



Fishers' perception on armored catfish (*Pterygoplichthys* spp.) invasion: ecologic and socioeconomic impacts in an estuarine protected area in Guatemala

MARÍA A. SCHOENBECK¹, EMILY A. PINEDA-POSADAS¹, YASMIN O. QUINTANA^{1,2} & FERNANDO J. CASTILLO-CABRERA¹

¹Centro de Estudios Conservacionistas CECON. Universidad de San Carlos de Guatemala.

²Winemiller Aquatic Ecology Lab. Department of Ecology and Conservation Biology Texas A&M University.

* Corresponding author: schoenbeck.maria@usac.edu.gt

ORCID numbers: MAS: 0000-0003-4220-8478; YOQ: 0000-0002-1051-0202; FJCC: 0000-0002-8198-8748.

Abstract: Armored catfishes from the genus *Pterygoplichthys* spp. (family Loricariidae) have established populations in tropical and sub-tropical regions worldwide. The negative impacts caused by these catfishes have been studied in various ecosystems, especially in Mexico and the United States. Nevertheless, the impacts of invaded aquatic ecosystems and fisheries on the Pacific Coast of Guatemala remain undocumented. This study brings novel evidence about the impacts of this invasive species using local fishers' perceptions in an estuarine ecosystem on the pacific coast of Mesoamerica. During the rainy season of 2021 at Monterrico Multiple Use Natural Reserve, we conducted participatory activities with fishers. The study found that fishers perceived economic, social, and ecological impacts, including damage to fishing gears, ghost fishing, and habitat modification due to armored catfish nesting, among others. Fishers' perceptions indicate that controlling the invasive species is necessary to reduce the damage to local fisheries and fishers' livelihoods.

Key words: Armored catfish, Monterrico, ecological impacts, socioeconomic impacts, invasive species.

Percepciones locales de los impactos de un pez invasor en la costa del Pacífico de Guatemala. Resumen: Los peces diablo o plecostomos del género *Pterygoplichthys* spp. (familia Loricariidae) tienen poblaciones establecidas en regiones tropicales y subtropicales de todo el mundo. Los impactos negativos causados por estos plecostomos se han estudiado en diversos ecosistemas, especialmente en México y Estados Unidos. Sin embargo, los impactos sobre los ecosistemas acuáticos invadidos y las pesquerías en la costa del Pacífico de Guatemala permanecen sin documentar. Este estudio aporta evidencia novedosa sobre los impactos de esta especie invasora utilizando la percepción de pescadores locales en un ecosistema estuarino en la costa del Pacífico de Mesoamérica. Durante la temporada de lluvias de 2021 en la Reserva Natural de Uso Múltiple Monterrico, realizamos actividades participativas con pescadores. El estudio encontró que los pescadores percibieron varios impactos en las dimensiones económica, ecológica y social, como el daño a las redes de pesca, pesca fantasma y modificación del hábitat, entre otras. Las percepciones de los pescadores indican que el control de la especie invasora es necesario para reducir el daño a las pesquerías locales y a los medios de vida de los pescadores.

Palabras clave: pez diablo, Monterrico, impactos ecológicos, impactos socioeconómicos, especies invasoras.

Introduction

Invasive species are among the most critical threats to biodiversity and ecosystem integrity (IUCN 1999, McNeely & Mainka 2009). These species are considered responsible for local and regional biodiversity decrease (Wilcove *et al.* 1998, Ricciardi *et al.* 2013) and loss of ecosystem services, including fisheries (Lovell *et al.* 2006). Invasive fishes, directly and indirectly, affect native species across different scales, from the genome to habitat and ecosystem functioning (Cucherousset & Olden 2011). Furthermore, invasive species could promote biotic homogenization in some ecosystems and displace unique species (McKinney & Lockwood 1999).

Once invasive species are established, it is almost impossible to eradicate them (Reaser *et al.* 2007). Therefore, identifying, characterizing, and analyzing invasive species impacts is paramount for managers to take control measurements. At least 22 non-native freshwater fishes (NNFF) have been reported in Guatemala (Elías *et al.* 2022). These species were introduced without a previous impact assessment. Although some species were introduced to enhance local fisheries (e.g., Nile tilapia *Oreochromis niloticus*, jaguar guapote *Parachromis managuensis*, and largemouth bass *Micropterus salmoides*), some have negatively affected biodiversity. For example, LaBastille (1983) reported the Atitlan grebe (*Podilymbus gigas*) extinction in Lake Atitlan because of the largemouth bass introduction.

Recently, armored catfishes (*Pterygoplichthys* spp.) from the Loricariidae family have been reported in Guatemala (Elías *et al.* 2022). This family is naturally distributed from Costa Rica to South America (Armbruster & Page 2006) and is characterized by having a bony breastplate extending through three lines of their dorsal surface and a flat belly and spines that protect them against predators (Weber 1992, Page & Robins 2006). Their suckermouth is adapted for grazing and attaching to substrates (Buck & Sazima 1995, Nico *et al.* 2009). *Pterygoplichthys* can grow up to 50 cm and weigh more than 3 kg (Bunkley-Williams *et al.* 1994, Mendoza *et al.* 2007, CEC 2009). Their physiological tolerance allows them to survive at 12 ppt salinity for certain periods (Capps *et al.* 2011), resist hypoxic conditions, and survive through times of drought (Graham & Baird 1982). Armored catfishes are particularly prized in the aquarium market because of their appearance and alleged capability to control algae (Pound *et al.* 2011).

However, ecologists have highlighted the invasive potential of armored catfishes due to their physiology and life history traits (i.e., early age reproduction, high reproductive rate, and parental care to support larvae survival) and the negative consequences derived from this invasive fish (Armbruster 2004, Juárez-Sánchez *et al.* 2019, Mendoza *et al.* 2007, Orfinger & Goodding 2018, Quintana *et al.* 2023).

One species of armored catfish (*Hypostomus* sp.) was first reported in eastern Guatemala in 1996 at Lake Izabal on the Atlantic Coast. Later, two species, *Pterygoplichthys disjunctivus*, and *P. pardalis* were identified in the Usumacinta River basin in northern Guatemala (DIPESCA 2010). Since then, its presence has been recorded in other ecosystems, including northern locations like Lake Petén Itzá, La Pasión River, Lachuá Lagoon, and central highlands in Lake Atitlán (Wakida-Kusunoki *et al.* 2007, Quintana & Barrientos 2012, Echeverría *et al.* 2015, PNUD 2018a). More recently *Pterygoplichthys* was reported in Monterrico Multiple Use Natural Reserve (RNUMM), located on the Pacific coast in south Guatemala (Elías *et al.* 2022). Like in other countries where armored catfishes are invasive, in Guatemala, these species have non-commercial value for consumption by local communities; therefore, their control and eradication are challenging. For example, the armored catfish invasion in Mexico has caused economic loss valued at millions of dollars in the fisheries from El Infiernillo dam (Mendoza *et al.* 2007). Similarly, in Winter Haven, Florida, armored catfish catch showed low profit compared to other non-native species with commercial value (Orfinger *et al.* 2019).

Addressing biological invasions requires a deep understanding of the ecological and socioeconomic components associated. It has been reported that insights from the human dimension are critical to effectively tackle the problems associated with invasive species like awareness of their risks and support management actions (García-Llorente *et al.* 2008, Ricciardini *et al.* 2013, Lipták *et al.* 2023). Fishers' local knowledge is gaining attention in fisheries and conservation research because it provides knowledge from long-term empirical observation, which can provide new data and fill the gaps in scientific knowledge (Begossi 2008, Sagarin & Pauchard 2010, Tesfamichael *et al.* 2014). In studies on invasive fish, fishers' knowledge has proven helpful in identifying the impacts caused and making management decisions towards fish

invasions (Carballo-Cárdenas 2015, Azzurro & Bariche 2017). In the RNUMM the armored catfish has become a cause of concern for local fishers and managers in multiple ways.

The aim of this study was to identify the social, economic, and ecological impacts of the armored catfish invasion in the RNUMM and areas of influence through fishers' perceptions. Fishers' experience could provide key information on ecological impacts observed in the area and the main aspects identified as threatening to their livelihoods.

Material and Methods

Study Site: This study was conducted in the protected area of Monterrico Multiple Use Natural Reserve (RNUMM) and its area of influence. The RNUMM consists of 2800 ha. located on the Pacific Coast of Guatemala (13°58'28", 14°0'38" N and 90°26'21", 90°30'14" W) (Fig. 1), where about 80% of the country's artisanal and subsistence fishers are located (OSPESCA 2011, Muñoz *et al.* 2021). The area is composed of a complex set of brackish and freshwater lagoons and canals with diverse aquatic vegetation (e.g. *Typha* sp., *Phragmites australis*, *Eichhornia crassipes*, *E. heterosperma*, *Najas guadalupensis*, *Neptunia prostrata*, *Nymphaea*

ampla, *Paspalidium germinatum*, *Pistia stratiotes*, *Salvinia minima*, *S. auriculata*, *Hydrilla verticillata*, *Utricularia foliosa*) and canals surrounded by mangrove forests (e.g. *Rhizophora mangle*, *Rhizophora racemosa*, *Conocarpus erectus*, *Laguncularia racemosa*, and *Avicennia germinans*) (Ruiz-Ordóñez & Sigüenza 1999).

The main canal is known as Canal de Chiquimulilla, which runs across the RNUMM. The area of influence located in "La Zona", the village of El Garitón (13°55'47.86" N, 90°35'55.43" W) includes man-made canals known as "quineles." These features are artificial linear structures that conduct and supply water for irrigation, livestock, and navigation and connect to the Chiquimulilla Canal.

The RNUMM harbor about 36 fish species (Barrios 2013) and provides nurseries for economically important fish and shellfish species such as the white-leg shrimp (*Penaeus vannamei*), long-arm river prawn (*Macrobrachium tenellum*), yellowfin snook (*Centropomus robalito*), tropical gar (*Atractosteus tropicus*) and blackthroat cichlid (*Astatheros macracanthus*) among others (Ruiz-Ordóñez & Sigüenza 1999). Non-native species such as Nile tilapia (*Oreochromis niloticus*), jaguar

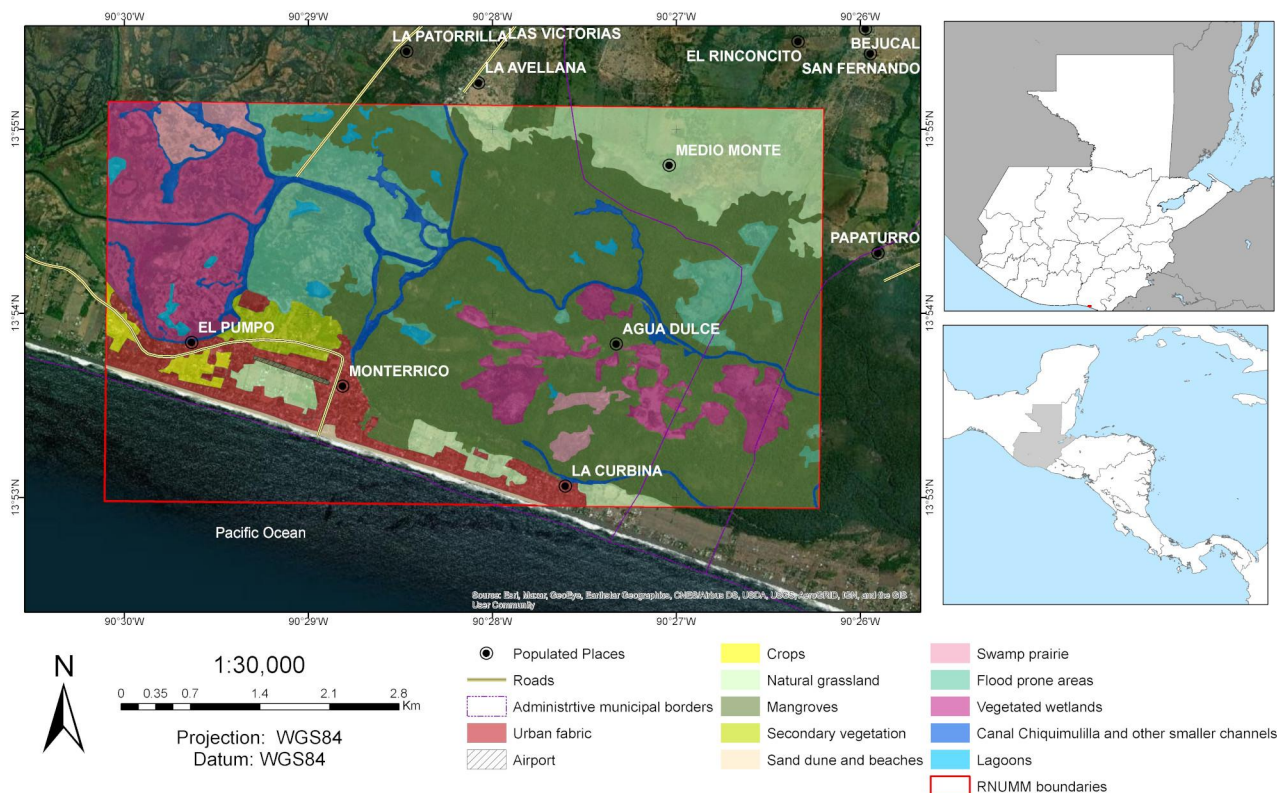


Figure 1. Location of the study site: Reserva Natural de Usos Múltiples Monterrico (RNUMM) and the surrounding area under its influence.

guapote (*Parachromis managuensis*), and the armored catfish (*Pterygoplichthys* sp.) have been reported within the RNUMM basin (Elías *et al.* 2022) (Fig. 2). According to fishers, aquarists, and other aquatic experts, armored catfish presence in the area has two hypotheses: escaping from cultivation tanks and release to the streams. But so far, we cannot confirm which one is more likely to have happened in the RNUMM.

The reserve has five communities: Monterrico, El Pumpo, La Curvina, Agua Dulce, and La Avellana. The main economic activities in these communities are tourism and marine/ estuarine fishing (DIPESCA/MAGA-PNUD 2018). Most of these communities live in poverty or extreme poverty and have low human development indexes (PNUD 2018b). They use fishing as the main livelihood of many families and represent an important source of income in the area (Ruiz-Ordoñez & Sigüenza 1999).

Methods

Workshops strategy:

Between May and October 2021, we conducted three workshops to gather fishers' perceptions regarding armored catfish's potential ecological and socioeconomic impacts. Two types of participatory activities were carried out during workshops using different methodologies: participatory mapping and focus groups using group interviews in which discussion centered on a special topic and facilitated by a moderator (Chestnutt & Robson 2001). Participatory mapping was carried out during the first workshop. Two focus groups were developed in two subsequent workshops, the

first one addressing the economic impacts of the invasion, and the second one addressing the social impacts

Workshops included 33 fishers (~47% of fishers in the RNUMM, Cecon *personal comm.*) belonging to four communities within the RNUMM and 2 communities in the reserve's area of influence (Las Quechas and Papaturro). Each workshop lasted about 4-5 hours. Since activities were conducted during the COVID-19 pandemic, group size was limited since some fishers could not participate.

Participatory mapping and focus groups: The activities were developed under a series of guiding questions according to the objective of each workshop. The methodology promoted a participatory environment in which the discussion was opened based on formulating questions to bring fishers' opinions and promote knowledge exchange among themselves. The aim of the participatory mapping (IFAD 2009) was to spatially represent the collective knowledge on a) the presence and distribution of armored catfish in the area, b) the observed local impacts of armored catfish in the ecosystem, and c) the impacts on artisanal fisheries and fisher's livelihoods. To build the map, fishers were asked to locate places on maps where armored catfishes have been captured or seen, potential nesting sites, and places where ecological and socioeconomic impacts have been detected. Towards the end, fishers also discussed the perceived problems caused by this fish (Fig. 3a, Table I-II).

Focus groups were carried out in small groups with collective discussions about the impacts of armored catfish in the reserve. In the first group, we addressed the economic impacts caused by the



Figure 2. Armored catfish caught by artisanal fishers in the RNUMM. Credit: Maria A. Schoenbeck and Emily Pineda.



Figure 3. Activities. (A) Participatory mapping with fishermen and (B) Interviews with fisherwomen.

invasive fish on fishing activities, including the household economy. We also discussed alternatives to reduce economic impact and identified other impacts due to this invasive fish. The second focus group addressed the social impacts caused by the armored catfish in the reserve, i.e., how the armored catfish has impacted their daily lives, how they personally feel about these impacts, and what actions they have taken to reduce them. The focus group methodology allowed us to gather local knowledge, which is an important source of information for subsequent management plans. In addition, the participation of fishers from different communities allowed productive discussions due to the exchange of opinions and the different experiences related to the armored catfish presence through the RNUMM and area of influence.

Finally, we separately interviewed eight fisherwomen since they have an active role in both fishing and family life. We used open questions to inquire about the impacts of the armored catfish on their livelihoods. They provided complementary

information on how this invasive species has affected their family economy (Fig. 3b).

In each activity, an atmosphere of trust was established through communication and the presentation of the objectives of the study to the participants, letting them know the importance of their participation. Ethical dilemmas that could arise during each activity were considered through consent, anonymity, and confidentiality, as suggested by Sim & Waterfield (2019). However, we solved these dilemmas through informed consent from the fishers, we were allowed to record and photograph the development of the activities, as well as the dissemination of their knowledge. Park rangers contributed by talking beforehand about the workshops to potential participants who have worked together with the reserve.

Collection of information and analysis: The information provided by participatory mapping was collected on maps, photographs, and notes. During the focus groups and interviews with fisherwomen, the information was collected through voice recordings and notes. All the information was then analyzed, and the impacts perceived by the fishers were classified according to the associated component: a) ecological impacts (on biodiversity and habitat) and b) socioeconomic impacts. The fisher's perceptions were synthesized and classified according to the type of impact.

Results

Artisanal fishers of the RNUMM perceived that armored catfish cause various impacts in terms of biodiversity, habitat quality, and structure and have produced socioeconomic consequences (Table I and II). According to fishers, one of the impacts experienced is local loss of fish biodiversity, including important commercial species such as the three-spot cichlid (*Amphilophus trimaculatus* Günther, 1867), blue sea catfish (*Ariopsis guatemalensis* Günther, 1864), and yellowfin snook (*C. robalito* Jordan & Gilbert, 1882). Fishers suggested that armored catfish feed on the larvae of these native fishes, and its aggressive behavior, and aggregations patterns, displace other fish. Fisherwomen mentioned that when fishers catch armored catfish in high abundance, they can abandon their gillnets causing ghost fishing (i.e., catches by fishing gear that continues to operate because it has been lost or neglected) (Breen 1987).

Two nesting sites were reported and associated with ecological impacts. One is located in

Table I. Perceived ecological impacts caused by armored catfish, reported by fishers from the RNUMM.

Type of Impact	Impacts perceived by fishers	Description
Impacts on Biodiversity	1. Decrease of native species since the introduction of armored catfish	Fishermen stated that armored catfish ingest the larvae of native fish causing population decline of native fish such as cichlids, blue sea catfish (<i>Arius guatemalensis</i>), and snook.
	2. Alteration of native species behavior and native species displacement	Armored catfish display aggressive behavior when they move in aggregations or "spots" causing other native species to disperse to other sites. Fishers stated that when they catch large numbers of armored catfish, the catch of native fish is low.
	3. Ghost fishing	When a large abundance of armored catfish is caught, some fishers abandon gillnets, temporarily or permanently, to avoid wasting time. This results in the gillnets continuing to catch native and commercially important species.
Impacts on Habitat	4. Destruction of feeding and nesting sites of other species	Some fishers pointed out that the armored catfish feed in aggregations and do so aggressively, which causes the destruction of aquatic vegetation and displacement of cichlids from their nesting sites.
	5. Modification of the canal banks of "quineles"	In the site "La Zona", armored catfishes have built numerous nesting burrows in the "quineles", modifying and altering the structure of the banks. The fishers claim that the number of nesting burrows is high and extends for several kilometers, and they do not know to what extent it may impact the structure of the canal banks.
	6. Alteration of water aspect	Fishers have noticed that the armored catfish modify the water quality where they are, or as they state that armored catfish "dirty" the water referring to the water looking "murky".
	7. Pollution	The bodies of armored catfish caught by fishers are discarded on the shores. Sometimes the carcasses are piled up in specific sites, and as they rot, they become sources of contamination. Fishers report that the smell of rotting armored catfish carcasses is very unpleasant.

the "quineles" at the east of the reserve, and the second is located in the west, near Papaturro village. Fishers mentioned that armored catfish modify the physical environment, particularly in the "quineles" located in the site "La Zona", numerous armored catfish nesting burrows have modified the canal banks (Fig. 4). Fishers also have the perception that armored catfish modify the water quality of the canal and lagoons because the water looks "murky" where they are found. Another perception is that armored catfish capture depends on spatial and

temporal factors. For example, they are highly abundant in the quineles zone and nearby bodies of water such as Rancho Alegre lagoon (Fig. 5); therefore, fishers avoid this area. One fisherman also mentioned that he prefers to fish during daylight hours because the armored catfish aggregate at night.

Among the socioeconomic impacts perceived by fishers are the decrease of commercial species caught, the loss and damage of fishing gears when catching high abundances of armored catfish, and

Table II. Perceived socioeconomic impacts caused by armored catfish were reported by fishers in the RNUMM.

Impacts perceived by fishers	Description
1. Fisheries economic loss	According to fishers, the catch of commercial species has decreased since the armored catfish was reported in the reserve. This affects most areas outside the RNUMM during the dry season. Consequently, fishers' economic income has decreased.
2. Increase in fishing time	Fishers spend more time than planned to remove armored catfishes from fishing gear, increasing the fishing efforts required to catch commercial species.
3. Human population health	Rotting armored catfish carcasses from fishing discards produces a bad odor and contamination in certain areas where they are piled up.
4. Psychosocial consequences	Catching numerous armored catfish induces stress and discomfort in fishers because they feel frustrated due to the increase in fishing effort and the reduction of valuable catches. They think it is a waste of time and feel discouraged to go fishing.
5. Damage to fishing gears	The nets sometimes are damaged due to the spiny fins of the catfish. The effect increases when fishers catch numerous catfishes. In addition, fishers must spend time repairing the nets, and sometimes the fishing nets become completely useless.
6. Injuries on fishers' hand's	Armored catfish's spiny fins and corps cause wounds on fisher's hands when trying to remove them from fishing nets. This can cause infections and further expenses.

**Figure 4.** Armored catfish nesting burrows in the “quineles” located at the site “La Zona”, El Garitón village, in the RNUMM area of influence. Credit: Emily Pineda.

injuries on fishers' hands due to wounds during fish removal (Table II). Fishers perceived that this invasion had generated an economic loss, a waste of time due to increased work on fishing gear repair, and a total loss of fishing nets. Fishers also complained about an unpleasant odor in areas where the invasive catfish is discarded.

Discussion

In this study, we documented artisanal fishers' perceptions of the armored catfish presence in a

protected area where artisanal fishing is critical to the economy and food security of local communities (PNUD 2018b). The local fishers are aware of the potential impacts of the armored catfish presence in the RNUMM. This study provides insights into how the fishers have been affected by this invasion, according to their perspectives. According to fishers' responses, we identified three major categories of negative impacts: 1) Impacts on biodiversity and fishery, 2) impacts on habitat, and 3) social economic consequences.



Figure 5. Visual evidence of abundant catch of armored catfish by artisanal fishermen in El Palmo lagoon, within the area of influence of the RNUMM.

One of the fishers' major concerns regarding the armored catfish invasion is the potential displacement of native fish species and the reduction of native fish biomass catch. Often invasions cause species displacement due to competition for food and habitat (Bunkley-Williams *et al.* 1994, Cook-Hildreth 2008, Krishnakumar *et al.* 2009, Mendoza *et al.* 2009, Chaichana *et al.* 2011, Orfinger & Goodding 2018). Armored catfishes from the genus *Pterygoplichthys* spp. have shown to have trophic overlap with native species where it has been reported (Wijethunga & Epa 2008, Hill *et al.* 2015), and trophic displacement has been suggested as a sign of competition with native species (Quintana *et al.* 2023). This catfish can become dominant in the ecosystems and its abundance can overtake catch biomass or at least become significant in the catch (Wei *et al.* 2017, Orfinger *et al.* 2019). For example, Mendoza *et al.* (2007) reported that armored catfish replaced 70-80 % of the fish caught in the El Infiernillo reservoir in Mexico. There is consistent evidence from fishers' reports, analysis of commercial catch, and experimental studies that demonstrate the decrease of native species biomass caused by armored catfish abundance (Hoover *et al.* 2004, Chaichana & Jongphadungkiet 2012, Barba-

Macías *et al.* 2017, Suresh *et al.* 2019, Elfidasari *et al.* 2020, Seshagiri *et al.* 2021).

Fishers reported armored catfish feeding on fish larvae, and they suggest this is one of the causes of the decrease in native fishes. Nonetheless, fish and invertebrates larvae ingestion only have been reported incidentally, because they are grazers that mainly feed on detritus and periphyton (Özdilek 2007, Mendoza *et al.* 2009, German & Miles 2010, Hoover *et al.* 2014, Stolbunov *et al.* 2021). Scott *et al.* (2012) stated that the intensive grazing behavior of armored catfish can decrease food resources in the ecosystems. Moreover, Cook-Hildreth (2008) found out that fish egg survival can decrease when exposed to armored catfish foraging. Therefore, armored catfish foraging behavior could directly or indirectly impact the native fauna population dynamics as fishers had observed.

For the RNUMM, there is a lack of scientific studies demonstrating that the abundance of native fish has decreased due to the presence of the armored catfish. However, the experience of fishers should not be neglected. The reduction of native fish catch could likely be occurring, but besides the impact caused by armored catfish, other factors could be contributing to this phenomenon, such as

overfishing (USAID 2020), habitat degradation (Barrios 2013), deforestation (López *et al.* 2016) and other potentially invasive species (Sala, 2000). It cannot be ruled out that one or multiple of these factors may exacerbate the impacts that fishers have added to the armored catfish.

Fishers have observed that armored catfish show aggressive behavior when feeding and nesting. When grazing, these catfish can damage aquatic vegetation and the benthic areas, directly affecting fish nesting sites (Nico 2010). This concurs with fishers' claims that armored catfish displace cichlids from their nesting sites, which could be affecting important commercial fish species such as the native three-spot cichlid (*A. trimaculatus*), the black throat cichlid (*A. macracanthus*), and the introduced Nile tilapia (*O. niloticus*) (USAID 2020). There are few studies on the interactions (predation and potential competition) of armored catfish as an invasive species (Mendoza-Carranza *et al.* 2010, Gaitán *et al.* 2020), but aggressive behavior that affects other species has been documented, for example, with pelicans (Bunkley-Williams *et al.* 1994) and grazing algae from Manatees skin (Pérez-Flores & Pigenutt-Galindo 2020).

One of the most affected sites is the area known as "quineles" in "La Zona", an important nesting site for armored catfish near the RNUMM. Local fishers report the modification of the banks by numerous burrows where loricariids built their nests. This is consistent with what researchers have reported in other locations (Hoover *et al.* 2004, Mendoza *et al.* 2009). In addition, it has been reported that sites with higher numbers of burrows present increased bank erosion and destabilization, affecting wetlands and embankments (Yamamoto & Tagawa 2000, Lienart *et al.* 2013, Van den Ende 2014, Moroni *et al.* 2015).

Fishers reported high catch rates of armored catfishes at the site los "quineles" and nearby lagoons. The abundance of catfish varies seasonally, but in this site, up to 100 individuals can be caught per fishing trip, according to fishers. In the "quineles" zone, the salinity is low due to the influx of fresh water from the nearby lagoons. The proximity of the site to rural communities and an agricultural area has increased a load of nutrients such as phosphorus and coliform bacteria (Franco 2008). According to Escalera-Vásquez *et al.* (2019), nutrients promote a greater abundance of armored catfish. This agrees with the disturbance hypothesis, which states that the most disturbed areas are more susceptible to being invaded by non-native species

(Elton 1958, Hobbs & Huenneke 1992). However, the presence of other factors that cause this great abundance of catfishes cannot be ruled out.

During the dry season (October-April), the salinity within the RNUMM ecosystems increases, so catfishes aggregate on water bodies with low salinity outside the reserve. According to fishers, in this season, the capture of armored catfish increases in the "quineles" and nearby lagoons such as "Rancho Alegre," "Palmeritos," and "Puente Grande". This causes a significant impact on fisheries because most of the fishing takes place in the aforementioned lagoons. As a result of armored catfish abundance in the lagoons, fishers are forced to search alternative areas, which sometimes, they said, are difficult to find. According to fishers, commercially important species such as *P. vannamei* are displaced to other areas when the catfish is abundant in these lagoons, affecting the fishers that benefit from this species. A factor that could aggravate this problem is sediment silting derived from land-use change, which promotes blockage of hydrobiological flow within the reserve and areas of influence, and causes the salinity current not to reach areas beyond the reserve.

Fishers have perceived that armored catfish modified water quality in some areas. Elfidasari *et al.* (2020) reported that the high density of *Pterygoplichthys pardalis* causes an increase in water turbidity. This could be related to armored catfishes' burrows excavation for nesting (Aguirre-Muñoz & Alfaro 2009) and armored catfish's aggregations due to feeding behavior (Hossain *et al.* 2018). Chemical changes in the water are not always evident; researchers have reported that armored catfish aggregations generate nutrient hotspots due to excretions, affecting nutrient ratios nitrogen and phosphorous (Capps & Flecker 2013, Capps *et al.* 2014, Rubio *et al.* 2016). Temporality and sedimentation resulting from the erosion of the area can be factors that can contribute to increased water turbidity. Knowing that this could likely happen in areas where armored catfishes become abundant (although see Escálera-Vasquez *et al.* 2019), it is important to study whether these aggregations in the dry season could affect RNUMM ecosystems negatively in the long term.

Another problem derived from the armored catfish presence in the RNUMM is the increase in ghost fishing. To our knowledge, this problem has not been reported in the literature yet and could have serious implications for native biodiversity. In the RNUMM, this situation was only reported by

fisherwomen. They have observed damaged fishing nets abandoned by fishermen, and they suggested this could be due to the high abundance of armored catfish captured. Abandoned nets continue to catch fish and potentially other organisms, increasing mortality and affecting populations of other species. The lack of armored catfish commercial value discourages fishers from harvesting them, and although fishing gear can be expensive, fishers value their time and effort over fishing gear. A solution to reduce ghost fishing could be to increase awareness of this major problem among fishers, provide feasible solutions, and technical support to recover and remove the damaged fishing gear from the water. Although this could result expensive, government agencies often lack the resources to implement management strategies, as it is common in developing countries.

Fishers reported that since the armored catfish was established in the RNUMM, they capture less biomass of commercial species. The same has been reported by Mexican fishers in the Biósfera Pantanos de Centla at Grijalva-Usumacinta basin (Barba-Macías *et al.* 2017) and "El Infiernillo" reservoir in Michoacan state, where 70-80% of the tilapia fishery has been affected by armored catfish (Mendoza *et al.* 2009). Also, in Guatemala, the armored catfish have established populations in freshwater ecosystems, where it has become significant to the fish biomass. For example, in La Pasión river, the incidence of armored catfish capture reaches 31% (Ochaeta 2017). In the RNUMM, it is difficult to estimate the economic loss due to armored catfish catch, given the lack of specific studies assessing the quantitative impact on the fisheries; however, fishermen state that on occasions, when many armored catfish are caught, the losses are significant, due to damage of fishing gears, increased effort to remove fish, and reduced capture of valuable species. For example, in Asia, fishers lose 4.5% of their salary to fixing damaged nets caused by armored catfish (Seshagiri *et al.* 2021). In the RNUMM, the most significant loss occurs when the entire net cloth breaks. This has happened to only a few fishers so far.

The capture of armored catfish in the RNUMM also has repercussions for fishers' health since their hands get wounded by fish's spines when they remove fish from fishing gear. This generates fishers' discontent since they go fishing daily while having pain and sometimes infections. Another impact is related to psychosocial stress among fishers. Fishers are reluctant to go out fishing because of the possibility of catching more armored

catfish than valuable fish or experiencing the loss or damage of fishing nets. The fisherwomen in charge of the household feel helpless in this situation. The increased fishing effort to replace the loss caused by the capture of armored catfish generates stress and discomfort among fishermen as their livelihoods are hampered, which the fishers refer to as "a waste of time." This has been observed in other fisheries where this invasive catfish has been established (Sumanasinghe & Amarasinghe 2013, Velásquez 2013, Hussan *et al.* 2019).

Conclusions and Management needs: The perceptions that fishers of the RNUMM have about the armored catfish reflect major problems derived from the presence of this fish in localized areas in the RNUMM and surrounding areas. Since the species of the genus *Pterygoplichthys* are blacklisted under the Regulation of exotic and invasive species in Guatemala (CONAP 2011), this could guide actions for its control, especially during the dry season. Fishers highlight the negative impact caused on their livelihoods and the aquatic ecosystems on which they rely. Particularly, fisherwomen are highly impacted since they often have less economic independence and have reduced time for fishing.

The problem of the armored catfish invasion seems to be worsened by its lack of use or economic value. Consumption of *Pterygoplichthys* catfishes is strongly rejected due to their appearance and the existence of better alternatives. This catfish has not been part of their diets, there is a lack of knowledge of how to cook it, and fishers think that there is little meat in their bodies, and it is difficult to handle. Also, the discarding of captured armored catfish on the shores increases people's rejection because they are seen as a source of pollution. Therefore, actions to find alternative uses are urgent.

The armored catfish presence could be one of the main factors impacting the economy and food security of local communities in the RNUMM, since fishers' perceptions indicate a decrease in the capture of valuable species or species used for consumption. Alternative solutions for the use of armored catfish have not been promoted by government agencies in the RNUMM. However, fishers are open to proposals for utilization of this fish as suggested in other countries such as México and Costa Rica (Ayala-Pérez *et al.* 2015, Fonseca-Hernández & Vargas-Alpizar 2018). In northern Guatemala, a study proposed using armored catfish as a protein source in the formulation of animal and human food products (Ochaeta 2017), however, it is necessary that the fishers accept and implement the proposals,

and should be backed by the government, private sector, or organizations.

Besides the negative impacts of armored catfish on local fisheries, fishers recognize that there are other factors in play, such as habitat degradation, deforestation, increased pollution with agrochemicals, and illegal fishing. Similar problems have been documented for the entire coastal zone in the country (López-Selva 2022). The erosion and transformation of areas severely impacted by armored catfish could decrease with the restoration of riverbanks (e.g., increasing riparian forest), guided by analytical information on the distribution and intensity of the impact derived from burrows. It must be considered that the configuration of the RNUMM is complex and is subjected to constant anthropogenic pressure, which makes it more vulnerable to the effects of invasion (Didham *et al.* 2005).

The willingness of fishers to learn how to use this fish opens opportunities to create collaborative efforts among fishers, together with municipal and national authorities to control this fish and try to get economic benefits from it. We suggest that technical assistance could guide alternatives for the use of armored catfish and promote the control of the species in the RNUMM and surrounding areas. Also, education on biological invasions to the general public can raise support for native species and their habitat (Lipták, *et al.*, 2023). This would benefit the local biodiversity, the ecosystem, and artisanal fisheries that are highly valued in the area and are key for food security.

Acknowledgments

We thank all the fishers who participated in the study. We also thank the park guards and the administration of CECON at the RNUMM for their help in fieldwork. This study was co-financed by the research fund of the General Directorate of Research Digi/USAC 2020, project AP20-2021 “Analysis of the ecological and socio-economic impact caused by the exotic species *Pez Diablo* (Loricariidae) in the Monterrico Natural Reserve.”

Ethical statement

The present investigation did not involve the use of regulated animals and did not require approval by an ethical Committee.

References

Aguirre-Muñoz, A. M. & Alfaro, R. A. 2009. Especies exóticas invasoras: impactos sobre

las poblaciones de flora y fauna, los procesos ecológicos y la economía. Pp. 277-318. In: Sarukhán, J. *et al.* (Eds.). **Capital natural de México, vol. II: Estado de conservación y tendencias de cambio**. CONABIO, México, 806 p.

Armbruster, J. 2004. Phylogenetic relationships of the suckermouth armored catfishes (Loricariidae) with emphasis on the Hypostominae and the Ancistrinae. **Zoological Journal of the Linnean Society**, 141: 1–80.

Armbruster, J. W. & Page, L. M. 2006. Redescription of *Pterygoplichthys punctatus* and description of a new species of *Pterygoplichthys* (Siluriformes: Loricariidae). **Neotropical Ichthyology**, 4(4): 401–410.

Ayala-Pérez, L., Vega, B., Terán G. & Martínez, G. 2015. **El pez diablo en México. Guía para administradores y usuarios de recursos pesqueros**. Universidad Autónoma Metropolitana, México, 64 p.

Azzurro, E. & Bariche, M. 2017. Local knowledge and awareness on the incipient lionfish invasion in the eastern Mediterranean Sea. **Marine and Freshwater Research**, 68(10): 1950-1954.

Barba-Macías, E., Mendoza-Carranza, M., Trinidad-Ocaña, C., Juárez-Flores, J. & Martínez, M. L. 2017. **Contrastes en el manejo del cangrejo azul y el pez diablo: Perspectiva de los pobladores de la Reserva de la Biósfera Pantanos de Centla, Tabasco**. ECOSUR, México, 48 p.

Barrios, M. 2013. Actualización del Plan Maestro 2000-2005 de la Reserva Natural de Usos Múltiples Monterrico, Taxisco, Santa Rosa. Tomo 1: Aspectos Biofísicos. **Master's Thesis**. Universidad de San Carlos de Guatemala, Guatemala, 124 p.

Begossi, A. 2008. Local knowledge and training towards management. **Environment, Development and Sustainability**, 10: 591-603.

Breen, P. A. 1987. Mortality of Dungeness Crabs Caused by Lost Traps in the Fraser River Estuary, British Columbia. **North American Journal of Fisheries Management**, 7(3): 429–435.

Buck, S. & Sazima, I. 1995. An assemblage of mailed catfishes (Loricariidae) in southeastern Brazil: distribution, activity, and

- feeding. **Ichthyological Exploration of Freshwaters**, 6: 325-332.
- Bunkley-Williams, L., Williams, E. H., Lilystrom, C. G., Corujo-Flores, I., Zerbi, A. J., Aliaume, C. & Churchill, T. N. 1994. The South American sailfin armored catfish, *Liposarcus multiradiatus* (Hancock), a new exotic established in Puerto Rican fresh waters. **Caribbean Journal of Science**, 30(1-2): 90-94.
- Capps, K. A., Nico, L. G., Mendoza-Carranza, M., Arévlo-Frías, W., Ropicki, A. J., Heilpern, S. A. & Rodiles-Hernández, R. 2011. Salinity tolerance of non-native suckermouth armored catfish (Loricariidae: Pterygoplichthys) in south-eastern Mexico: implications for invasion and dispersal. **Aquatic Conservation: Marine and Freshwater Ecosystems**, 21(6): 528-540.
- Capps, K. A. & Flecker, A. S. 2013. Invasive Fishes Generate Biogeochemical Hotspots in a Nutrient-Limited System. **PLoS ONE**, 8(1): 1-7.
- Capps, K. A., Ulseth, A. & Flecker, A. S. 2014. Quantifying the top-down and bottom-up effects of a non-native grazer in freshwaters. **Biological Invasions**, 17(4): 1253-1266.
- Carballo-Cárdenas, E. C. 2015. Controversies and consensus on the lionfish invasion in the Western Atlantic Ocean. **Ecology and Society**, 20(3): 24.
- Chaichana, R., Pouangcharean, S. & Yoonphand, R. 2011. Habitat, abundance and diet of invasive suckermouth armored catfish (Loricariidae Pterygoplichthys) in the Nong Yai Canal, East Thailand. **Tropical Zoology**, 24(1): 49-62.
- Chaichana, R. & Jongphadungkiet, S. 2012. Assessment of the invasive catfish *Pterygoplichthys pardalis* (Castelnau, 1855) in Thailand: Ecological impacts and biological control alternatives. **Tropical Zoology**, 25(4): 173-182.
- Chestnutt, I. G. & Robson, K. F. 2001. Focus groups—what are they?. **Dental Update**, 28(4): 189-192.
- Commission for Environmental Cooperation (CEC). 2009. **Trinational Risk Assessment Guidelines for Aquatic Alien Invasive Species**, accessible at <http://www.cec.org/> (Accessed 02/11/2021).
- Consejo Nacional de Áreas Protegidas (CONAP). 2011. **Reglamento de Especies Exóticas e Invasoras de Guatemala. Fortalecimiento de las Capacidades Institucionales para Abordar las Amenazas Provocadas por la Introducción de Especies Exóticas en Guatemala**. Serviprensa, Guatemala, 132 p.
- Cook-Hildreth, S. L. 2008. Exotic armored catfishes in Texas: reproductive biology, and effects of foraging on egg survival of native fishes (*Etheostoma fonticola*, endangered and *Dionda diaboli*, threatened). **Master's Thesis**. Texas State University, Texas, United States, 51 p.
- Corea, J. T., Hernández, G. M., Solís, V. & Aguilar, A. J. 2014. Distribución y abundancia de peces de la familia Loricariidae (Pleco) y su relación con los peces de interés comercial en los alrededores de la Isla de Ometepe. **Encuentro**, 98: 44-59.
- Cucherousset, J., & Olden, J. D. 2011. Ecological impacts of nonnative freshwater fishes. **Fisheries** 36(5):15-230.
- Delariva, R. L. & Agostinho, A. A. 2001. Relationship between morphology and diets of six neotropical loricariids. **Journal of Fish Biology**, 58(3): 832-847.
- Didham, R. K., Tylianakis, J. M., Hutchison, M. A., Ewers, R. M., & Gemmell, N. J. (2005). Are invasive species the drivers of ecological change?. **Trends in ecology & evolution**, 20(9), 470-474.
- Dirección de Pesca y Acuicultura (DIPESCA). 2010. **Intercambio de experiencias Nicaragua-Guatemala para identificar acciones de manejo del pez diablo en Guatemala**. Sub-áreas de Monitoreo y Evaluación y sub área de Acuicultura y Aguas Continentales, Guatemala, 12 p.
- Dirección de Normatividad de la Pesca y Acuicultura del Ministerio de Agricultura, Ganadería y Alimentación (DIPESCA/MAGA) & Programa de las Naciones Unidas para el Desarrollo (PNUD). 2018. **Caracterización de la Pesca Artesanal del Pacífico de Guatemala: 3. Tercer Cuatrimestre**. Fundación Defensores de la Naturaleza, Guatemala, 196 p.
- Didham, R. K., Tylianakis, J. M., Hutchison, M. A., Ewers, R. M. & Gemmell, N. J. 2005. Are invasive species the drivers of ecological change?. **Trends in ecology & evolution**, 20(9): 470-474.
- Echeverría, J., Jiménez, J., Ojeda, L., Madrid, J., García, F., Marroquín, A. & López, A. 2015.

- Informe sobre muestreo de peces en el Río La Pasión**, accessible at <http://www.chmguatemala.gob.gt> (Accessed 06/01/2022).
- Elfidasari, D., Wijayanti, F. & Muthmainah, H. F. 2020. Short communication: The effect of water quality on the population density of *Pterygoplichthys pardalis* in the Ciliwung river, Jakarta, Indonesia. **Biodiversitas**, 21(9): 4100-4106.
- Elías, D. J., Fuentes-Montejo, C. E., Quintana, Y. & Barrientos, C. A. 2022. Non-native freshwater fishes in Guatemala, northern Central America: introduction sources, distribution, history, and conservation consequences. **Neotropical Biology and Conservation**, 17(1): 59-85.
- Elton, C. S. 1958. **The ecology of invasions by animals and plants**. Springer, New York, 181 p.
- Escalera-Vázquez, L. H., García-López, J. E., Sosa-López, A., Calderón-Cortés, N. & Hinojosa-Garro, D. 2019. Impact of the non-native locariid fish *Pterygoplichthys pardalis* in native fish community on a seasonal tropical floodplain in Mexico. **Aquatic Ecosystem Health & Management**, 22(4): 462-472.
- Fonseca-Hernández, R. & Vargas-Alpizar, P. 2018. Estudio de factibilidad del aprovechamiento económico de una especie invasora *Hypostomus plecostomus* en el humedal de Caño Negro, Costa Rica. **Revista Ciencias Marinas y Costeras**, 10(2): 31-49.
- Franco, I. 2008. Calidad del agua del canal de Chiquimulilla dentro del complejo de humedales marino-costeros Iztapa, Escuintla-La Candelaria, Taxisco, Santa Rosa, Guatemala. **Master's Thesis**. Universidad de San Carlos de Guatemala, Guatemala, 116 p.
- Gaitán, C. A., Fuentes-Montejo, C. E., García, M. J. & Romero-Guevara, J. C. 2020. An update of the invasive *Pterygoplichthys* Gill, 1858 (Actinopterygii, Loricariidae) in Guatemala: new records and notes on its interactions with the local fauna. **Neotropical Biology and Conservation**, 15(3): 285-300.
- García-Fuentes, A., Castillo-Cabrera, F. J., Dávila-Pérez, C. V., Morales, A. S., Salazar-Mendías, C., Lendínez-Barriga, M. L., Torres-Cordero, J. A. & Ruiz-Valenzuela, L. 2014. Study of the vegetation in the Multiple Use Natural Reserve of Monterrico (Guatemala). **Plant Biosystems**, 148(6): 1064-1074.
- García-Llorente, M., Martín-López, B., González, J. A., Alcorlo, P., & Montes, C. 2008. Social perceptions of the impacts and benefits of invasive alien species: implications for management. **Biological conservation**, 141(12), 2969-2983.
- Graham, J. B. & Baird, T. A. 1982. The transition to air breathing in fishes. I. Environmental effects on the facultative air breathing of *Ancistrus chagresi* and *Hypostomus plecostomus* (Loricariidae). **Journal of Experimental Biology**, 96: 53-67.
- German, D. P. & Miles, R. D. 2010. Stable carbon and nitrogen incorporation in blood and fin tissue of the catfish *Pterygoplichthys disjunctivus* (Siluriformes, Loricariidae). **Environmental Biology of Fishes**, 89(2): 117-133.
- Hill, J. M., Jones, R. W., Hill, M. P. & Weyl, O. L. 2015. Comparisons of isotopic niche widths of some invasive and indigenous fauna in a South African river. **Freshwater Biology**, 60(5): 893-902.
- Hobbs, R. J. & Huenneke, L. F. 1992. Disturbance, diversity, and invasion: implications for conservation. **Conservation Biology**, 6(3): 324-337.
- Hoover, J. J., Killgore, J. K. & Cofrancesco, A. F. 2004. Suckermouth Catfishes: Threats to Aquatic Ecosystems of the United States?. **Aquatic Nuisance Species Research Program Bulletin**, 4(1): 1-9.
- Hoover, J. J. Murphy, C. E. & Killgore, J. 2014. Ecological Impacts of Suckermouth Catfishes (Loricariidae) in North America: A Conceptual Model. **Aquatic Nuisance Species Research Program Bulletin**, 14(1): 1-20.
- Hossain, M. Y., Vadas Jr, R. L., Ruiz-Carus, R., & Galib, S. M. (2018). Amazon sailfin catfish *Pterygoplichthys pardalis* (Loricariidae) in Bangladesh: a critical review of its invasive threat to native and endemic aquatic species. **Fishes**, 3(1), 14.
- Hussan, A., Sundaray, J. K., Mandal, R. N., Hoque, F., Das, A., Chakrabarti, P. P. & Adhikari, S. 2019. Invasion of non-indigenous suckermouth armored catfish of the genus *Pterygoplichthys* (Loricariidae) in the East Kolkata Wetlands: Stakeholders' perception. **Indian Journal of Fisheries**, 66(2): 29-42.

- International Union for Conservation of Nature (IUCN). 1999. **Report of the thirteenth global biodiversity forum, San Jose, Costa Rica**. International Union for the Conservation of Nature and Natural Resources, United Kingdom, 197 p.
- International Fund for Agricultural Development (IFAD). 2009. **Good practices in participatory mapping. A review prepared for the International Fund for Agricultural Development (IFAD)**, accessible at <https://www.ifad.org/documents/> (Accessed 20/01/2022).
- Juarez-Sanchez, D., Blake, J. G. & Hellgren, E. C. 2019. Variation in Neotropical river otter (*Lontra longicaudis*) diet: Effects of an invasive prey species. **PLoS ONE**, 14(10): 1-21.
- Krishnakumar, K., Raghavan, R., Prasad, G., Bijukumar, A., Sekharan, M., Pereira, B. & Ali, A. 2009. When pets become pests—exotic aquarium fishes and biological invasions in Kerala, India. **Current science**, 97(4): 474-476.
- LaBastille, A. 1983. Drastic Decline in Guatemala's Giant Pied-billed Grebe Population. **Environmental Conservation**, 10(4): 346–348.
- Lienart, G. D. H., Rodiles-Hernández, R. & Capps, K. A. 2013. Nesting Burrows and Behavior of Nonnative Catfishes (Siluriformes: Loricariidae) in the Usumacinta-Grijalva Watershed, Mexico. **The Southwestern Naturalist**, 58(2): 238-243.
- Lipták, B., Kouba, A., Patoka, J., Paunovic, M. & Prokop, P. 2023. Biological invasions and invasive species in freshwaters: perception of the general public. **Human Dimensions of Wildlife**: 1-16.
- López, J., Morales, A., Soberanis, H. & Ramírez, M. 2016. **Restauración Ecológica Participativa del Ecosistema de Manglar en la Reserva Natural de Usos Múltiples Monterrico**. Dirección General de Investigación, Universidad de San Carlos Guatemala, Guatemala, 146 p.
- López-Selva, M. 2022. **Zona marino-costera**. Cara Parens, Guatemala, 36 p.
- Lovell, S., Stone, S. & Fernandez, L. 2006. The Economic Impacts of Aquatic Invasive Species: A Review of the Literature. **Agricultural and Resource Economics Review**, 35(1): 195-208.
- McKinney, M. L. & Lockwood, J. L. 1999. Biotic Homogenization: A Few Winners Replacing Many Losers in the Next Mass Biotic homogenization: A few winners replacing many losers in the next mass extinction. **Trends in Ecology & Evolution**, 14: 450–453.
- McNeely, J. A. & Mainka, S. A. 2009. **La Conservación en una Nueva Era**. Gland, Suiza, 235 p.
- Mendoza, R., Contreras, S., Ramírez, C., Koleff, P., Alvarez, P. & Aguilar, V. 2007. Los peces diablo: Especies invasoras de alto impacto. **Biodiversitas**, 70: 1-5.
- Mendoza, R. A., Escalera, C. G., Contreras, S. B., Koleff, P. O., Ramírez, C. M., Álvarez, P. T., Arroyo, M. D. & Orbe-Mendoza, A. 2009. Chapter 5 Invasion of Armored Catfish in Infiernillo Reservoir, Michoacán-Guerrero, Mexico, Socio-economic Impact Analysis: A Tale of Two Invaders. Pp. 51-59. In: Commission for Environmental Cooperation (CEC). **Trinational Risk Assessment Guidelines for Aquatic Alien Invasive Species**. CEC, Canada, 100 p.
- Mendoza-Carranza, M., Hoeinghaus, D. J., Garcia, A. M. & Romero-Rodriguez, Á. 2010. Aquatic food webs in mangrove and seagrass habitats of Centla Wetland, a Biosphere Reserve in Southeastern Mexico. **Neotropical Ichthyology**, 8: 171-178.
- Moore, J. C., Berlow, E. L., Coleman, D. C., de Ruiter, P. C., Dong, Q., Hastings, A. ... & Wall, D. H. 2004. Detritus, trophic dynamics and biodiversity. **Ecology letters**, 7(7): 584-600.
- Moroni, F. T., Ortega, A. C., Moroni, R. B., Mayag, B., Souza de Jesus, R. & Lessi, E. 2015. Limitations in decision context for selection of amazonian armored catfish acari-bod (*Pterygoplichthys pardalis*) as candidate species for aquaculture. **International Journal of Fisheries and Aquaculture**, 7(8): 142-150.
- Muñoz, A., de la Cruz, D. & Josupeit, H. 2021. Cadena de valor de los productos de la pesca artesanal en Guatemala. **Circular de Pesca y Acuicultura de la FAO**, (1202): 1-100.
- Nico, L. G. 2010. Nocturnal and diurnal activity of armored suckermouth catfish (Loricariidae: *Pterygoplichthys*) associated with wintering

- Florida manatees (*Trichechus manatus latirostris*). **Neotropical Ichthyology**, 8(4): 893-898.
- Nico, L. G., Loftus, W. F. & Reid, J. P. 2009. Interactions between non-native armored suckermouth catfish (Loricariidae: *Pterygoplichthys*) and native Florida manatee (*Trichechus manatus latirostris*) in artesian springs. **Aquatic Invasions**, 4(3): 511-519.
- Nico, L. G. & Martin, T. R. 2001. The South American Suckermouth Armored Catfish, *Pterygoplichthys anisitsi* (Pisces: Loricariidae), in Texas, with comments on foreign fish introductions in the American Southwest. **Southwestern Naturalist**, 46(1): 98-104.
- Ochaeta, G. 2017. Estudio de Mercado del aprovechamiento de la especie pez bagre armado en el río La Pasión. **Fortalecimiento de la institucionalidad ambiental para la gobernanza y manejo de la pesca en el río La Pasión, Sayaxché, Petén Project**. FAO, Guatemala, 36 p.
- Orfinger, A. B. & Goodding, D. D. 2018. The global invasion of the suckermouth armored catfish genus *pterygoplichthys* (Siluriformes: Loricariidae): Annotated list of species, distributional summary, and assessment of impacts. **Zoological Studies**, 57(7): 1-16.
- Orfinger, A. B., Lai, Q. T. & Chabot, R. M. 2019. Effects of nonnative fishes on commercial seine fisheries: Evidence from a long-term data set. **Water**, 11(6): 2-11.
- Organización del Sector Pesquero y Acuicola del Istmo Centroamericano (OSPESCA). 2011. Encuesta Estructural de la Pesca Artesanal y la Acuicultura en Centroamérica 2009-2011. **Apoyo al Proceso de Integración de la Pesca y la Acuicultura Centroamericana Project**, OSPESCA, 76 p.
- Özdilek, S. 2007. Possible Threat for Middle East Inland Water: an Exotic and Invasive Species, *Pterygoplichthys disjunctivus* (Weber, 1991) in Asi River, Turkey (Pisces: Loricariidae). **Journal of Fisheries & Aquatic Sciences**, 24 (3-4): 303-306.
- Page, L. M. & Robins, R. H. 2006. Identification of sailfin catfishes (Teleostei: Loricariidae) in southeastern Asia. **The Raffles Bulletin of Zoology**, 54(2): 455-457.
- Pérez-Flores, J. & Pigenutt-Galindo, O. 2020. Injuries caused by the invasive armored suckermouth catfish *Pterygoplichthys* sp. in three captive Antillean manatees *Trichechus manatus manatus*. **Hidrobiológica**, 30(2): 173-176.
- Pound, K. L., Nowlin, W. H., Huffman, D. G. & Bonner, T. H. 2011. Trophic ecology of a nonnative population of suckermouth catfish (*Hypostomus plecostomus*) in a central Texas spring-fed stream. **Environmental Biology of Fishes**, 90(3): 277-285.
- Programa de las Naciones Unidas para el Desarrollo (PNUD)a. 2018. Estudio Técnico para el Área de Uso Múltiple Marino-Costera Hawaii. **Conservación y Uso Sostenible de la Biodiversidad en Áreas Protegidas Marino-Costeras (APM) Project**, MARN-CONAP/PNUD-GEF, 272 p.
- Programa de las Naciones Unidas para el Desarrollo (PNUD)b. 2018. Estudio Técnico para el Área de Uso Múltiple Marino-Costera Monterrico. **Conservación y Uso Sostenible de la Biodiversidad en Áreas Protegidas Marino-Costeras (APM) Project**, MARN-CONAP/PNUD-GEF, 243 p.
- Quintana, Y. & Barrientos, C. 2012. Invasiones recientes de peces exóticos en la RBM, implicaciones para peces nativos de Petén. **Memorias del segundo simposium internacional de investigación multidisciplinaria**. Santa Elena, Petén, 175-180.
- Quintana, Y., Keppeler, F. W. & Winemiller, K. O. 2023. Does invasion by armored catfish shift trophic ecology of native fishes? Evidence from stable isotope analysis. **Ecology**, e4024.
- Ricciardi, A., Hoopes, M. F., Marchetti, M. P. & Lockwood, J. L. 2013. Progress toward understanding the ecological impacts of nonnative species. **Ecological monographs**, 83(3): 263-282.
- Reaser, J. K., Meyerson, L. A., Cronk, Q., De Poorter, M., Eldrege, L. G., Green, E. ... & Vaiutu, L. 2007. Ecological and socioeconomic impacts of invasive alien species in island ecosystems. **Environmental Conservation**, 34(2): 98-111.
- Rubio, V. Y., Gibbs, M. A., Work, K. A. & Bryan, C. E. 2016. Abundant feces from an exotic armored catfish, *Pterygoplichthys disjunctivus* (Weber, 1991), create nutrient hotspots and promote algal growth in a Florida spring. **Aquatic Invasions**, 11(3): 337-350.

- Ruiz-Ordoñez, J. A. & Sigüenza de Micheo, R. R. 1999. Plan Maestro de la Reserva Natural de Usos Múltiples Monterrico. **Aprovechamiento sostenible de los recursos asociados a los manglares del Pacífico de Guatemala Project**, INAB-UICN-UE, 454 p.
- Sala, O. E., Chapin, F. S., Armesto, J. J., Berlow, E., Bloomfield, J., Dirzo, R. ... & Wall, D. H. 2000. Global biodiversity scenarios for the year 2100. **Science**, 287: 1770–1774.
- Sagarin, R. & Pauchard, A. 2010. Observational approaches in ecology open new ground in a changing world. **Frontiers in Ecology and the Environment**, 8: 379–386.
- Scott, S. E., Pray, C. L., Nowlin, W. H. & Zhang, Y. 2012. Effects of native and invasive species on stream ecosystem functioning. **Aquatic Sciences**, 74(4): 793–808.
- Seshagiri, B., Kumar, S. S., Pillai, B. R., Satyavati, C., Sravanti, Y., Rangacharyulu, P.V., Rathod, R. & Ratnaprakash, V. 2021. Suckermouth armored catfish (*Pterygoplichthys* spp.) menace in freshwater aquaculture and natural aquatic systems in Andhra Pradesh, India. **International Journal of Fisheries and Aquatic Studies**, 9(1): 375–384.
- Sim, J. & Waterfield, J. 2019. Focus group methodology: some ethical challenges. **Quality & Quantity**, 53(6): 3003–3022.
- Suresh, V. R., Ekka, A., Biswas, D. K., Sahu, S. K., Yousuf, A. & Das, S. 2019. Vermiculated sailfin catfish, *Pterygoplichthys disjunctivus* (Actinopterygii: Siluriformes: Loricariidae): Invasion, biology, and initial impacts in east Kolkata Wetlands, India. **Acta Ichthyologica et Piscatoria**, 49(3): 221–233.
- Solano, D. H. & Molina, A. 2011. Peces Diablo (Teleosteo: Siluriformes, Loricariidae) en la cuenca del río Reventazón, Costa Rica. **Biocenosis**, 25(1-2): 79–86.
- Stolbunov, I. A., Gusakova, V. A., Dienb, T. D. & Thi Hai Thanh, N. 2021. Food Spectrum, Trophic and Length-Weight Characteristics of Nonindigenous Suckermouth Armored Catfishes *Pterygoplichthys* spp. (Loricariidae) in Vietnam. **Inland Water Biology**, 14(5): 597–605.
- Sumanasinghe, H. P. W. & Amarasinghe, U. 2013. Population dynamics of accidentally introduced Amazon sailfin catfish, *Pterygoplichthys pardalis* (Siluriformes, Loricariidae) in Pologolla reservoir, Sri Lanka. **Sri Lanka Journal of Aquatic Sciences**, 18: 37–45.
- Tesfamichael, D., Pitcher, T. J. & Pauly, D. 2014. Assessing changes in fisheries using fishers' knowledge to generate long time series of catch rates: a case study from the Red Sea. **Ecology and Society**, 19(1): 18.
- U.S. Agency for International Development (USAID). 2020. Caracterización de Desembarques de Pesca Artesanal Estuarina, Reserva Natural De Usos Múltiples Monterrico (Septiembre 2019 – Enero 2020). **Biodiversidad de USAID Project, USAID**, 49 p.
- Van den Ende, O. 2014. Burrowing by Sailfin Catfish (*Pterygoplichthys* sp.): A Potential Cause of Erosion in Disturbed Environments. **Aquatic Nuisance Species Research Program Bulletin**, 14(1): 1–9.
- Velásquez, V. W. 2013. The Devil comes through water: invasion of the devil fish (Loricariidae) in the Grijalva river, Mexico. **Master's Thesis**. Universidad Autónoma de San Luis Potosí, México, 108 p.
- Wakida-Kusunoki, A. T., Ruiz-Carus, R. & Amador-del-Angel, E. 2007. Amazon sailfin catfish, *Pterygoplichthys pardalis* (Castelnau, 1855) (Loricariidae), another exotic species established in southeastern Mexico. **The Southwestern Naturalist**, 52(1): 141–144.
- Wakida-Kusunoki, A. T. & Amador del Angel, L. E. 2008. Nuevos registros de los plecos *Pterygoplichthys pardalis* (Castelnau 1855) y *P. disjunctivus* (Weber 1991) (Siluriformes: Loricariidae) en el Sureste de México. **Hidrobiológica**, 18(3): 251–256.
- Wijethunga, U. & Epa, U. 2008. Food resource partitioning of accidentally introduced, *Pterygoplichthys multiradiatus* (Sucker mouth catfish) with some of the alien and indigenous fish species in Sri Lanka. **National Symposium on Invasive Alien Species**, Sri Lanka Foundation Institute, Sri Lanka, 103–119.
- Wilcove, D. S., Rothstein, D., Dubow, J., Phillips, A. & Losos, E. 1998. Quantifying threats to imperiled species in the United States. **BioScience**, 48(8): 607–615.
- Weber, C. 1992. Revision du genre *Pterygoplichthys* sensu lato (Pisces, Siluriformes, Loricariidae). **Revue Française d'Aquariologie**, 19(1-2): 1–36.

- Wei, H., Copp, G. H., Vilizzi, L., Liu, F., Gu, D., Luo, D., Xu, M., Mu, X. & Hu, Y. 2017. The distribution, establishment and life-history traits of non-native sailfin catfishes *Pterygoplichthys* spp. in the Guangdong Province of China. **Aquatic Invasions**, 12(2): 241-249.
- Yamamoto, M. N. & Tagawa, A. W. 2000. **Hawai'i's native and exotic freshwater animals**. Mutual Publishing, Hawaii, 200 p.

Received: October 2022

Accepted: April 2023

Published: April 2023