

ANNOTATED LIST OF LIVEBEARING FISHES
(CYPRINODONTIFORMES: POECILIINAE) FROM LAKE MIRAGOANE
IN SOUTHWESTERN HAITI, HISPANIOLA

**Lista anotada de los peces vivíparos (Cyprinodontiformes: Poeciliinae)
del Lago Miragoane en el suroeste de Haití, la Hispaniola**

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ABSTRACT

Within the Caribbean region Lake Miragoane in southwestern Haiti represents one of the most important radiation centers of livebearing fishes of the subfamily Poeciliinae. However, there is a lack of scientific studies documenting the distribution, number of species and conservation status of the fishes from that lake. In this work, an annotated list of livebearing fishes, the most well represented group of aquatic vertebrates in Lake Miragoane, is presented with the corresponding species identification and images. This is the first study in the last 40 years to capture most of the fish diversity in the lake originated from the subgenus *Limia* and especially in the species flock represented by the subgenus *Odontolimia*. It also includes two recently described species: *Limia islai* and *L. mandibularis*. Here we also report some conservation threats to the endemic freshwater fish fauna from Lake Miragoane that should be addressed to preserve the biodiversity in this important area.

Keywords: Caribbean, endemic, *Limia*, species radiation center.

RESUMEN

El Lago Miragoane, ubicado en el suroeste de Haití en la Hispaniola, es considerado uno de los centros de radiación más importantes de especies de peces vivíparos de la subfamilia Poeciliinae. A pesar de esto, no existen estudios que documenten el número de especies, la distribución o el estado de conservación de los peces de esta subfamilia que habitan en el lago. En este trabajo se presenta una lista anotada de las especies de peces vivíparos (grupo de vertebrados acuáticos más abundante en el Lago Miragoane) con la correspondiente diagnosis para cada especie colectada así como imágenes para su identificación. Nuestro estudio representa el primer análisis detallado que se haya realizado en los últimos 40 años de la mayoría las especies incluidas en el subgénero *Limia* y especialmente dentro del grupo de especies del subgénero *Odontolimia*. Se incluyen además reportes de distribución para dos especies recientemente descritas en esta área geográfica: *Limia islai* y *L. mandibularis*. Se reportan también algunas amenazas para la conservación de la fauna endémica de peces de agua dulce del Lago Miragoane y para la biodiversidad de esta importante área en general.

Palabras clave: Caribe, endémica, *Limia*, centro de radiación de especies.

INTRODUCTION

The high level of diversity and endemism that is found in several groups of the flora and fauna makes the Caribbean region one of the most important hotspots of biodiversity in the world (Myers *et al.*, 2000). Particularly, in the three archipelagoes that form the West Indies: the Greater Antilles, the Bahamas and the Lesser Antilles (Berman, 2008; Hofmann 2008), the Greater Antilles exhibit a significant species radiation in freshwater fishes (Rivas, 1958; Rosen & Bailey, 1963; Ponce de Leon *et al.*, 2014; Doadrio *et al.*, 2009), amphibians (Alonso *et al.*, 2012; Rodriguez *et al.*, 2010), reptiles (Glor *et al.*, 2003; Glor *et al.*, 2004; Gifford & Larson, 2008), some invertebrates (Gao & Perry, 2016; Matos-Maravi *et al.*, 2014; Čandek *et al.*, 2019) and also in different families of plants (Santiago-Valentin & Olmstead, 2004). While detailed and somehow updated species lists are available for some islands for various zoological groups such as amphibians and reptiles (Diaz & Cadiz, 2008; Hedges *et al.*, 2019), birds (Latta, 2012; Prins *et al.*, 2009; Gerbracht & Levesque, 2019) and even marine taxa (Miloslavich *et al.*, 2010), almost no inventories or updated records of species distribution exist for freshwater fishes. The latter is the case of livebearing fishes of the subfamily Poeciliinae (*sensu* Parenti, 1981), which are the dominant group of freshwater fishes in the area in terms of abundance and species richness (Rosen & Bailey, 1963; Burgess & Franz, 1989; Vergara, 1992).

Livebearing fishes are represented in the Greater Antilles by five genera, two of them, *Girardinus* Poey, 1854 and *Quintana* Hubbs, 1934 are endemic to Cuba, whereas two others, *Gambusia* Poey, 1854 and *Poecilia* Bloch and Schneider, 1801 are also widespread in Southern USA, Central America, South America, Trinidad and Tobago and Curazao. Finally, the genus *Limia* Poey, 1854, which is the most speciose genus in the area with 22 described species so far, is endemic to the Caribbean and currently known from Hispaniola, Cuba, Jamaica, and Cayman islands. Specifically, Hispaniola is considered to be the center of endemism for *Limia* since so far 19 species are described from this island whereas only one endemic species is known from Cuba, Jamaica, and Grand Cayman each (Chambers, 1987; Burgess & Franz, 1989; Weaver *et al.*, 2016). *Limia* shows a notable radiation in Lake Miragoane, an endorheic drainage located in southwestern Haiti (Curtis & Hodell, 1993), where nine endemic species are currently reported (Rodriguez-Silva *et al.*, 2020), probably a result of species flocks within the endemic subgenus *Odontolimia* (Rivas, 1980).

Lake Miragoane represents an exclusive geographic area in the Caribbean to study the evolution and *in situ* speciation processes of livebearing fishes in the Neotropics since it holds a high biodiversity of endemic species in a relatively small area. However, the lake has been largely ignored in terms of scientific research during at least the last 40 years and updated records of the fish species composition are not available. Lake Miragoane is also located in a geographic region that deserves more scientific work in light of the serious conservation challenges facing Haiti's biodiversity (Hedges *et al.*, 2018). In this paper we report eight endemic species of the subfamily Poeciliinae, including two recently described species of *Limia* (Rodriguez-Silva & Weaver, 2020; Rodriguez-Silva *et al.*, 2020), that were collected in Lake Miragoane as part of a faunistic study of the lake.

OBJECTIVE

- Present an annotated list of livebearing fish of the subfamily Poeciliinae from Lake Miragoane in southwestern Haiti, Hispaniola.

MATERIALS AND METHODS

Fish sampling was conducted in June 2019 in Lake Miragoane in southwestern Haiti, Hispaniola. We used a 7.0 m long, 1.5 m height and 3.0 mm mesh size seine to sample fish in different areas of the lake (Fig. 1). Collected fishes were euthanized using MS 222 and then preserved in ethanol 75% for further species identification in the laboratory based on morphometric and meristic characters with emphasis in the analysis of the gonopodium tip in males. Additionally, we also preserved some individuals in ethanol 95% for molecular studies (Spikes *et al.*, 2020). All fishes were collected with the authorization of the Ministry of Environment of Haiti as part of a survey of the native freshwater fish fauna of the lake.

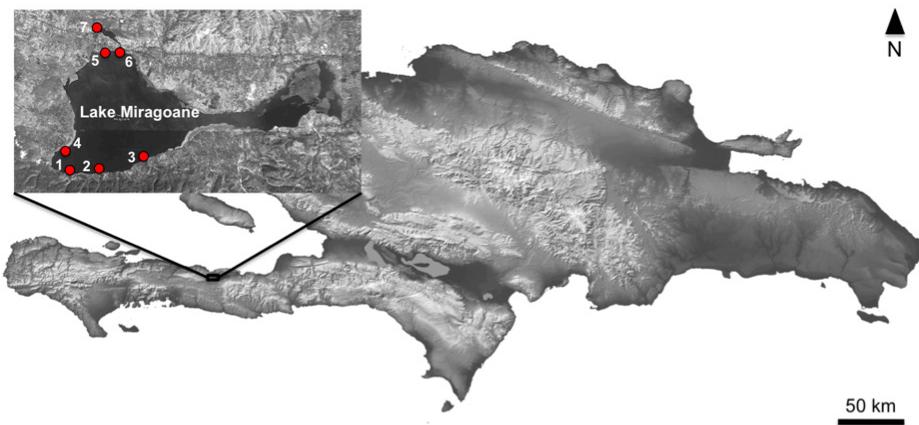


Figure 1. Map of the island of Hispaniola with enlargement showing greater details of the sampling sites in Lake Miragoane. Southwest bight: sites 1-4, north bight: sites 5-7.

Our sampling efforts were intentionally focused on the southwest bight and north end of Lake Miragoane because these areas were specifically defined by Rivas (1980) as the type localities for all the species described by him in that study. However, we also explored other areas in the east side of the lake. Unfortunately, those areas were impossible to sample because of the large extensions of dense aquatic vegetation that covered a significant portion of the lake. The eastern part of the lake is also dangerous since this is a very shallow area with a type of liquefied soil that cannot support weight.

Fish specimens were examined in the laboratory under an Olympus SZX7 stereomicroscope with direct and transmitted light and 50X magnification for species determination. Characters used by Rivas (1980) in the description of five *Limia* species from Lake Miragoane in Haiti were measured in all specimens of this genus using the methods described in Rivas (1963) and Rivas (1978). We also used the original descriptions of Regan (1913) for the identification of *Limia nigrofasciata* and *L. ornata* as well as the original description of Rodriguez-Silva *et al.* (2020) for the description of the gonopodium of *L. mandibularis*. In addition to the characters used by Rivas (1980), we also counted the number of segments distal to ray 3 keel, ray 4 grooved segments and segments distal to ray 5 keel of the gonopodium in males for the species identification. Gonopodial characters were named and counted as previously described by Chambers (1987). Two males of *Gambusia beebei* were cleared and stained following the protocol of Taylor and Van Dyke (1985) for description of the gonopodium tip. Moreover, we followed the methods described in Rivas (1969) and Rauchenberger (1989) for the description of elements of the gonopodium in the genus *Gambusia*. Scale counts were done according to Miller (1948). Morphometric measurements were taken using a DigitalAid caliper (to the nearest 0.1 mm).

Institutional abbreviations used: OMNH, Sam Noble Museum of Natural History, University of Oklahoma.

RESULTS

A total of 11 species of freshwater fishes belonging to three families and three orders were recorded (Table I). Livebearing fishes of the family Poeciliidae (subfamily Poeciliinae *sensu* Parenti, 1981) were dominant in terms of abundance and species composition. A total of 167 individuals representing two genera and eight endemic species of Poeciliinae were collected in this study.

Table I. Species collected in Lake Miragoane with corresponding information related to their family, GPS coordinates of the collecting sites and endemism

Species	Family	GPS coordinates of the collecting sites	Classification
<i>Limia garnieri</i> Rivas, 1980	Poeciliidae	18°25'33.2" N 73°02'56.9" W (6)	Local endemic
<i>Limia immaculata</i> Rivas, 1980	Poeciliidae	18°25'33.2" N 73°02'56.9" W (6)	Local endemic
<i>Limia islai</i> Rodriguez-Silva and Weaver, 2020	Poeciliidae	18°23'34.8" N 73°04'18.9" W (4)	Local endemic
		18°25'33.2" N 73°02'56.9" W (6)	
		18°25'59.4" N 73°03'33.5" W (7)	
<i>Limia mandibularis</i> Rodriguez-Silva <i>et al.</i> , 2020	Poeciliidae	18°25'33.2" N 73°02'56.9" W (6)	Local endemic
<i>Limia miragoanensis</i> Rivas, 1980	Poeciliidae	18°25'33.2" N 73°02'56.9" W (6)	Local endemic
<i>Limia nigrofasciata</i> Regan, 1913	Poeciliidae	18°23'18.3" N 73°04'12.1" W (1)	Local endemic
		18°23'11.2" N 73°03'26.7" W (2)	
		18°23'27.0" N 73°02'33.7" W (3)	
		18°23'34.8" N 73°04'18.9" W (4)	
		18°25'31.9" N 73°03'04.4" W (5)	
		18°25'33.2" N 73°02'56.9" W (6)	
		18°25'59.4" N 73°03'33.5" W (7)	
<i>Limia ornata</i> Regan, 1913	Poeciliidae	18°25'33.2" N 73°02'56.9" W (6)	Local endemic

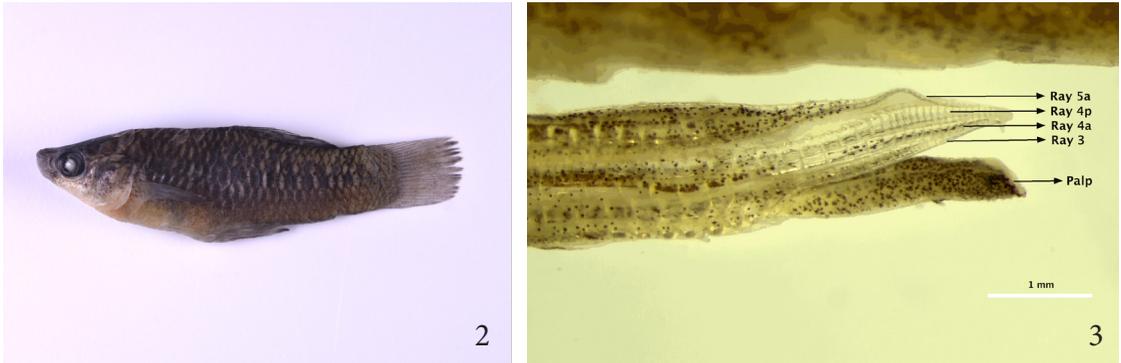
<i>Gambusia beebei</i> Myers, 1935	Poeciliidae	18°23'18.3" N 73°04'12.1" W (1)	Local endemic
		18°23'11.2" N 73°03'26.7" W (2)	
		18°23'27.0" N 73°02'33.7" W (3)	
		18°23'34.8" N 73°04'18.9" W (4)	
		18°25'33.2" N 73°02'56.9" W (6)	
		18°25'59.4" N 73°03'33.5" W (7)	
		<i>Nandopsis haitiensis</i> (Tee-Van, 1935)	
18°23'11.2" N 73°03'26.7" W (2)			
18°23'27.0" N 73°02'33.7" W (3)			
18°25'33.2" N 73°02'56.9" W (6)			
<i>Oreochromis mossambicus</i> (Peters, 1852)	Cichlidae	18°23'18.3" N 73°04'12.1" W (1)	Introduced
		18°23'11.2" N 73°03'26.7" W (2)	
		18°25'33.2" N 73°02'56.9" W (6)	
<i>Cyprinus carpio</i> Linnaeus, 1758	Cyprinidae	18°23'18.3" N 73°04'12.1" W (1)	Introduced
		18°23'11.2" N 73°03'26.7" W (2)	
		18°25'33.2" N 73°02'56.9" W (6)	
		18°25'59.4" N 73°03'33.5" W (7)	

Numbers in parenthesis after the GPS coordinates represent collection sites. Southwest bight: sites 1-4, north bight: sites 5-7.

Five species of the subgenus *Odontolimnaea*: *L. garnieri*, *L. immaculata*, *L. miragoanensis*, *L. ornata* and the recently described *L. mandibularis*, as well as two species of the subgenus *Limnaea*: *L. nigrofasciata* and *L. islai* also recently described were observed and collected in the lake. In addition, one species of the genus *Gambusia*: *G. beebei* was reported. The biodiversity of livebearing fishes is unequally distributed in Lake Miragoane with most of the species concentrated in the northwest bight of the lake (Fig. 1, Table I). The eight endemic livebearing fish species collected in our fieldwork are presented and annotated in this paper.

Limia (Odontolimia) garnieri Rivas, 1980

Diagnosis. Male was identified based on the following combination of characters: 9 dark vertical bars on both sides of body (Fig. 2), ray 4p of the gonopodium with 12 serrae. The number of segments distal to ray 4p serrae is 16 with the same number of grooved segments in ray 4a. Palp of the gonopodium reaches the tip of the structure (Fig. 3). Males have the origin of dorsal fin above the origin of the anal fin. Series of dark vertical bars are present on both sides of the body in females but they are not conspicuous like in males. Dorsal fin in both sexes with 8 rays and 15 or 16 branched rays in the caudal fin. Predorsal scales 13 and 27-28 longitudinal series of lateral scales along the body.



Figures 2-3. *Limia garnieri* species. 2, male, 31.5 mm SL, OMNH 87011. 3, Gonopodium tip, male, 31.5 mm SL, OMNH 87011 showing the ray elements and palp.

Limia (Odontolimia) immaculata Rivas, 1980

Diagnosis. This species can be easily distinguished from congeners by the total absence of spots, bars, blotches or any other distinctive coloration mark on the body of live specimens. In preserved individuals, however, the edges of scales present some black blotches which are more conspicuous in males (Fig. 4). Males with 9 serrae in ray 4p of the gonopodium. The number of segments distal to ray 4p serrae is 15 and ray 4a has 19 grooved segments. Palp present in the gonopodium but it does not reach the tip of the structure. Caudal fin convex in both sexes with 15 or 16 branched rays. Dorsal fin in both sexes with 8 rays. Predorsal scales 14 and lateral scales 27.



Figure 4. *Limia immaculata* male (top), 35.8 mm SL and female (bottom), 35.5 mm SL, OMNH 87012.

***Limia (Odontolimia) mandibularis* Rodriguez-Silva *et al.*, 2020**

Diagnosis. This is the most recently described species of *Limia* from Lake Miragoane and it is uniquely diagnosed by the presence of a well-developed lower jaw due to the presence of an elongate anguloarticular bone. No distinguishing coloring marks such as vertical bars, spots or blotches on body are present neither in males nor females (Fig. 5). Instead of presenting a closed preorbital and preopercular cephalic system with pores, they are opened and the neuromasts are placed in open grooves. Males have 12 serrae in ray 4p of the gonopodium. Palp of the gonopodium in males does not reach the tip of the structure. Dorsal fin in both sexes with 8 rays and its origin is slightly behind of the origin of anal fin in females. The caudal fin is truncate or slightly convex in both sexes with 15 to 17 branched rays (usually 16). Predorsal scales 13 and lateral scales usually 26.



Figure 5. *Limia mandibularis*, female, 41.0 mm SL, OMNH 86828.

***Limia (Odontolimia) miragoanensis* Rivas, 1980**

Diagnosis. There are no distinctive color marks on body other than irregular black blotches that extend longitudinally along the lateral line on both flanks of the fish (Fig. 6). Males with 11 serrae in ray 4p of the gonopodium. The number of segments distal to ray 4p serrae is 16. Palp present in the gonopodium and it reaches the tip of the structure. Caudal fin convex in both sexes with usually 16 branched rays. The dorsal fin in males and females with usually 8 rays and its origin is above the origin of anal fin in females. Predorsal scales 14 and lateral scales 26 to 28.



Figure 6. *Limia miragoanensis* male (top), 26.5 mm SL and female (bottom), 31.0 mm SL, OMNH 87013.

Limia (Odontolimia) ornata Regan, 1913

Diagnosis. Body covered by more or less conspicuous black, irregular spots (Fig. 7). The black spots can also turn into vertically expanded spots (Regan, 1913). The species presents between 8-10 preopercular pores. Dorsal fin with 9 rays. Caudal fin is truncate with 16 branched rays. Predorsal scales 13.



Figure 7. *Limia ornata*, female, 41.0 mm SL, OMNH 87014.

Limia (Limia) islai Rodriguez-Silva and Weaver, 2020

Diagnosis. This species can be distinguished from all other members of the genus *Limia* except *L. nigrofasciata* by the presence of vertical black bars on both sides of the body of males and females (Fig. 8). The number of these bars is highly variable in *L. islai*, usually between 4 to 12 and the barred pattern is frequently more conspicuous in *L. islai* than in *L. nigrofasciata*, with darker and wider vertical bars (Rodriguez-Silva & Weaver, 2020). *Limia islai* has a slender body with body depth approximately equal to the caudal peduncle length (distance from the posterior edge of the dorsal fin to the beginning of the caudal fin) which is also unique of this species. Males have 10 serrae in ray 4p of the gonopodium and the number of segments distal to ray 4p serrae is 16. Palp of the gonopodium in males almost reaching the tip of the structure. The origin of the dorsal fin of females is slightly posterior to the origin of the anal fin. Caudal fin slightly truncate in both sexes usually with 17 branched rays. Dorsal fin in both sexes with 8 rays. Predorsal scales 13 and lateral scales 26 or 27.



Figure 8. *Limia islai* male (top), 29.0 mm SL and female (bottom), 31.5 mm SL, OMNH 87015.

***Limia (Limia) nigrofasciata* Regan, 1913**

Diagnosis. Body with black transversal bars in both sexes, usually 7 to 9 bars present along the body. This species presents a marked sexual dimorphism with males more intensively pigmented than females and presenting a well developed dorsal fin (Fig. 9). In addition, adult males have a characteristic humpback shape not present in females. Body depth is larger than the length of the caudal peduncle (distance from the posterior edge of the dorsal fin to the beginning of the caudal fin), which is even more evident in males. Gonopodium in males with 11 serrae in ray 4p and 18 segments distal to ray 4p serrae. A very large palp that reaches the tip of the gonopodium is present in males. The dorsal fin has 10 rays with its origin above the origin of anal fin in females. The number of lateral scales is 27 or 28 in longitudinal series.



Figure 9. *Limia nigrofasciata* male (top), 41.5 SL and female (bottom), 38.0 mm SL, OMNH 87018.

***Gambusia beebei* Myers, 1935**

Diagnosis. Both sides of the body usually unspotted (Myers, 1935) or with 2 to 3 interrupted longitudinal rows of small dark spots (Rivas, 1969). No suborbital bar present as is common in many other species of *Gambusia* (Fig. 10). The distal segments of the ray 3 of the gonopodium present long spines, (usually 9 or 10). The elbow of ray 4a of the gonopodium is very well developed (Fig. 11). The elbow is composed of two segments partially divided and it reaches the spines of ray 3 of the gonopodium (Myers, 1935). The ray 4p of the gonopodium has 4 serrae. The dorsal fin has 9 rays.



Figure 10. *Gambusia beebei* male (top), 31.0 SL and female (bottom), 39.5 mm SL, OMNH 87019.

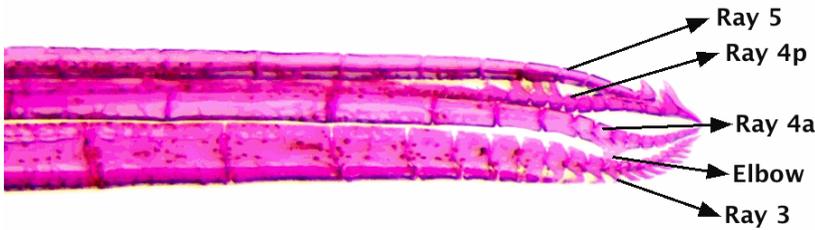


Figure 11. Cleared and stained gonopodium tip showing the ray elements of a male of *Gambusia beebei*, 28.5 mm SL, OMNH 87021.

Taxonomic note. The *Gambusia* specimens we collected in this study were identified as *G. beebei* because of the combination of meristic characters (mainly gonopodium features) mentioned above. However, the body shape observations made by Myers (1935) in the original description of *G. beebei* with a large head and well-developed jaws were not observed in our specimens. Rauchenberger (1989) pointed out that *G. beebei* is a rare species in Lake Miragoane and it is only known from the series designated by Rivas (1969). In addition, she stated that *G. hispaniolae* was also reported from Lake Miragoane. There is a possibility that our specimens are hybrid forms of *G. beebei* and *G. hispaniolae*. This is something that should be determined through further genetic and morphological analyses, which will definitely contribute to assess the status of *G. beebei*.

DISCUSSION

The study of freshwater fishes of the West Indies is extremely relevant to understand the origin of the Caribbean biota. Particularly, the analysis of the divergent patterns of biodiversity that is found in fishes of the subfamily Poeciliinae of the Greater Antilles offer a suitable model to analyze complex scenarios of colonization events in the Caribbean islands compared to other terrestrial or freshwater species. This is because livebearing fish show certain tolerance to variations in salinity levels, which could have made overseas dispersal from the mainland possible (Myers, 1938; Darlington, 1938; Rosen & Bailey, 1963; Briggs, 1984). Thus, this group of fish that lies between terrestrial and purely freshwater species may represent a unique model to explain the complex biogeography of the West Indies (Rivas; 1958; Rosen & Bailey, 1963; Hrbek *et al.*, 2007; Palacios *et al.*, 2016; Weaver *et al.*, 2016; Reznick *et al.*, 2017).

Lake Miragoane is an isolated, endorheic drainage (Curtis & Hodell, 1993) and considered a center of an adaptive radiation for species of *Limia* (Rivas, 1980; Vergara, 1992; Weaver *et al.*, 2016). So far, a total of nine species are known from the lake, which probably have resulted of ecological speciation (Rodríguez-Silva *et al.*, 2020). Although it is not completely clear whether Lake Miragoane filled principally as consequence of rising sea level or increasing moisture availability, it is a fact that the lake filling in this low elevation zone created new and unique habitats for aquatic organisms (Curtis *et al.*, 2001). Despite of the importance of this water reservoir as backdrop of biodiversity of freshwater fishes and the corresponding significance in the study of the Caribbean biota, there has been an overall lack of scientific studies during almost

half a century on the endemic fishes that live in the lake. This lack of information about even basic elements of the natural history of this flock of endemic species together with the human impact on Lake Miragoane creates serious conservation problems that may threaten the biodiversity in the lake. In this work we were able to document most of the livebearing fish species previously known from the lake. However, two of the *Limia* species (subgenus *Odontolimia*) reported by Rivas (1980): *L. grossidens* and *L. fuscomaculata* were not found in our study although we sampled the locations where Rivas reported the two species. This could either indicate that a more extensive sampling effort is needed in the future or that they are rare, possibly threatened, or even extinct.

During our sampling work of the fish community from Lake Miragoane we realized how people living in the surroundings depend on water from the lake for daily use including drinking water, washing clothes, and personal hygiene. These two last activities together with a few mobile car washing stations situated right on the banks of the lake on Route Nationale 2 could represent a threat to aquatic organisms because chemicals present in the soaps and detergents used in these activities go directly into the lake (Rodriguez-Silva *et al.*, 2020). Species introduction is another threat to the biodiversity in Lake Miragoane. In fact, human-mediated species introduction, intentionally or accidentally, is one of the leading causes of biodiversity loss in the West Indies (Ricklefs & Bermingham, 2008). Although not well documented, the main impacts of introduced fish species on native livebearing fishes may include predation, disease transmission and competition for resources, which also have been documented in other vertebrates (Courchamp *et al.*, 2003). In this study we documented the presence of two highly invasive species, *Cyprinus carpio* (Common Carp) and *Oreochromis mossambicus* (Mozambique Tilapia) (Canónico *et al.*, 2005; Zambrano *et al.*, 2006). The Mozambique Tilapia was reportedly introduced in the lake in 1951 to increase the fish production for human consumption (Phaneuf, 1981). Although this species is primarily considered herbivore or detritivore like other species of tilapias, there are reports that it can prey on larvae of other fish species and also small fish such as most of the native species in the Caribbean (Arthington *et al.*, 1994; Morgan *et al.*, 2004). The Common Carp also represents a threat to native species since it has an impact in the natural habitats by increasing solids suspended in the water column and reducing plant coverage with a corresponding decrease in habitat heterogeneity for native aquatic organisms (Zambrano & Hinojosa, 1999; Perrow *et al.*, 1999; Zambrano *et al.*, 2001).

Certainly the endemic fishes from Lake Miragoane deserve urgent scientific study and conservation actions. Some of these tasks are very challenging in the entire Caribbean region (Ricklefs & Bermingham, 2008) and even more difficult in Haiti because the lack of financial resources and qualified personnel. Collaborative work like this survey that involved both biologists from Haiti and the Dominican Republic and foreign specialists will hopefully help in the design of urgent management plans to ameliorate the biodiversity loss in the West Indies.

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