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RESEARCH ARTICLE

An update of the invasive *Pterygoplichthys* Gill, 1858 (Actinopterygii, Loricariidae) in Guatemala: new records and notes on its interactions with the local fauna

Carlos A. Gaitán[1], César E. Fuentes-Montejo[2], Manolo J. García[1], Julio C. Romero-Guevara[2]

1 *Centro de Estudios Conservacionistas, Facultad de Ciencias Químicas y Farmacia, Universidad de San Carlos de Guatemala. Avenida La Reforma 0-63 zona 10, 01010, Ciudad de Guatemala, Guatemala*
2 *Escuela de Biología, Facultad de Ciencias Químicas y Farmacia, Universidad de San Carlos de Guatemala. 2do nivel, Edificio T10, Ciudad Universitaria zona 12, 01012, Ciudad de Guatemala, Guatemala*

Corresponding author: César E. Fuentes-Montejo (cefmontejo14@gmail.com)

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Abstract

Fishes have been introduced in non-native ecosystems all over the world. These introductions have been recognised for their overall negative effects on native biodiversity. Plecos (*Pterygoplichthys* Gill, 1858) have been introduced worldwide due to bad practices in the aquarium trade and, in Central America, there is little information regarding these invasive fishes. Plecos have been demonstrated to be a threat in non-native ecosystems because they interfere with their new ecosystems through bottom-up impacts, altering nutrient availability and interactions with native wildlife. Herein, new records of plecos are reported for river basins from Guatemala in northern Central America where they had not previously been reported. Evidence of interactions of plecos with the native fauna that had not been recorded to date are also included. We compiled a total of 34 records in Guatemala, with eight new records. We present the first records of the genus in a river basin of the Caribbean drainage for Guatemala. Three new interactions of fauna preying upon plecos are presented (Black vulture, Bare-throated tiger Heron and Domestic dog), along with a compilation of previously known interactions. Establishing a monitoring and surveillance programme should be a priority in Guatemala, along with other actions to safeguard the native wildlife that could be at high risk because of biological invasions, such as the one with plecos. In order to better understand this invasion, joint efforts of local fishermen and rangers with State institutions should be promoted.

Keywords
biological invasions, Central America, dispersion strategies, exotic fish, non-native fauna, river basins, threatened ecosystems

Introduction

Fishes have historically been introduced in non-native ecosystems all over the world for several purposes, including sport and food fisheries, as well as biocontrol and as an effect of the aquarium trade (Pípalová 2006; Rahel 2007; Walsh et al. 2016). However, many of these introductions have been recognised for their negative effects on native biodiversity (Moyle and Light 1996; Vitousek et al. 1996; Eby et al. 2006; Gozlan et al. 2010; Alexiades et al. 2017). Suckermouth armored catfishes, "peces diablo" or "plecos", *Pterygoplichthys* Gill, 1858 is a genus of fishes that belong to the family Loricariidae, which are naturally distributed in southern Central America and in South America, but their diversity is higher in the latter (Armbruster 2004). These species have been introduced worldwide due to bad practices in the aquarium trade, where they are popular (Orfinger and Goodding 2018). Releases for the genus have been reported in southern Mexico that led to a later invasion in Guatemala, where two species have been recorded: *P. pardalis* Castelnau, 1855 and *P. disjunctivus* Weber, 1991. Visual morphological and colouration characters conventionally used to identify species of the genus present "intermediate states" that make accurate taxonomic recognition of these two species difficult, and hybridisation has been suggested, either previously in aquarium trade or directly in the introduced regions (Orfinger and Goodding 2018).

In Guatemala, the Guatemalan System of Protected Areas (SIGAP, by its acronym in Spanish) is responsible for the management and conservation of protected areas and biodiversity. The SIGAP is made up of over 300 protected areas (31% of Guatemalan territory), where there are six management categories, based on the foci for conservation (Conap 1999). The largest continuous protected area complex in the SIGAP is the Maya Biosphere Reserve (MBR) in northern Guatemala, that, along with other protected areas from southern-northern Guatemala, southern Mexico and north-western Belize, make up the so-called Selva Maya (SM), which comprises the largest protected area complex in Central America and the largest continuous patch of tropical forest in the Neotropics after the Amazon Forest (Conap 2015). The MBR belongs to the Biosphere Reserve category, which considers multiple actions and activities, both cultural and biological (Conap 2015). These actions and activities define the administration of the MBR in its different management categories: Core Zones (National Parks and Protected Biotopos), Multiple-use Zone (Forestry and Community Concessions and Biological Corridors) and a Buffer Zone (Radachowsky et al. 2012). In addition to the MBR, there are other protected areas in northern Guatemala that seek to preserve natural ecosystems and processes. The hydrology of this area is determined by karst conditions and the headwaters of two international drainage systems are formed here, although approximately 80% of the extension of the MBR belongs to the Usumacinta drainage.

Different non-native fishes have been reported in the MBR and surrounding areas, including *Pterygoplichthys* plecos (Quintana and Barrientos 2012; Penados-Saravia 2014; Sánchez et al. 2015; Ariano-Sánchez et al. 2017; Barrientos et al. 2018). Introduced species like *Pterygoplichthys* spp. have been shown to interfere with invaded ecosystems through bottom-up alterations and creating "nutrient hotspots" (Capps and Flecker 2013, 2015; Capps et al. 2014). Despite efforts to manage these species and their effects, non-native and invasive species continue to be recognised as one of the main threats to biodiversity and one of the main causes of global change through biotic exchange and homogenisation (Sala et al. 2000; Rahel 2002; Garcia-Berthou 2007). In order to document the spread of non-native plecos in northern Guatemala, Central America, the main objective of this paper is to report new records for river basins. We also include evidence of interactions between plecos and the native fauna in the MBR that had not been recorded to date.

Methods

Study area

We used four different areas inside and one outside of the MBR as study sites (see Fig. 1), which were not a priori selected, but represented sites where random encounters occurred. The first one is Yaxhá Nakum Naranjo National Park (YNNNP), a Core Zone of the MBR. With 371.6 km^2 in area, it is situated in the Northeast of Petén department in Guatemala. The second is El Lechugal Management Unit (ELMU), with 664.58 km^2 in area, which is inside the Multiple-use Zone of the MBR. The third is Tikal National Park (TNP), with 575.83 km^2 in area and located west of YNNNP. This iconic archaeological site and cultural World Heritage Monument receives a high incidence of tourism activities (Cleere 1995). The fourth is San Miguel La Palotada-El Zotz Protected Biotopo (SMPZPB), with 349.34 km^2 in area and located west of TNP. The only site outside of the MBR, but still in the SM, is La Pasión River, which is located within La Pasión River Basin (12,156 km^2). This river drains to the Gulf of Mexico, through the Usumacinta River when it meets the Salinas River Basin in west Petén. There are several protected areas associated with La Pasión River, such as El Ceibal Cultural Monument (ECCM) and El Pucté Wildlife Refuge (EPWR). However, there is still high fisheries activity in the river, as well as in San Pedro River. These two rivers are in the top five rivers in Guatemala with the greatest water volume flows (Barrientos et al. 2018). The general physiography in northern Guatemala is characteristic of lowlands and has several hills, which makes the surface water concentrated in low parts, principally in the MBR (Conap 2015).

Data collection

In field expeditions in ELMU during the rainy season (September to February) 2017, Mirador-Río Azul National Park (MRANP) rangers of the *Fundación para el Ecodesarrollo y Conservación* (FUNDAECO) and the *Consejo Nacional de Áreas*

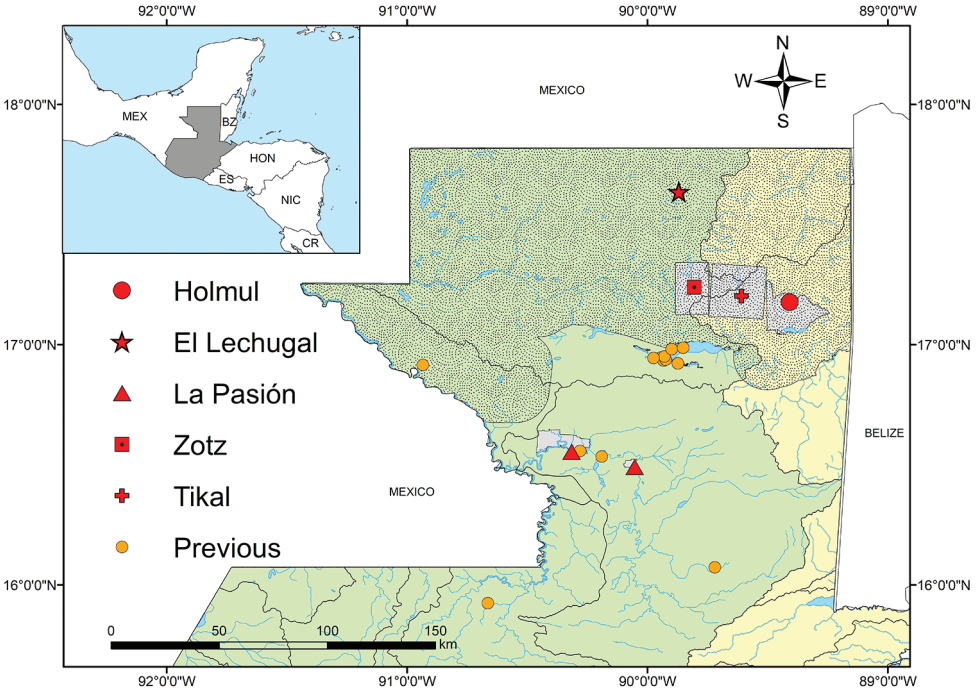

Figure 1. Distribution of the records of *Pterygoplichthys* spp. in river basins of Guatemala, Central America. Green: Usumacinta drainage, light yellow: Caribbean drainage, grey: Protected areas with new records, red: new records, shaded area: Maya Biosphere Reserve.

Protegidas (CONAP) obtained a photographic record of a pleco. In YNNNP during the dry season (March to August) 2018 and 2019, researchers from the *Centro de Datos para la Conservación* -CDC- of the Centro de Estudios Conservacionistas -CECON- of San Carlos University and rangers from CONAP and *Ministerio de Cultura y Deportes* (MCD) obtained photographic records of plecos during field expeditions, but also by camera-traps installed for surveys of Baird's tapir (*Tapirella bairdii* Gill, 1865) along the shores of water-bodies. Additionally, the presence of plecos was recorded during field expeditions in La Pasión River by direct observation and properly registered by photographs. This included recording individuals being predated upon by different predators. In La Pasión River, observations were conducted in a transect of the river between a site inside ECCM, Sayaxché, Petén, to another in Nueva Canaán Community, Las Cruces, Petén. All new records reported in this study are based on field observations, supported by photographic records, but no specimens were collected. For this reason, our records are considered at a genus designation given intermediate phenotypes are recognised as difficult to determine an accurate taxonomic recognition at a species level (Orfinger and Goodding 2018).

To compare with previous records, we searched for voucher specimens deposited in museum collections (Museo de Historia Natural, Escuela de Biología, Universidad de San Carlos de Guatemala, Ciudad de Guatemala – USAC, Louisiana Museum of Natural History – LSUMZ), which were either accessed from online databases (GBIF 2019) or from direct database searches (USAC). We searched for records available in literature (Kihn-Pineda et al. 2006; Kihn-Pineda and Cano 2012; Ariano-Sánchez et al. 2017; Barrientos et al. 2018). Additionally, we included records available in grey literature (Penados Saravia 2014) and records from unpublished data in short reports (Cano Alfaro, unpublished data) deposited in the CDC-CECON database. Interactions with the environment and interspecific interactions of plecos with local fauna were described and compiled along with previous literature describing interactions outside the natural range of plecos (Rice et al. 2007; Nico 2010; Amador del Ángel et al. 2014; Toro-Ramírez et al. 2014; Ríos-Muñoz 2015; Wakida-Kusunoki and Toro-Ramírez 2016), expanding on the natural history of *Pterygoplichthys* as an invasive genus in the rivers of Central America.

Results

We found 26 previous records for the distribution of *Pterygoplichthys* spp. in Guatemala, in the La Pasión, Salinas, San Pedro and Usumacinta River Basins, draining to the Gulf of Mexico. Eight records have voucher specimens (LSUMZ 16833, 16486, 16487; USAC 2258, 2264, 2263, 2262, 2261), 17 come from grey literature (Penados Saravia 2014) and only one record is a photographic record found in published literature (Ariano-Sánchez et al. 2017) (Fig. 1). We report eight new distributional records of *Pterygoplichthys* in Guatemala (see Fig. 1), which sums to a total of 34 records in the country (see Suppl. material 1: Table S1). The first record is a photograph of an individual found alive over a mud trail, from ELMU in 2017 (northernmost record in Guatemala, Fig. 2). Three more records were found in the Holmul River from the Mopán-Belize River Basin, which drains into the Caribbean, from two photographs obtained from CDC-CECON research team by direct observation of dead individuals on banks of the Holmul River in YNNNP during the dry seasons of 2018 and 2019 (Fig. 3) and another based on a photograph recorded by camera-trapping during the dry season 2018 (Fig. 4). Two more records come from observations in the La Pasión River transect between ECNP and Nueva Canaán (Fig. 5). The remaining two records belong to unpublished data (Cano Alfaro, unpublished data) we found in the CDC-CECON database, where two plecos are reported. In 2009, park rangers found and deliberately killed one individual in TNP and another in SMPZPB (Suppl. material 2: Figure S1), as they recognised them as an invasive species.

We report new predation and carrion consumption interactions of plecos in Guatemala from different species (Table 1) in three sites (Fig. 1). In the Holmul River, we report a Bare-throated tiger Heron (*Tigrisoma mexicanum* Swainson, 1834) preying on a pleco, based on a photograph recorded by camera-trapping (Fig. 4).

Table 1. Predator and scavenger species of *Pterygoplichthys* spp. in non-native ecosystems. GUA: Guatemala; MEX: Mexico; USA: United States of America; CC: Carrion Consumption.

Major taxa	Species	Common name	Country	Reference
Actinopterygii				
Perciformes				
Centropomidae				
	Centropomus undecimalis Bloch, 1792	Common Snook	MEX	Toro-Ramírez et al. 2014
	Centropomus poeyi Chavez, 1961	Mexican Snook	MEX	Wakida-Kusunoki and Toro-Ramírez 2016
Elopiformes				
Megalopidae				
	Megalops atlanticus Cuvier & Valenciennes, 1846	Atlantic Tarpon	MEX	Toro-Ramírez et al. 2014
Lepisosteiformes				
Lepisosteidae				
	Atractosteus tropicus Gill 1863	Tropical Gar	MEX	Wakida-Kusunoki and Toro-Ramírez 2016
Sauropsida				
Crocodilia				
Alligatoridae				
	Alligator mississipensis Daudin, 1802	American Alligator	USA	Rice et al. 2007
Crocodylidae				
	Crocodylus moreletii Duméril & Bibron, 1851	Morelet's Crocodile	MEX, GUA	Amador del Ángel et al. 2014; This study
Aves				
Accipitriformes				
Cathartidae				
	Coragyps atratus Bechstein, 1793	Black vulture	GUA	This study (CC)
Pandionidae				
	Pandion haliaetus Linnaeus, 1758	Western Osprey	MEX	Amador del Ángel et al. 2014
Pelecaniformes				
Ardeidae				
	Ardea herodias Linnaeus, 1758	Great blue Heron	USA	Rice et al. 2007; Nico 2010
	Tigrisoma mexicanum Swainson, 1834	Bare-throated tiger Heron	GUA	This study
Suliformes				
Anhingidae				
	Anhinga anhinga Linnaeus, 1766	Anhinga; American Darter	USA	Nico 2010
Phalacrocoracidae				
	Phalacrocorax auritus Lesson, 1831	Double-crested Cormorant	USA	Nico 2010
	Phalacrocorax brasilianus Gmelin, 1789	Olivaceous Cormorant	MEX, GUA	Amador del Ángel et al. 2014; Ríos-Muñoz 2015; This study
Mammalia				
Carnivora				
Mustelidae				
	Lontra canadensis Schreber, 1777	North American river Otter	USA	Nico 2010
	Lontra longicaudis Major, 1897	Neotropical Otter	MEX, GUA	Amador del Ángel et al. 2014; Juarez-Sanchez et al. 2019; This study
Canidae				
	Canis lupus familiaris Linnaeus, 1758	Domestic dog	GUA	This study (CC)

Figure 2. Direct observation of alive *Pterygoplichthys* sp. individual crawling in a muddy trail in El Lechugal Management Unit, Maya Biosphere Reserve, Guatemala.

Figure 3. Direct observation of *Pterygoplichthys* sp. individuals during dry season 2018 (A, B) and 2019 (C) in banks of Holmul River, Yáxha Nakum Naranjo National Park, Maya Biosphere Reserve, Guatemala.

Figure 4. Predation of *Pterygoplichthys* sp. by a Bare-throated tiger Heron *Tigrisoma mexicanum* in Holmul River, Yaxhá Nakum Naranjo National Park, Maya Biosphere Reserve, Guatemala.

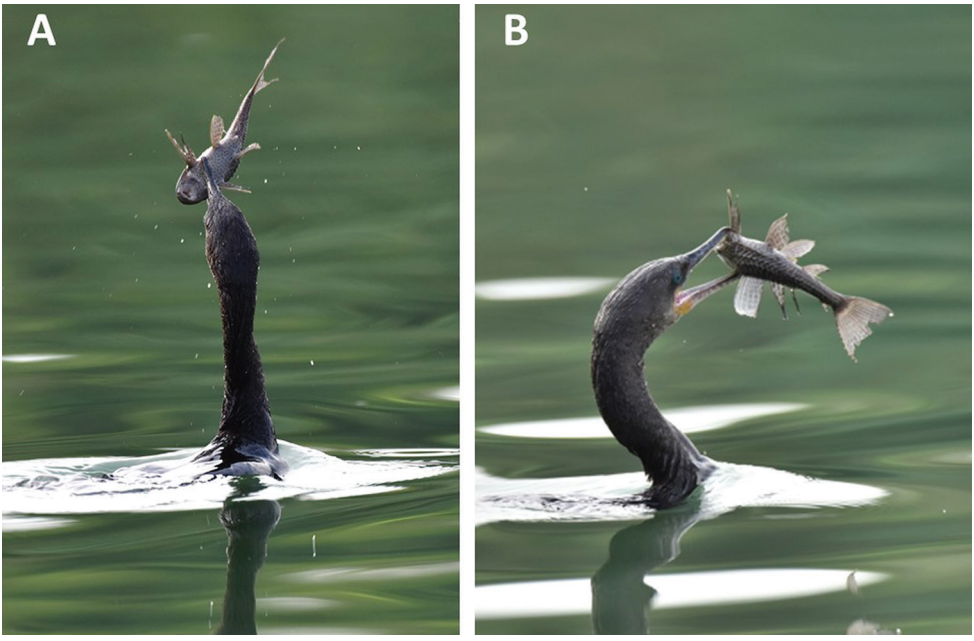

Figure 5. Predation of *Pterygoplichthys* sp. by an Olivaceous Cormorant *Phalacrocorax brasilianus* in La Pasión River, Guatemala. Visible ventral (**A**) and (**B**) dorsal view of pleco.

In La Pasión River, we report the Olivaceous Cormorant (*Phalacrocorax brasilianus* Gmelin, 1789) as a pleco predator, based both on field observations and photographs (Fig. 5) and the Neotropical Otter (*Lontra longicaudis* Major, 1897) as a pleco predator, based solely on field observations. Added to this, we report direct observations of individuals of black vultures (*Coragyps atratus* Buchstein, 1793), domestic dogs (*Canis lupus familiaris* Linnaeus, 1758) and Morelet's Crocodile (*Crocodylus moreletii* Duméril & Bibron, 1851) feeding on pleco carcasses (scavenging) on the banks of La Pasión River. The Olivaceous Cormorant was observed as the most abundant bird species in the segment of the La Pasión River, with groups of over 50 individuals resting on the river beach and surrounding vegetation.

Discussion

While the presence of plecos is widely known in the territory of Guatemala by local people, formal records are still scarce, especially those with voucher specimens. Although the number of records we compiled is low, we believe that this represents under-sampling due to the lack of a monitoring and surveillance programme that shows the progress of this invasion. Recording the presence of plecos in both the San Pedro (northernmost record in Guatemala) and Mopán-Belize River Basins leaves the Río Hondo River Basin as the only one without confirmed records in northern Guatemala. However, plecos have been recorded in the Mexican and Belizean sides of the Río Hondo River Basin (Schmitter-Soto et al. 2015). It is important to note that the Moho and Temash River Basins, both in the Petén department, remain without records of plecos in Guatemala. We also emphasise the importance of the Usumacinta drainage, which covers most of the territory of the MBR with surface water that drains to the Gulf of Mexico. In total, four out of seven river basins of the Usumacinta drainage in the Guatemalan side now have records of plecos.

Despite the lesser covered area in the MBR and northern Guatemala compared to the Gulf of Mexico drainage, the Caribbean drainage now shows the Mopán-Belize River Basin with records of plecos in YNNNP, leaving Río Hondo, Moho and Temash River Basins vulnerable to further invasions. This national park is one of the Core Zones most prone to threats within the MBR, as it is located on the southern border of the reserve close to towns in the Buffer Zone, as well as being prone to illegal hunting, fires and encroachment (Conap 2015). On the other hand, recording the presence of plecos in YNNNP would imply a direct threat due to the hydrological priority of this area for conservation in having important water-bodies, such as the Holmul and Naranjo Rivers, as well as the Yaxhá, Sacnab and Lancajá lagoons and numerous aguadas (Cecon 1996). This is the case of aguadas, which correspond to temporary or seasonal ponds that form from depressions in the SM karstic landscape within higher clayey soil composition, allowing the capture of rainwater during the rainy season (Reyna-Hurtado et al. 2010). The importance of available surface water in these systems is particularly highlighted during the dry season, given the temporal climate variation that causes water shortage.

The under-sampling of plecos and lack of a unified compilation of the genus is evident as unpublished data show. Plecos recorded and killed in TNP and SMPZPB by rangers during park patrols correspond to data that were unknown for more than a decade until our search and query for available records of plecos in Guatemala using the CDC-CECON database. Furthermore, this demonstrates that the knowledge of plecos by the local people in Guatemala is well known, to such an extent that the inhabitants themselves take measures to try to control and reduce the populations of these invasive fish (see Supplementary Fig. 1). Additionally, together with the new records of plecos in YNNNP, it is important to note that plecos have been recorded in this area in the last 10 years (now two years in a row just in YNNNP), which may show that plecos have been established in the Holmul River and within the Mopán-Belize River Basin. The importance of TNP and SMPZPB, together with YNNNP, is of great interest to conservation of the SM. These protected areas comprise the southern border of the MBR and are currently facing higher risks and threats due to the advancing agricultural frontier, extraction of precious woods, poaching, as well as forest fires (Cecon 1996; Conap 2015). There is now the added pressure of this biological invasion.

The success of the rapid spread and establishment of invasive populations of plecos worldwide is due to their easy adaptation and high breeding and survival rates in new environments (Armbruster 1998; Liang et al. 2005; Page and Robins 2006; Bijukumar et al. 2015), along with possessing morphological characteristics that hinder their predation by natural and indigenous predators in new places (Ebenstein et al. 2015; Orfinger and Goodding 2018). Regarding these characteristics, we suggest that the ability to withstand extreme droughts (Armbruster 1998) by surviving in muddy environments (away from water bodies) represents a new strategy for their success in colonising new areas and future population establishment. The new report at ELMU in a locality where superficial water is only seasonally available, as in northern Guatemala, demonstrates a plausible explanation for their dispersal in these environmental conditions (Fig. 2). Similarly, plecos show a tolerance for high salinity changes (Capps et al. 2011). This strategy is added to the possibility of hybridisation in *Pterygoplichthys* spp., that may be responsible for many recorded plecos showing intermediate phenotypic states (Fig. 3), but this still has not been demonstrated using molecular data (Orfinger and Goodding 2018).

The effect that plecos have on the water quality and river nutrients has been explored in the region (Capps and Flecker 2013, 2015; Capps et al. 2014) and is ongoing in Guatemala (Quintana, Y., comm. pers.). However, no formal records of their direct interactions with local fauna have been described in Guatemala. Herein, we compiled 13 species predating on plecos outside their native range (Table 1), where we recorded two of them (*Phalacrocorax brasilianus* and *Crocodylus moreletii*) in Guatemala. Additionally, we report three new species predating and scavenging on plecos (*Tigrisoma mexicanum*, *Coragyps atratus* and *Canis lupus familiaris*), increasing the list of pleco predators in non-native environments to 16 species. Knowing these interactions is highly important in discussions about the management plans

that should be initiated regarding plecos in Guatemala. The effects of plecos are already being noticed, as the niche breadth and the trophic level of the Neotropical Otter have been altered (Juarez-Sanchez et al. 2019) and this should be assessed with the additional species that we report.

Plecos have spread over the region in a little more than 10 years and are now spreading into new drainage systems and river basins (Kihn-Pineda and Cano 2012), even in river basins not connected with others where the genus was previously known (Lardizabal et al. 2020). Given the importance of the MBR for conservation in northern Central America, these new records should be taken into account for conservation priorities and management actions. Considering that this is one of the most pristine and important conservation areas in the Neotropics, the presence and strengthening of State institutions in the area must be prioritised. Additionally, the involvement of local and small-scale fisheries that might be threatened due of the presence of plecos (Orfinger et al. 2019) should lead the collaborative work between fishermen, the Fishing Agency (DIPESCA-*Dirección de Normatividad de la Pesca y Acuicultura*) and Environment Ministry (MARN-*Ministerio de Ambiente y Recursos Naturales)*. Local fishermen and park rangers recognise plecos as a non-native and invasive species in Guatemala and, because of this, they deliberately kill and discard the individuals when they are caught while fishing and during park patrols, respectively. Although fishermen and park rangers acknowledge plecos as an invasive species and actively try to reduce their populations, State institutions should accompany their efforts. An example of these actions is the proposal to use plecos for consumption purposes, either directly or in the production of flour as a dietary supplement for stock of other animal species of regular consumption (Filigrana Celorio 2016; Ixquiac 2016; Fonseca-Hernández and Vargas-Alpízar 2018). These actions should highlight the best way to work and solve this ecological problem.

Conclusions

Although the presence of plecos in many water-bodies in Guatemala is well known, there is still no precise information about the current distribution status of these invasive fish and in what other ecosystems we find them. There are very few published records, such as those presented in this study. We identified predation interactions of plecos, with three new species feeding on them. More sampling efforts are necessary to better understand the invasion of plecos in northern Central America and it is a priority to generate actions to safeguard the native wildlife that could be at high risk due to this biological invasion. In addition, knowing that withstanding droughts in environments far from water-bodies (crawling in muddy trails) is a dispersion strategy for this fish, the seasonality and availability of usable surface water in the MBR will not be an obstacle for this invasive species to continue colonising and impacting the native wildlife of Guatemala and other areas of the Neotropics.

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Supplementary material 1

Table S1

Authors: Carlos A. Gaitán, César E. Fuentes-Montejo, Manolo J. García, Julio C. Romero-Guevara

Data type: occurences

Explanation note: Compilation of distributional records of *Pterygoplichthys* spp. in Guatemala.

Link: https://doi.org/10.3897/neotropical.15.e53020.suppl1

Supplementary material 2

Figure S1

Authors: Mirtha Yolanda Cano Alfaro

Data type: image

Explanation note: Direct observations of *Pterygoplichthys* sp. during ranger patrols in Tikal National Park (A, B) and in San Miguel La Palotada-El Zotz Protected Biotopo (C, D), in the Maya Biosphere Reserve, Guatemala (M.Y. Cano Alfaro 2010).

Link: https://doi.org/10.3897/neotropical.15.e53020.suppl2