliferation of *Lemna gibba* directly affecting fishing activities. In recent years, there has been a growing concern among fishing cooperatives as the catch has been decreasing to a point where it is considered an unprofitable activity (López-Hernández et al., 2021).

The situation is concerning since in the riverside populations of the Zimapán Dam, fishing is the dominant economic activity, followed by agriculture in localities such as Tziquia and Tzibantzá (Querétaro), where water is extracted from the reservoir for drip irrigation of crops such as tomatoes, pumpkins, chili peppers, beans, and corn (López-Hernández et al., 2021). Livestock breeding is also practiced, mainly goats and sheep, and there is migration to nearby cities for jobs in the primary sector (SAGARPA, 2011). This situation led the Tecozautla Municipality, starting 2021, to promote the cultivation of tilapia through a scheme where the fish are placed in floating enclosures with the aim of increasing the size by three inches before their release on the dam.

Zimapán is a relatively recently created ecosystem, distinguished by its high complexity and distinct anthropization, where fishing is intertwined with ecological, environmental, and social factors. Given the growing anthropization trend in Mexico's water bodies, Zimapán represents a paradigmatic example of an ecosystem highly modified by human activities. Nonetheless, these complex systems are precisely the ones that pose new challenges for limnology and the approach to studying these water bodies. Within the framework of this study, an updated list of fish species present in the dam was compiled. Daily registers of the “13 de Junio” Fishing Cooperative, the largest in the dam, were analyzed, aiming to understand the dynamic of the fishing activity from the beginning of June 2021 through August 2023. Additionally, semi-structured interviews were conducted with fisherman from various communities aiming to encapsulate their perceptions regarding the situation, identify underlying causes, and explore potential solutions. With this information, the goal is to delve deeper into understanding how these various issues interplay and shape a complex socio-ecological situation.

Materials and Methods

The Zimapán Dam is situated between coordinates 20°35’-20°40’N and 99°22’-99°37’W, at an elevation of 1,870 m above sea level, and has an extension of approximately 2,300 ha. The dam represents the territorial confluence of Hidalgo and Querétaro states, extending into the municipalities of Zimapán, Tasquillo, and Tecozautla in the western part of Hidalgo, as well as in the municipality of Cadereyta de Montes in Querétaro (Figure 2). The region’s climate is classified as BSh, indicating a dry and semi-arid profile with an average annual temperature of 19.1°C. The prevalent vegetation in the area corresponds to xerophytic shrubland. The National Fisheries Institute identifies the reservoir as suitable for tilapia fishing, based on physicochemical conditions and the availability of food resources, both natural and artificially induced (López-Hernández et al., 2007).

Figure 2. Location of the Zimapán Dam and Neighboring Municipalities.

Six field trips were conducted to cover an annual cycle and consider different seasons of the year (October and November 2022, February, May, August, and November 2023). To assess species richness, various fishing techniques were employed during four days during each visit. Five trap nets were set on the dam's shore, fixed to nearby rocks and left for six-hour periods. Casting nets with a diameter of three metres and mesh size of one inch were thrown from the quay and boats. Two sets of gill nets of 100 metres in length and five metres deep, with different mesh size openings (2, 3, 3.5, 4, and 4.5 inches) were installed and checked every 24 hours. Simultaneously, the species captured by commercial fishermen, who delivered their catches to the cooperative collection center, and those caught by sports fishermen at the dam were noted.

To analyze the fishing dynamics, a collaboration with the "13 de Junio" cooperative, was established. Access to the daily fishing logbook was obtained, going from June 2021 to August 2023, with a total of 4,923 records. This detailed record contains daily information on each fisher, including the daily kilograms captured of each species (tilapia, carp, and silver carp). It's important to highlight that the data in this logbook are considered of high quality as it's the same logbook used for fish commercialization. Using this information, the catch per unit effort (CPUE) was calculated, a metric allowing evaluation of fishery behavior (Díaz & Goenaga, 2003). The CPUE calculated represents the daily kilograms obtained by a fisherman over each week of the year. Additionally, the weekly number of fishermen delivering products to the collection center was examined to understand whether the quantity of active fishers' changes over time.

To comprehend the fisher's perception of the socio-environmental vulnerability of the fishing situation in the Zimapán Dam, semi-structured interviews were conducted. The main objective of these interviews was to clarify the economical relevance of fishing and acquire information about the evolution of the fishing situation over time. During these interviews, inquiries were made about the main issues identified by them, seeking information on potential solutions to improve the fishing activity. This approach provided a complete and detailed perspective of the locals' view, adding valuable insights complementing the technical and quantitative analysis of fishing at the Zimapán Dam.

Results

The fish community in the dam consists of eight species distributed among three taxonomic orders: Cypriniformes, Perciformes and Siluriformes (Table 1). The order Cypriniformes is represented by a single family: Cyprinidae, with three species: *Hypophthalmichthys molitrix* (Silver carp), *Ctenopharyngodon Idella,* (Grass carp) and *Cyprinus carpio* (Common carp) with two subspecies: *Cyprinus carpio specularis* (Mirror carp) and *Cyprinus carpio koi* (Koi carp). The order Perciformes is represented by two families: Centrarchidae and Cichlidae. The family Centrarchidae includes *Lepomis macrochirus* (Bluegill) and *Micropterus salmoides* (Largemouth bass). The family Cichlidae contained *Oreochromis* spp. (Tilapia) and *Herichthys carpintis* (Pearlscale cichlid). In the order Siluriformes, the family Ictaluridae was represented by a single species, *Ictalurus punctatus* (Channel catfish). The eight species and two subspecies identified are exotic species originating from various regions: America, Asia, and Africa. The Pearlscale cichlid is native to the Gallinas River basin and the upper Tamasopo River basin in Mexico.

Table 1. Fish Species and their Records in the Zimapán Dam.

Order	Family	Species/Subspecies	Local name	Body shape
Cypriniformes				
	Cyprinidae			
		Cyprinus carpio (Linnaeus, 1758)	Carpa común	
		specularis	Carpa espejo	
		koi	Carpa koi	
		Hypophthalmichthys molitrix (Valenciennes, 1844)	Carpa plateada	
		Ctenopharyngodon idella (Valenciennes, 1844)	Carpa herbívora	
Perciformes				
	Centrarchidae			
		Lepomis macrochirus (Rafinesque, 1819)	Mojarra azul	
		Micropterus salmoides (Lacepède, 1802)	Lobina	
	Cichlidae			
		Oreochromis spp. (Günther, 1889)	Tilapia	
		Herichthys carpintis (Jordan & Snyder, 1899)	Mojarra tampiqueña*	
Siluriformes				
	Ictaluridae			
		Ictalurus punctatus (Rafinesque, 1818)	Bagre	

The catch per unit effort (CPUE) analysis revealed that tilapia reached its peak during the month of November 2022, with an average of 23 kg/fisher/day (Fig. 3A). Similarly, carp recorded its highest average value in January 2023, achieving a CPUE of 9 kg/fisher/day (Fig. 3B). On average, during the study period, the CPUE was 10 kg/fisher/day for tilapia and 5 kg/fisher/day for carp. The fishing dynamics of both species were influenced by various factors, including environmental conditions, seasonal changes, ecological interactions, and social dynamics. In October 2021, fishing was suspended preventively due to an extraordinary influx of wastewater into the reservoir. Throughout 2022, there was an uncontrolled proliferation of *Lemna gibba*, commonly known as duckweed. Duckweed is a fast-growing aquatic plant that quickly covers the water surface, blocking sunlight and hindering the growth of other photosynthetic organisms (Arroyave, 2004). This proliferation affected fishing activities during six months. After overcoming the contingency, the highest record of catch per unit effort was observed in November of the same year. However, this efficiency was followed by a rapid decrease in the following weeks.

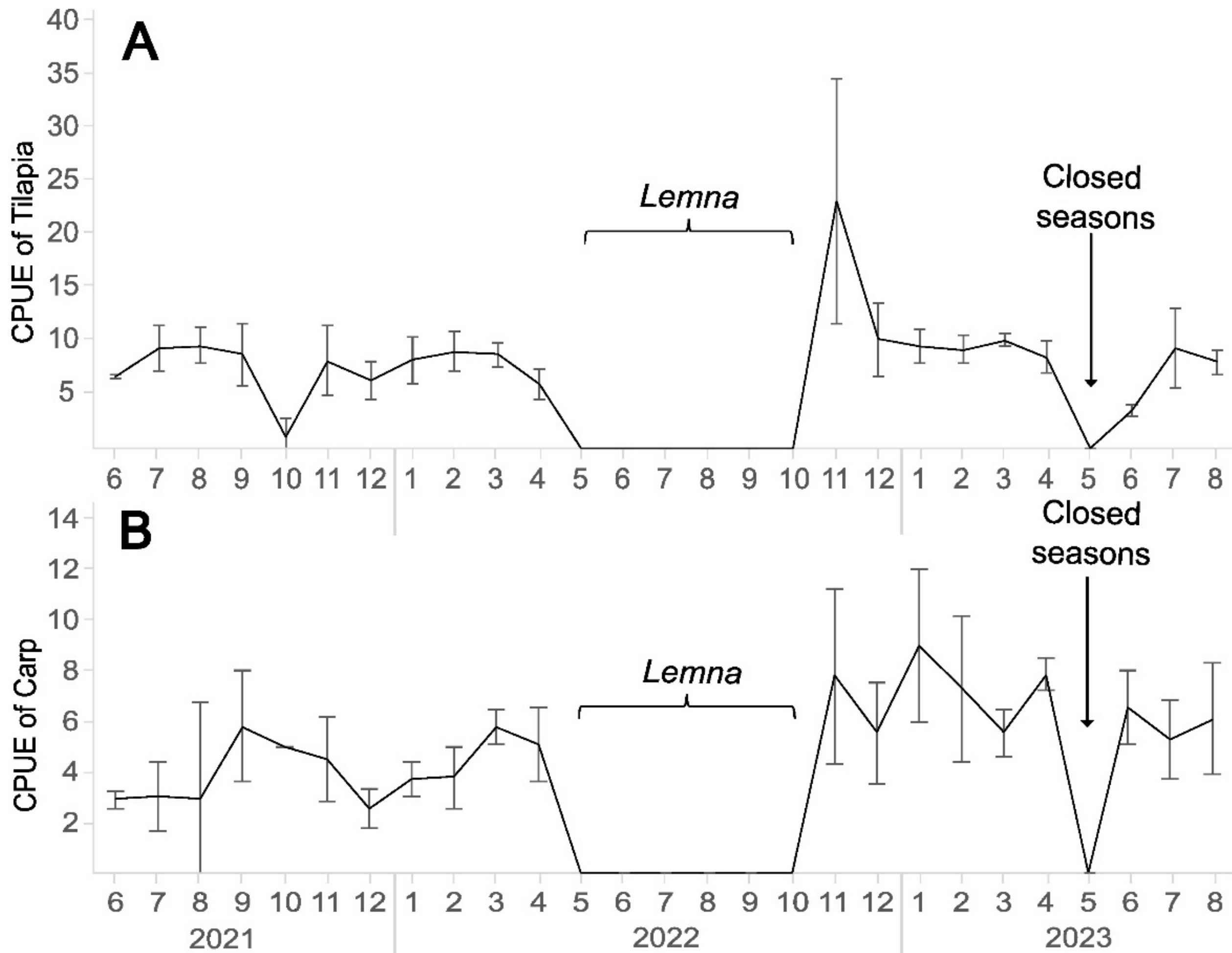

Figure 3. Mean and Standard Deviations of the Catch per Unit Effort (CPUE) for (A) Tilapia (*Oreochromis* sp.) and (B) Common Carp (*Cyprinus carpio*). The CPUE is Expressed as the Average Daily Catch in Kilograms per Fisher.

The fishing activity of the “13 de Junio” Fishing Cooperative has experienced notable variations over time, lacking evident consistency (Fig. 4). November 2022 stands out as the period of highest activity, with the participation of over 40 fishers. In contrast, during July 2023, the historical minimum activity was recorded, with only three fishers. On average, fishing activity remained at approximately 15 fishermen throughout the study period. Noteworthy is the dynamic of peaks where an increase in the number of fishermen is followed by a sharp decline in participation. This phenomenon is clearly observed in June 2021, at the conclusion of the annual closed season. Similarly, the pattern is also present after the contingency related to *Lemna gibba*, and after the closed season in June 2023.

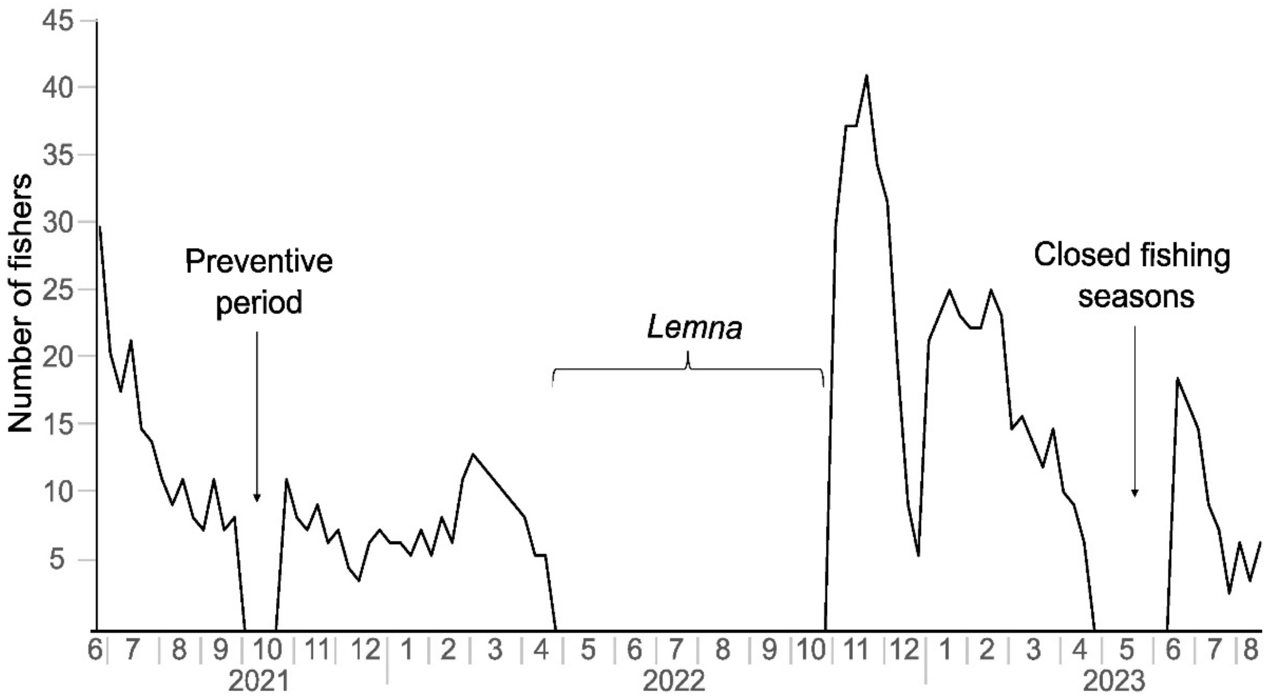

Figure 4. Behavior of Fishing Activities in the “13 de Junio” Cooperative.

In total, 43 interviews were conducted. Out of these interviews, 28 (65 %) corresponded to men, and 15 (35 %) to woman. Regarding the highest level of education among fishermen, 2 (5 %) have university education, another 2 (5 %) completed high school, 21 (49 %) attended middle school, 17 (39 %) have elementary education, and 1 (2 %) are in a situation of illiteracy. On the other hand, 31 (74 %) of the interviewees stated that fishing was their main economic activity, while 11 (26 %) indicated having another occupation besides fishing.

Several causes for the decrease in fishing and the gradual abandonment of the activity due to lack of profitability were pointed out by the interviewees. The introduction of carnivorous species, particularly the largemouth bass, a consequence of sport fishing, was often referred to as a significant problem. Around 50 % of the interviewees mentioned that the largemouth bass feeds on tilapia, identifying that before its introduction, more tilapia was fished. “[...] initially, there wasn’t a fish that eats on tilapia… and when we opened it (the bass), there were fish in its stomach. I imagine they eat them because the fishing has been decreasing little by little, and yes, we attribute it to that, to the bass”. Despite efforts in tilapia fingerling restocking, fishers expressed concern about the lack of recovery in the captured quantities. It was mentioned that the largemouth bass, being carnivorous, could be negatively affecting the success of restocking. “[...] the bass is carnivorous, so, we believe that it also eats a lot of what is being stocked and also small fish. We have even caught bass weighing 4 kg with a tilapia weighing half a kilogram in its belly”. Furthermore, concern was highlighted regarding the increasing population of largemouth bass and the lack of economic benefits for commercial fishers. Restrictions on catching and commercializing largemouth bass were mentioned as a limitation. “We can only catch tilapia, not bass. They said we can’t catch bass”. “Yes; the stocking of tilapia. But this goes hand in hand with the utilization of bass or the reduction of its population. It’s useless to restock if you have an excess population of bass”.

Only 10 % of the fishermen acknowledge overexploitation as a cause of the decrease in catch. “The cause is that the reservoir was excessively exploited from the beginning”. “I think the causes might have been that, at the time when there was good fishing, maybe we didn’t know how to control it. I think we might have overexploited it then”. A lower percentage (8 %) of the interviewees considered water quality an issue, highlighting the decrease in oxygen in the reservoir. “Because yes, we have noticed, especially with the cages, we take measurements, and we realize that oxygen is already very low sometimes and other times it’s not”.

Around 15 % mentioned that fishing has become unsustainable, jeopardizing the economic security and causing the abandonment of fishing in Zimapán, some people are migrating in search of better opportunities. “Well, fishing is really low at the moment. That’s why we are leaving, because we must look for another job because if we don’t, if we just rely on this, we won’t survive”. “Very critical and very difficult. No more. That’s why there’s not many fishers, because, well, it’s not worth it anymore. We have to find elsewhere because fishing won’t do”. Regarding possible solutions, 23 % of the interviewees saw tilapia restocking as an alternative to increase daily catches. “Well, now we are restocking in higher quantities. Maybe it’s what affected us, at the beginning, when we started fishing, we didn’t repopulate, we just fished”.

Discussion

The Zimapán hydroelectric dam stands out as a paradigmatic case of a complex system heavily influenced by human activities. Within this context, fishing, which initially emerged as an activity after the relocation of Otomi communities, has evolved into the primary source of income in the area. However, fishing in the Zimapán dam faces significant challenges, a product of the complex interaction between ecological, environmental, and social factors.

Exotic species represent a major concern for the conservation of aquatic ecosystems as they often displace native species, particularly in polluted habitats (Bourret et al., 2008). The fast loss of species and habitats in Mexico's central region, identified as a key ichthyic endemism center in the country (Miller, 2009), has raised concerns regarding the need to protect and conserve areas and species of ecological importance (Gutiérrez-Yurrita et al., 2013). In this regard, Mexico's National Strategy on Invasive Species is a comprehensive plan established by the Mexican government to address the management of invasive species. Its main objective is to prevent the introduction and spread of exotic species that may pose a threat to biodiversity and native ecosystems (CONABIO, 2010).

The species introduction phenomenon can trigger irreversible damages (Strayer, 2010). However, the continuous introduction of exotic species into artificial reservoirs is mainly attributed to socioeconomic factors (De la Lanza-Espino & García-Calderón, 2002). This circumstance presents a dilemma regarding the encouragement of the expansion of exotic species in these water bodies, posing a rising potential risk. In the Zimapán dam, 8 exotic species were recorded coexisting within the reservoir, raising interesting questions for future exploration about ecological interactions and the factors enabling their coexistence.

The introduction of largemouth bass as a measure to promote recreational fishing to diversify economic activities might be among the main causes of the decrease in tilapia population, thereby generating a socioecological conflict between both fishing practices. The presence of largemouth bass is identified by commercial fishermen as a key factor in the decline of catches. Furthermore, the coexistence of other exotic species suggests the possibility of competition for food resources and habitat, both with the native species (Pearlscale cichlid) and also tilapia (Córdova-Tapia et al., 2015). The presence of carnivorous species, such as largemouth bass and catfish, poses an additional challenge to the survival of tilapia fingerlings and juveniles.

The results reveal significant variability in fishing activity, characterized by peaks of participation followed by abrupt declines. These patterns highlight the susceptibility of fishing in Zimapán due to economic, ecological, environmental, and social factors. The interaction among species introduction, recreational fishing, and wastewater discharges could be generating complex and synergistic dynamics (Simberloff et al., 2013).

In 2021, precautionary measures after a flood caused by Hurricane Grace resulted in four weeks without records (from September 27th to October 24th) due to the severe flooding affecting Hidalgo state from the overflowing Tula River. In 2022, a few months after the floodings, *Lemma gibba*. In April of the same year, fishing was suspended due to the mandatory closed season. However, upon its conclusion in June, it was impossible to resume fishing activities as a great part of the reservoir was covered by *L. gibba*, making it impossible to set nets. Several months of that year were dedicated to removing it. Once the dam was cleared at the end of October, fishing activities resumed. November was the month with the highest presence of fishers, followed by a rapid abandonment. In 2023, the lowest number of active fishermen was recorded.

Interviews with the fishermen reveal a growing concern about the profitability of fishing. This concern is supported by the results of the analysis of catch per unit effort (CPUE), showing that, on average, fishermen obtain around 10 kg of tilapia/day and 5 kg of carp/day. The selling prices of tilapia is 40 Mexican pesos per kilogram (2.3 USD), while carp sells for one Mexican peso per kilogram (0.05 USD). Consequently, the average daily income of fishermen is 405 Mexican pesos (23.7 USD). However, this income is affected by associated expenses, such as transportation from their homes to the dam and the cost of gasoline for the boat used during checking of the nets (190 per day, 11.3 USD). Therefore, on average, a fisher earns 215 Mexican pesos (12.8 USD) per day of work. This situation generates uncertainty about the economic sustainability of fishing activities and poses a challenging outlook for the fishermen, raising legitimate concerns about the future of this activity at Zimapán Dam.

The restocking of tilapia emerges as a potential solution, according to the perception of some fishers, to increase daily catches and strengthen fishing activity at Zimapán dam. Even so, this approach faces significant challenges arising from the increased population of largemouth bass and the restrictions associated with their capture. The coexistence of these factors raises questions about the long-term viability of this strategy. It is imperative to reconsider fishing management strategies at Zimapán, considering not only tilapia stocking but also critically evaluating the continuous introduction of exotic species into bodies of water for socioeconomic purposes. This needs a relevant debate about the appropriateness of such practices given their long-term ecological impact (Simberloff et al., 2013).

The complex interaction between the introduction of several exotic species, the adaptation of local fishing to changing conditions, and the exploration of economic alternatives such as tourism, emphasizes the need to comprehensively understand the ecological and socio-economic dynamics of artificial reservoirs. This scenario underscores the importance of developing sustainable management strategies and biodiversity conservation. This could involve the implementation of sustainable land use practices, pollution reduction, population regulation of species like largemouth bass, effective fishing regulation, and the promotion of community participation in decision-making.

Conclusions

Fishing at the Zimapán dam faces multifaceted challenges, from environmental issues to socioeconomic challenges. The water crisis, human impact, and a lack of sustainable management threaten the long-term viability of this activity, indicating complex problems occurring at different spatial and temporal scales. This study highlights the need for integrated approaches and collaborative solutions addressing both the ecological problems and the social dimensions of fishing in the ecosystem. Ecosystems like the Zimapán Dam will become increasingly important in a context of global change; therefore, understanding them as key ecosystems upon which we will depend in the near future is essential. We consider that such ecosystems will become more frequent, posing significant challenges for a field like limnology.

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Authors’ Contributions

RCB, MLH, and FCT conducted fieldwork. RCB and FCT performed data analysis. RCB, KERV, MLH, MAGP, and FCT wrote and reviewed the manuscript.

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This book takes a significant step in showcasing the relevance of limnology to our survival. Freshwater habitats, though they cover less than 1 % of the Earth's surface, are home to a substantial portion of the world's biodiversity—at least 10 % of all known species. Freshwater habitats and the biodiversity they support are under threat. Moreover, our survival depends on access to high-quality freshwater. This book not only highlights the beauty of limnology and the scientific methods used to study it, but it also draws attention to the major causes of biodiversity loss in freshwater ecosystems. It shows all readers what it means to deal with inland waters as a scientist interested in understanding ecosystems and protecting them.

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