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The fish assemblage of a Mexican protected spring system dominated by invasive fishes

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Abstract

Springs, as sensitive freshwater ecosystems, are particularly vulnerable to anthropogenic factors such as water extraction, pollution, and climate change. Las Estacas spring in Central Mexico, managed as a water park within a state reserve, serves as an ideal space for environmental education and conservation efforts. Snorkel surveys identified 14 fish species, with 70% being invasive and most of these come from ornamental fish. The fish assemblage was dominated by *Xiphophorus helleri* and *Amatitlania nigrofasciata* with 23% and 21% of the sample respectively, followed by two native species *Poecilia sphenops* and *Astyanax mexicanus* with 15% each aquaculture. To address this, a rewilding project is now in place, with the goal to establish a fish assemblage dominated by native species through habitat management, invasive species control, native species introduction, and education.

Introduction

Freshwater ecosystems account for less than 1% of the planet's surface, are home to 11% of all animal species and 5% of all plant species (Román-Palacios et al. 2022), and provide important global ecosystem services that contribute to human well-being and the livelihoods of many people (Acreman et al. 2020).

Springs are among the most sensitive freshwater ecosystems, and despite being abundant globally, many are disappearing due to local and global anthropogenic factors, such as water extraction, pollution, recreational use, habitat alterations, and climate change (Cantonati et al. 2020). This is unfortunate because springs are considered "hotspots" that allow species to remain during past climate change, and many of them will be stable hydrological refuges in the future in the face of current anthropocentric climate change (Cartwright et al. 2020). This has led various international organizations to call for the global protection of springs, which should be considered a distinct group of ecosystems that deserve special conservation attention (Cantonati et al. 2020).

Las Estacas spring is found in Central Mexico, it is managed and operated as a Water Park, that is in a State Reserve with the same name, that was decreed on June 22, 2008 (González-Flores and Contreras-MacBeath 2020). Due to the influx of visitors who enjoy its crystal

clear waters, the Las Estacas Water Park represents an ideal space for environmental education, especially in terms of the conservation of freshwater aquatic species, which is uncommon in Mexico.

Las Estacas is not a conventional water park; for more than 20 years, it has promoted a conservation project that promotes sustainable practices, environmental protection, and the species that live there (Contreras-MacBeath and Burgess 1999). Although all these efforts have managed to maintain the quality of the water and beauty of the site, the aquatic environment is dominated by invasive species that come from extensive and ornamental aquaculture.

To reverse this situation, the owners of Las Estacas Water Park, in collaboration with researchers from the Autonomous University of the State of Morelos, are developing a rewilding project that seeks to reduce the populations of invasive fish species and to reintroduce native species of the Balsas River basin to create a sanctuary for these aquatic organisms. The first part of this intervention consists of knowing the diversity of fish species that occur in spring as well as their relative abundance, which will serve as a basis for the development of a comprehensive strategy for the sustainable management of its biodiversity.

Methods

Study Area

The study was carried out in a spring fed stream, localized within “Las Estacas” State Protected Area, in Morelos, Mexico. The coordinates of the spring are 18° 44’ N; 99°06'48″ W (DMS), at an altitude of 951m above sea level (Niedzielski 1994). The stream is a tributary of the Yautepec River, Amacuzac sub-basin, which is one of the runoffs that drain from the State of Morelos to the Balsas River system in Central Mexico (Pease et al. 2023).

Based on the classification by Stevens et al. (2021), the spring is considered an upland hillslope type, with an average flow rate of 6,750 l/s, with minimal variations between the dry and rainy seasons (IMTA 2018). The water arises in the site known as "El Borbollón" (Figure 1a) that creates a stream of clear waters, which has a stretch of one kilometer within a Water Park (Las Estacas) that is mainly used for recreation, to later be channeled by the “Agro Siglo XXI” Irrigation District in southern Morelos. Due to the agricultural and recreational uses given to the water, the spring is periodically monitored by the Mexican environmental authority, so its water quality parameters are well known: water temperature ranges between 22-23.7 0C, pH between 6.87-7.06, conductivity between 1,242-1,345 µS/cm and Because of its chemical composition, it is classified as having calcium-sulfated-bicarbonate water (INEGI 2020). An evaluation of the bathymetry of the study area (Figure 1e) showed that the maximum depth in the stream is 8.5 m, at the site known as "Poza Azul,” while the depth in most of the stream ranges from 1.5 to 3.7 m. The deepest area of "El Borbollón", where the water emerges, has a depth of 6.4 m (Contreras-MacBeath et al. 2022).

Figure 1. different views of Las Estacas spring. (a) El Borbollón, (b) underwater habitat with silt, (c) stretch of the stream showing aquatic vegetation, (d) habitat with sandy and stone bed, (e) bathymetric model of the site.

Over the years, seeking to promote tourist activity, a good part of the bank of the stream has been modified to stabilize slopes and retain soil through the placement of sandbags so that the littoral zone in most of the stream is vertical; however, it maintains acceptable conditions that favor the presence of aquatic species. The stream bed is composed mainly of sandy and rocky substrates (Figure 1d), although in some areas, it has silt (Figure 1b). There are dense patches of *Vallisneria americana* as well as some other *Cabomba palaeformis* (Figure 1c) that serve as a habitat for fish and macroinvertebrates. Arredondo et al. (2015) reported the presence of 28 species of aquatic plants in Las Estacas, belonging to 23 genera and 19 families. As can be seen in the photographs (Figure1) along its course, the stream is bordered by riparian vegetation.

There are few published recollections of the fishes from Las Estacas; a popular publication (Contreras-MacBeath and Burgess 1999) mentions the presence of nine species, but several other invasions have been introduced in the region over the years, which are now in the spring (Contreras-MacBeath et al. 2014).

Fish assemblage evaluation

To characterize ichthyofauna, snorkel surveys were used to study fish assemblages by quantifying the relative abundance of each species present. This technique has been proven to be effective for this type of evaluation (Matthews et al. 1994; Johnson et al. 2007; Martens 2023). Diurnal fish counts were calculated from April to July 2023 in six 20 meter reaches of the spring, and due to the amplitude of the channel, the expansion estimate method (Thurow 1994) was employed, where four trained snorkelers counted the fish, and their observations were then summed for the total count of the reach sampled. Snorkel surveys also allowed us to obtain information related to habitat use for each species.

Results

Fish diversity and relative abundance

As a result of fish surveys in Las Estacas Spring, 14 species of fish belonging to 6 families and 13 genera were recorded. Ten of these species are invasive (Table 1), and only four are native to spring (*Astyanax mexicanus* (De Filippi 1853), *Amphilophus istlanus* (Jordan and Snyder 1899), *Ictalurus balsanus* (Jordan and Snyder 1899), *and Poecilia sphenops* (Valenciennes 1846). Poecilids are represented by five species, four which are invasive to the site, and are naturally distributed in river systems along the Gulf of Mexico region (*Pseudoxiphophorus bimaculatus* (Heckel 1848), *Poeciliopsis gracilis* (Heckel 1848), *Xiphophorus helleri* Heckel (1848), and *Xiphophorus variatus* (Meek 1904)); the last Poecilid is *Poecilia sphenops,* which is native to the Balsas River basin. Cichlids are also represented by five species *Amatitlania nigrofasciata* (Günther 1867) and *Andinoacara rivulatus* (Günther 1860) from Central and South America, *Oreochromis niloticus* (Linnaeus 1758) from Africa, *Thorichthys maculipinnis* (Steindachner 1864) from the Papaloapan River Basin, and the native *Amphilophus istlanus*. The Acestrorhamphidae family is represented by one species native to the Balsas River, *Astyanax mexicanus*. There are two catfish species, the native Ictalurid *Ictalurus balsanus* and an armored catfish from South America, *Pterygoplichthys disjunctivus* (Weber 1991). It is important to note that the remaining Cyprinid species (*Cyprinus carpio*) Linnaeus (1758), was only found in an irrigation canal adjacent to the main spring channel.

Table 1. Fish species found in Las Estacas spring showing their origin and natural distribution.

FAMILY	**SPECIES**	**ORIGIN**	**NATURAL DISTRIBUTION**
Cyprinidae	*Cyprinus carpio* Linnaeus 1758	Invasive	Eurasia
Acestrorhamphidae	*Astyanax mexicanus* (De Filippi 1853)	Native	Balsas River Basin
Loricariidae	*Pterygoplichthys disjunctivus* (Weber 1991)	Invasive	South America
Ictaluridae	*Ictalurus balsanus* (Jordan and Snyder, 1899)	Native	Balsas River Basin
Poeciliidae	*Poecilia sphenops* Valenciennes 1846	Native	Balsas River Basin
	Poeciliopsis gracilis (Heckel 1848)	Invasive	Gulf of Mexico
	Pseudoxiphophorus bimaculatus (Heckel 1848)	Invasive	Gulf of Mexico
	Xiphophorus helleri Heckel 1848	Invasive	Gulf of Mexico
	Xiphophorus variatus (Meek 1904)	Invasive	Gulf of Mexico
Ciclidae	*Amatitlania nigrofasciata* (Günther 1867)	Invasive	Central America
	Amphilophus istlanus (Jordan and Snyder, 1899)	Native	Balsas River Basin
	Andinoacara rivulatus (Günther 1860)	Invasive	South America
	Oreochromis niloticus (Linnaeus, 1758)	Invasive	Africa
	Thorichthys maculipinnis (Steindachner 1864)	Invasive	Papaloapan River Basin

By means of the snorkel surveys 4,521 fishes were counted, and results show that the fish assemblage was dominated by *Xiphophorus helleri* and *Amatitlania nigrofasciata* with 23% and 21% of the sample respectively (Figure 2), followed by two native species *Poecilia sphenops* and *Astyanax mexicanus* with 15% each. Tilapias (*Oreochromis niloticus*) represented only 11% of the sample, but were conspicuous due to their size. *Poeciliopsis*

gracilis represented 7% of the sample, followed by *Andinoacara rivulatus* and *Pseudoxiphophorus bimaculatus,* with 4% each. Another group of six species (n=36) was occasionally observed, representing less than 1% of the sample (*Cyprinus carpio, Pterygoplichthys disjunctivus, Ictalurus balsanus, Xiphophorus variatus, Thorichthys maculipinnis,* and *Amphilophus istlanus*).

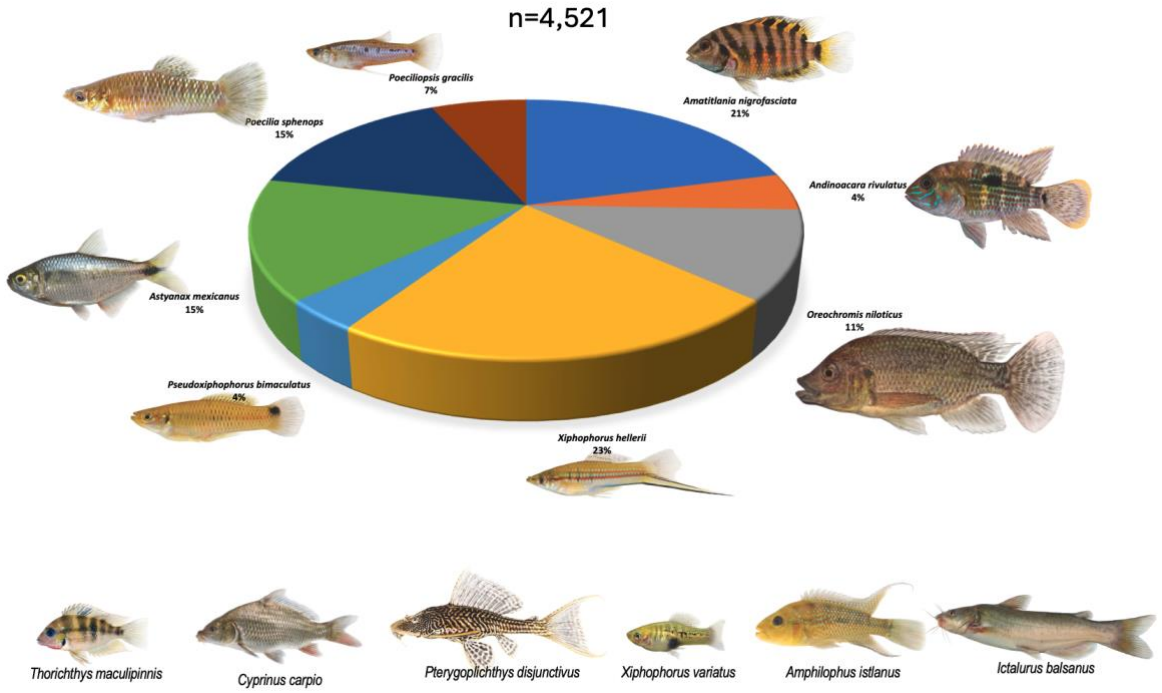

Figure 2. Fish assemblage found at Las Estacas spring showing the relative abundance of each species. The six species represented on the lower part of the figure were only occasionally seen and account for less than 1% of the sample.

Having found species from other regions of Mexico, Eurasia, Africa, and Central and South America, and that invasives dominate with 70% of the sample, reflects on the lack of attention that has been paid to the aquatic fauna of the spring and highlights the need to establish management actions to revert this situation.

Discussion

Perhaps the most outstanding result of the study is the fact that most species (70%) are invasive, something that has been found in many parts of the world (Mitchell and Knouft 2009; Clavero et al. 2013; Maceda-Veiga et al. 2022), which reflects the little care that has been taken regarding the movement and management of species from one place to another. This situation can seriously impact the populations of native species and, in many cases, also have economic impacts (Britton 2023).

Previous studies have shown that prior to the year 2000 (Contreras-MacBeath and Burgess 1999), there were nine species of fish in the spring, and now there are 14, which means that in 25 years, five species or the equivalent of one every five years were added. It is important to clarify that the fish assemblage structure present in the cuttings, which is largely dominated by exotic species, reflects what occurs in the aquatic ecosystems of the region (Contreras-MacBeath et al. 2020) and not the specific introductions that occurred in the spring. This

reflects the condition of the aquatic ecosystems of the state of Morelos and the Central region of Mexico, where 25 species of invasive exotic fish have been documented (Mejía-Mojica et al. 2012; Contreras-MacBeath et al. 2014).

If we consider the origin of the exotic species present in the spring, it stands out that 80% comes from ornamental aquaculture, a situation that makes sense since the State of Morelos and the region near the Las Estacas Spring stand out as one of the most important points for the production of ornamental fish in Mexico (Ramírez-Martínez et al. 2010). Most ornamental fish farms lack safeguards that prevent the escape of organisms into the natural ecosystems of the state.

The low population of the Balsas River Cichlid (*Amphilophus istlanus*) may be due to the presence of other invasive cycle species such as Convicts (*Amatitlania nigrofasciata*) that have been shown to have a detrimental effect on populations of this species in aquatic environments of the region (Contreras-MacBeath et al. 1998). Another native species that is not very abundant is the Balsas catfish (*Ictalurus balsanus*), of which only one specimen was observed, even though the Park staff mentioned that many years ago, it was common to see them in the spring. This species is subject to significant fishing pressure in the rivers of the region (Domínguez-García 2015) and apparently due to this same situation, overfishing, was practically eradicated from the spring.

Based on the above results, work has been conducted in collaboration with the Park authorities to develop an intervention strategy that aims to "establish a fish assemblage dominated by native species in the Las Estacas Spring," for which a Theory of Change model has been integrated that presents four themes or chains of intervention: (1) management and adaptation of aquatic habitat, (2) control of invasive species, (3) introduction of native species, and (4) education and training. This project called "Rewilding Las Estacas" has already been authorized and financed by the Park authorities, and the first results will be available soon.

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