Revista de Biología Tropical, ISSN: 2215-2075, Vol. 73: e20252701, enero-diciembre 2025 (Publicado Nov. 04, 2025)

REVISTA DE
Biología Tropical

https://doi.org/10.15517/mhtgnw19

Biology of an introduced species of Pleco fish (Siluriformes: Loricariidae) in a tropical freshwater ecosystem

Alexandre Tisseaux-Navarro[1*]; https://orcid.org/0000-0003-2634-2036

1. Universidad Nacional, Department of Physics, Heredia, 86-3000, Costa Rica; alexandre.tisseaux.navarro@una.cr (*Correspondence)

Received 14-XII-2024. Corrected 19-V-2025. Accepted 02-X-2025.

ABSTRACT

Introduction: Loricariid species have been introduced in many countries in the world, causing negative ecosystem effects wherever they invade. Species from this family, also known as Pleco, have been recorded from Lake Nicaragua for several years.
Objective: investigate basic aspects of the biology of Pleco in Lake Nicaragua, as an initial step to generating information to contribute to establishing management strategies for this species.
Methods: We assessed relative abundance and relative weight, Gonadosomatic index (GSI), Capture optimization Index, Catch composition by Net type, and environmental variables.
Results: 23 different species were captured, with the Pleco being the species represented in the greatest number of individuals and weight. Mature ovaries were observed throughout the year, except in July, GSI values were always high between September and June. High number of females were capture in September and October, as well as the period between March and May. The highest values of the capture optimization index were obtained in September and October. Additionally, the loricariids tended to prefer sites and times where water levels were deepest, potentially as a response to increased Río Frio's flow. This aligns with the strategy of conserving energy by seeking areas of reduced water current.
Conclusions: In the Southeast of Lake Nicaragua, increases in Pleco (*Hypostomus* sp.) populations have been matched corresponding declines in the capture of species of commercial interest. As a result, switching to target the Pleco in the area could provide an opportunity for local fishers to extract an abundant resource and avoid the extraction of local species, as long as viable markets are developed for Pleco.

Key words: invasive species, Loricariidae, Nicaragua, Gonadosomatic index, fishing.

RESUMEN

Biología de una especie introducida del pez Pleco (Siluriformes: Loricariidae) en un ecosistema de agua dulce tropical

Introducción: En todo el mundo, las especies de loricáridos introducidas han tenido un impacto negativo en los ecosistemas invadidos.
Objetivo: explorar la biología básica del Pleco (*Hypostomus* sp.) en el sureste del lago de Nicaragua como un primer paso para establecer estrategias de manejo.
Metodología: Evaluamos la abundancia, el peso, el índice gonadosomático (IGS), índice de optimización de la captura, la selectividad de las redes y factores ambientales.
Resultados: Capturamos 23 especies, siendo el Pleco el más común. Se observaron ovarios maduros durante todo el año, excepto en julio; los valores del IGS fueron constantemente altos entre septiembre y junio. Se capturaron muchas hembras en septiembre, octubre y de marzo a mayo. Los valores más altos de optimización de captura se

obtuvieron en septiembre y octubre. Los loricáridos preferían sitios y momentos con mayor profundidad, posiblemente debido al aumento del caudal del Río Frío.
Conclusiones: En el sureste del Lago de Nicaragua, el incremento de las poblaciones de Pleco ha coincidido con la disminución de especies de interés comercial. Enfocarse en la captura del Pleco podría beneficiar a los pescadores locales y preservar especies locales.

Palabras clave: especie invasora, Loricariidae, Nicaragua, índice gonadosomático, pesca.

INTRODUCTION

Until a recently, documented cases of invasive fish species around the world were confined to particular areas, since natural barriers were sufficient to prevent widespread dispersion. However, recently the introduction of non-native species into new ecosystems has become more frequent due to a range of anthropogenic causes (Lowe et al., 2000). Invasive species do not just challenge the conservation of biological diversity but can generate substantial additional ecological impacts (Gallardo et al., 2015; Simberloff et al., 2013). In fact, their impacts have the potential to become a major cause of extinction of fish around the world (Clavero & Garcia-Berthou, 2005).

In Nicaragua, the biology of introduced fish species, and their impact on ecosystems, has received little study. However, tilapia (*Oreochromis* spp.) were introduced into Lake of Nicaragua at least 35 years ago (McKaye et al., 1995) and recently been followed by the introduction of "Pleco". Pleco, belongs to the Loricariidae (Nelson, 2006). They are frequently displayed in aquariums (Krishnakumar et al., 2009), and it is believed that release by aquarists, or accidentally escape, has led to invasions in inland waters around the world (Mendoza et al., 2008).

Loricariids often have negative ecosystem effects; their armoured bodies and strong spines on the fins mean that few native species can feed on them (Armbruster & Page, 2006; Karunarathna et al., 2008; Nico, 2010; Ríos-Muñoz, 2015) leading to their hyper-abundant and the exclusion of native fish from their traditional niches. Ecosystem effects range from competition for resources (food and space), predation of eggs and larvae, alteration to the environment (erosion on the banks), and other harmful interactions, such as birds drowning when try to consume a Pleco (Bunkley-Williams et al., 1994; Gibbs et al., 2010; Karunarathna et al., 2008; Kolar et al., 2010; Nico et al., 2009). In addition, those captured by commercial fishers are typically released because they usually do not have commercial value, further accelerating population growth.

Introduction of a loricariid (*Pterygophlicthys* spp.) into the Infiernillo dam, Mexico, saw the decline of one of the most important freshwater fisheries in Mexico, with a progressive reduction in the capture of marketable species until *Pterygophlicthys* spp. Came to represent almost all of the catch by local fishers, leading to fishing becoming economically unfeasible. This left 3 600 fishers out of work and flowed on to impact a total of 46 000 people, including fish processors and the families of those depending on the fishing industry (Mendoza et al., 2008). Consequently, there are serious concerns about the damage that Pleco may be causing to the fisheries production and livelihoods of those depending on fishing in Lake Nicaragua. The risk is substantial. In the town of San Carlos, to the Southeast of Lake Nicaragua, employment options focus on livestock and agricultural activities, and in general these opportunities are scarce, so many turn to artisanal fishing as the main source of family income (Gadea, 2003). Reports from artisanal fishers in the area indicate that Pleco are already causing serious problems because of damage to nets, and many associate the appearance of Pleco with decreases of species of commercial interest (Härer et al., 2017; Maradiaga, 2009).

Artisanal fishing is critical to Nicaragua. In 2016, there were about 1 407 artisanal fishers in Nicaraguan inland waters registered with

(Instituto Nicaragüense de la Pesca y Acuicultura [INPESCA], 2018). This gives an idea of the number of families that depend on fishing in these systems. Added to this are many fishers who do not register with INPESCA, and people who fish for self-consumption. Indeed, given that Lake Nicaragua (including the San Juan River) is not only the largest freshwater system in Nicaragua but the largest in Central America, coupled with the current difficult economic situation in Nicaragua, means that a large part of the populations around the coast of the lake rely on fishing-related activities for survival.

Detailed knowledge of the fisheries biology of Pleco is a vital basis for the establishment of effective measures to manage this invasive species. Consequently, we investigated basic aspects of the biology of Pleco in Lake Nicaragua as an initial step to generating information to support the establishment of management strategies for the loricariids introduced in Lake Nicaragua. In particular, we assessed (a) relative abundance and relative weight, (b) Gonadosomatic index (GSI), (c) Capture optimization Index (COI), (d) Catch composition by Net type, and (e) environmental variables.

MATERIALS AND METHODS

Study area: The study area is located Southeast of Lake Nicaragua (11°7'00" N & 84°47'00" W), in the Department of Río San Juan. Sampling was conducted monthly for one year at two locations (Fig. 1). Site A is located 500 m from the coastline of the lake, where local fishers regularly set their nets. Site B is located near the coast (150 m offshore), an area not commonly used by artisanal fishers.

Fish capture: Fish were collected between July 2017 to June 2018 using a combination of three methods: mesh nets, traps and cast nets. A set of mesh nets (Table 1), together with a fish trap, were deployed simultaneously at both locations, on two nights per month, for approximately twelve and a half hours (from

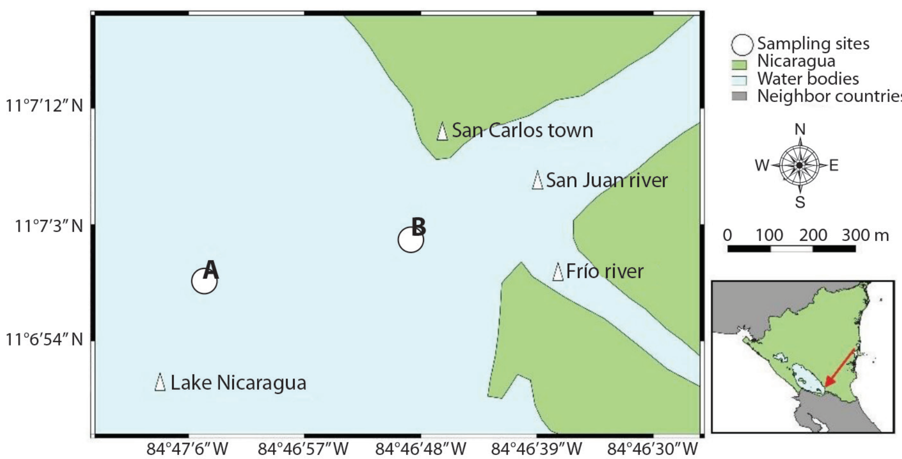

Fig. 1. Location of sampling sites. (Source: adapted from Sierra, 2012).

Table 1
Measures of gillnets used for catching fish in two sites Southeast of Lake Nicaragua between July 2017 and June 2018.

Net identification	Mesh size (in)	Length (m)	Height (m)	Yarn thickness	Legality
Net 1	2	17	1.2	0.4	Illegal
Net 2	4	33	1.2	0.4	Legal
Net 3	4.5	40	1.2	0.2	Illegal

4:45 pm to 5:15 am). The nets were anchored so they remained near the bottom. The same number of cast net samples were collected at the two sites. Organisms were identified to the lowest possible taxonomic level with the help of taxonomic keys and literature (Armbruster, 2004; Armbruster et al., 2015; Bussing, 2002; Hoover et al., 2004); organisms not belonging to the Loricariidae family were released. The species from Loricariidae family found in this drainage have been identified by Dr. Jonathan Armbruster (Matamoros et al., 2016) as *Hypostomus cf. niceforoi*. In the current study we only found one species of loricariid, so we prudently decided to use *Hypostomus* sp. to refer to the species.

Relative abundance and relative weight: The number of specimens per species was counted and the total weight (TW) of all the fish measured using an American Weight Scales digital scale model AWS-600-BLK, with an accuracy of 0.1 g. In addition, the total lengths (TL) of the Pleco were with a 0.5 mm precision ichthyometer. In this way it was possible to estimate monthly from the catches per unit of effort (CPUE), the relative abundance (RA %) and the relative weight (RW %) of the Pleco and the rest of the species captured. Relative abundance was determined by the following formula:

$$RA(\%) = \frac{number\ of\ organisms\ for\ the\ species}{total\ number\ of\ organisms} \times 100$$

Relative weight was determined by the following formula:

Relative weight was determined by the following formula:

$$RW(\%) = \frac{total\ weight\ of\ the\ organisms\ of\ the\ species}{total\ weight\ of\ the\ organisms} \times 100$$

Reproductive parameters: Gonads were extracted from each Pleco, sex was determined by macroscopic observation, and the proportion of males and females was calculated. The gonads of each female were weighed with an American Weigh Scales digital scale, model AWS-600-BLK, with an accuracy of 0.1 g. Gonadosomatic index (GSI) was calculated for each fish individually using the following formula:

$$GSI = \frac{GW}{TW} \times 100$$

Where: GSI is Gonadosomatic index, GW is gonad weight, TW is fish total weight.

Subsequently, the GSI values grouped monthly were compared through a Dunn test with the R program (R Core Team, 2018), to assess changes in average GSI over time.

Capture optimization Index: Three variables were considered in formulating a recommendation on the sampling time that would maximize Pleco capture success: (i) GSI, since the higher its value the greater the number of eggs and offspring, (ii) the number of females per male, since if few females are captured even if the GSI is high the total number of eggs will be low, so it is desired to capture large numbers of females and, (iii) the relative abundance of Pleco was assessed, in order to determine when Pleco captures could be maximized while minimizing the catch of native fish. An index was formulated to unite the three variables of interest. First, the value of these three variables in each month was normalized with the following formula:

$$zi = \frac{xi - min\,(x)}{(x)\ - min\,(x)}$$

Where: zi is normalized value of the variable in the month *i*, xi is value of the variable in the month *i*, min(x) and max(x) represent the minimum and maximum value of the variable across the entire year.

Once the variables were normalized the capture optimization index was obtained using the following formula:

$$COIi = \frac{NIGSi + NARi + NHMi}{3}$$

Where: COIi is value of the optimization capture index in the month *i*, NGSi is normalized GSI value in the month *i*, NARi is normalized value of the relative abundance in the month i for the site with greater abundance, NHMi is normalized value of the number of females per male in the month *i*.

Catch composition by Net type: to determine which net would capture more Pleco and fewer native fish, data were standardized to provide an estimate of weight relative to each net being 100 meters long, and a new relative weight was estimated for each of the nets used. Each native fish was classified as legal or illegal, legal catch refers to fish longer than minimum size established by INPESCA in continental waters Ministerio del Ambiente y los Recursos Naturales (MARENA) y el Instituto Nicaragüense de la Pesca y Acuicultura (INPESCA, 2013), regardless of the net where it was caught was legal or not (Table 1).

Environmental variables: The surface temperature and depth were recorded from a Garmin model Striker 4 echosounder, equipped with a CHIRP transducer (77/200 kHz). This was done every time the nets were placed and collected at various points along the net set and used to calculate average temperature and depth for each site per month.

Data analysis: A Kruskal-Wallis test was performed to compare the relative abundance and relative weight of fish between the two sampling sites. Gonadosomatic index values grouped by month were also compared with a Kruskal-Wallis test. Kruskal-Wallis tests were also performed to compare the normalized relative weight of native fish and Pleco between the three nets used. In addition, the relationships between the relative abundance at each site and the environmental variables were assessed using Spearman rank correlations. Analyzes were carried out using R software (R core team, 2018).

RESULTS

Relative abundance and relative weight: A total of 1 881 organisms were captured, from 23 different species belonging to 10 families, with Cichlidae being the most common family. The species represented by the greatest number of individuals was the Pleco, *Hypostomus* sp. (618 organisms), followed by the cichlid *Amphilophus citrinellus* (552 organisms) (Fig. 2).

There were significant differences ($p < 0.05$) in the relative abundance (RA) of *Hypostomus* sp. at both sites. The RA of this species at

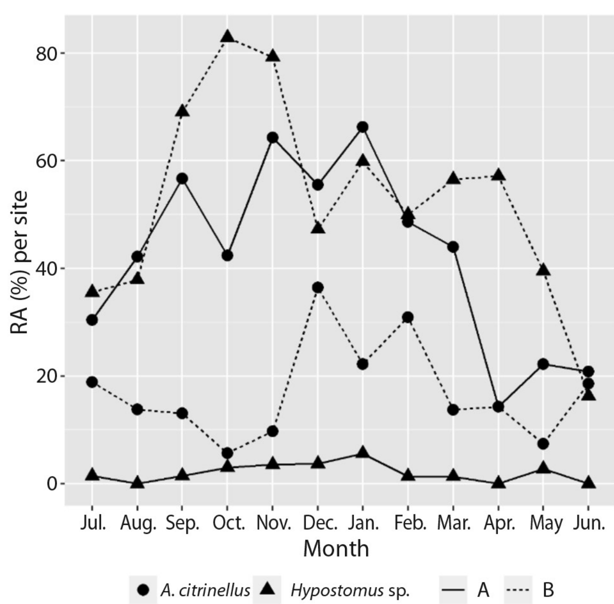

Fig. 2. Relative monthly abundance (between July 2017 and June 2018) of the species with the highest number of catches at the two sampling sites (Site A: continuous line, Site B: dashed line) in the Southeast of Lake Nicaragua.

the site near the coast (Site B) was significantly greater than at the site far from the coast (Site A) (Fig. 2). *Amphilophus citrinellus* occurred in the higher RA than *Hypostomus* sp. at Site A but the pattern was reversed at Site B. The relative abundance of the Pleco was high at Site B from September to April, with the highest values in September, October and November. The abundance of Pleco was very low at Site A, with none captured in several months and no more than 5 specimens were captured in a single month. At site B, at least 7 Pleco were captured per month, and more than 50 were caught in 8 of the 12 months sampled.

The relative weight (RW) of Pleco was high at site B (near the coast) and only failed to exceed 50 % of the total weight captured at the site in June (Fig. 3). From August to April RW varied between 78 and 94 %, with the highest values in September, October and November. There were significant differences in the RW of Pleco between the two sites ($p < 0.05$), with the RW at site A (far to the coast) lower in every month. At this site *Amphilophus citrinellus* had the highest RW over most of the year.

Reproductive parameters: Mature ovaries were observed throughout the year, except in July, and it was in this month that the lowest average value of GSI was obtained, while the highest values were obtained in May and June. Despite this, GSI values were always high between September and June (Fig. 4). Only significant differences were found between the values in July and those in December, January, March, April, and May.

The number of females and males varied according to the month (Table 2); from September to May more than 20 females were captured per month, but not in the months of June, July and August. The number of females for each male changed over the sampling year, high in September and October, as well as between March and May.

Capture optimization index: Due to low abundance of Pleco in site A, only site B values

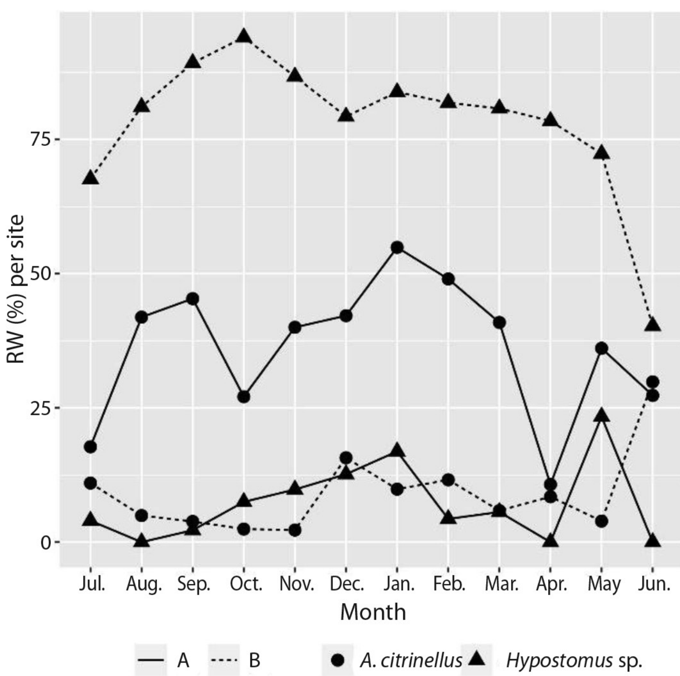

Fig. 3. Monthly relative weight (between July 2017 and June 2018) of the species with the highest number of catches at the two sampling sites (Site A: continuous line, Site B: dashed line) in the Southeast of Lake Nicaragua.

Table 2
Number of females, number of males and male:female ratio captured per month and Capture optimization index (COI) of *Hypostomus* sp. between July 2017 and June 2018 in the Southeast of Lake Nicaragua.

Month	N females	N males	Male: female	COI
July	12	21	1:0.57	0.12
August	13	20	1:0.65	0.23
September	43	16	1:2.69	0.90
October	42	17	1:2.47	0.92
November	38	29	1:1.31	0.68
December	39	26	1:1.50	0.57
January	39	35	1:1.11	0.55
February	25	31	1:0.81	0.38
March	51	28	1:1.82	0.68
April	34	18	1:1.89	0.69
May	23	10	1:2.30	0.74
June	2	5	1:0.40	0.07

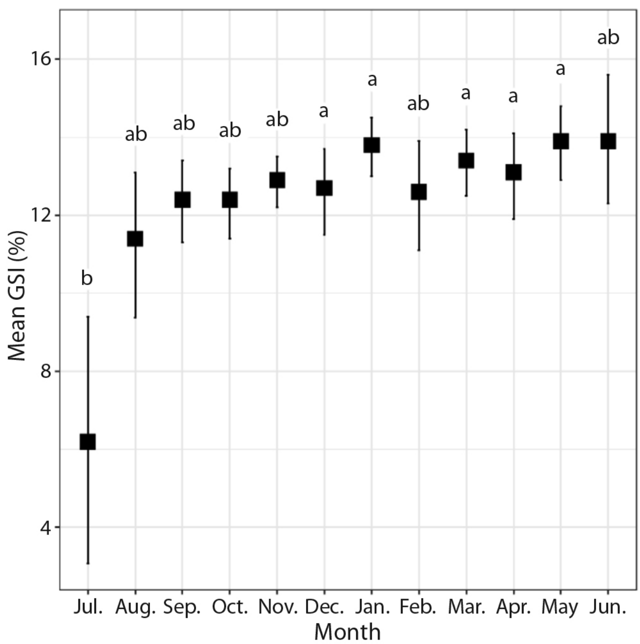

Fig. 4. Monthly average of the gonadosomatic index (GSI) of females of *Hypostomus sp.* captured between July 2017 and June 2018. Error bars represent the lower and upper percentiles (95 %). The letters represent the Dunn test result for comparison of means. Months that share one or both letters do not show significant differences from each other in the value of the GSI.

were considered for this analysis. The highest values of the capture optimization index were obtained in September and October. In addition, in November, March, April and May the value of the COI be high (greater than 0.67). The rest of the months the COI was low, less than 0.6, especially in June, July, and August (Table 2).

Catch composition by Net type: The percentage of legal catch was significative higher in Net 2 (Fig. 5A), and all the catch by Net 2 in site

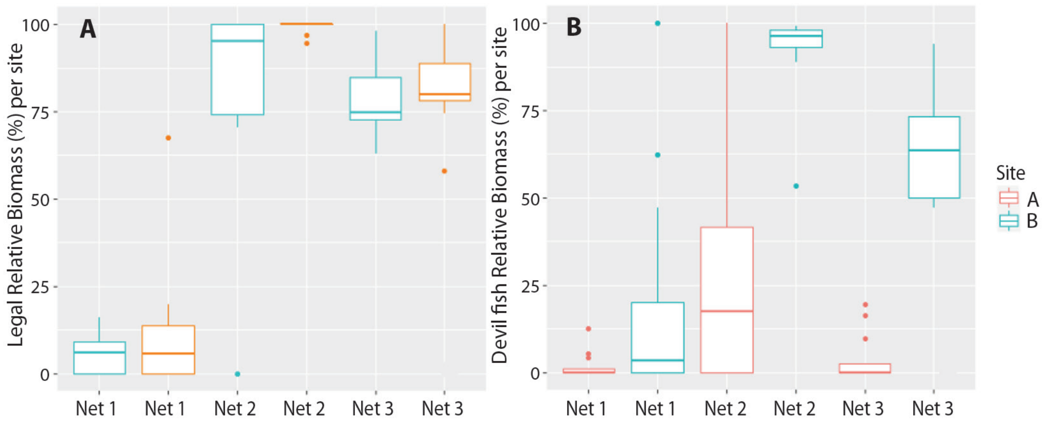

Fig. 5. Boxplots of relative weight (between July 2017 and June 2018) of legal catch (at the left) and Pleco (at the right) at the two sampling sites in the Southeast of Lake Nicaragua using three kinds of nets.

B was legal in almost every month sampled. Net 3 also captured a high percentage of legal fish. In addition, the relative weight of Pleco was significantly higher in Net 2 and Net 3 than Net 1, and high in Net 2 in site B (Fig. 5B).

Environmental variables: The surface temperature (Fig. 6) showed similar behaviors at both sites, however, there were differences between months. The temperature was low in July, rose from August to November, and decreased again between December and February, with lowest values in January. Between March and June, it was very high, with May having the highest temperature of the whole year.

Fig. 6 shows the distribution of temperature and water level in the two locations studied. Although the temperature was similar at both sites, water levels varied between them.

The loricariids tended to prefer sites and at times where water level was deepest, with a positive relationship between abundance and water depth ($rs = 0.93$, $p < 0.05$). No relationship was found between the abundance of this species and surface temperature ($rs = -0.25$, $p > 0.05$).

DISCUSSION

Currently, it is likely that artisanal fishers avoid catching Pleco due to the time required to remove them from nets, the damage they cause to the gear, and their lack of commercial value fishers. When a non-native fish has little or no socioeconomic value, it can acquire the status of a plague (Britton et al., 2011), this is certainly true in the case of the Pleco in the Southeast of Lake Nicaragua.

Pleco in Lake Nicaragua seems to have a strong positive relationship with sites and times of greater water depth (Fig. 2, Fig. 5). Víquez (2017) used a cast net in a rapid evaluation of six sites in the Northeast Caribbean Ramsar Wetland in Costa Rica, which fluvially connects with the Lake Nicaragua, and found loricariids in only two sites, but in low abundances (8 % and 19 %). However, since no gillnets were used in that study, the relative abundance of loricariids cannot be directly compared. Nonetheless, both studies suggest that Pleco may favor specific habitats.

The abundance of species of the genus *Hypostomus* has been linked to sites of greater depth (Gerhard et al., 2004; Jayaratne & Surasinghe, 2010; Mazzoni et al., 2009). Fialho et al. (2008), on the Meia Ponte River in Brazil, found a greater number of specimens of the genus *Hypostomus* in periods when the water level and temperature were highest. These authors argue that changes in the abundance of *Hypostomus* may be due to variations in the

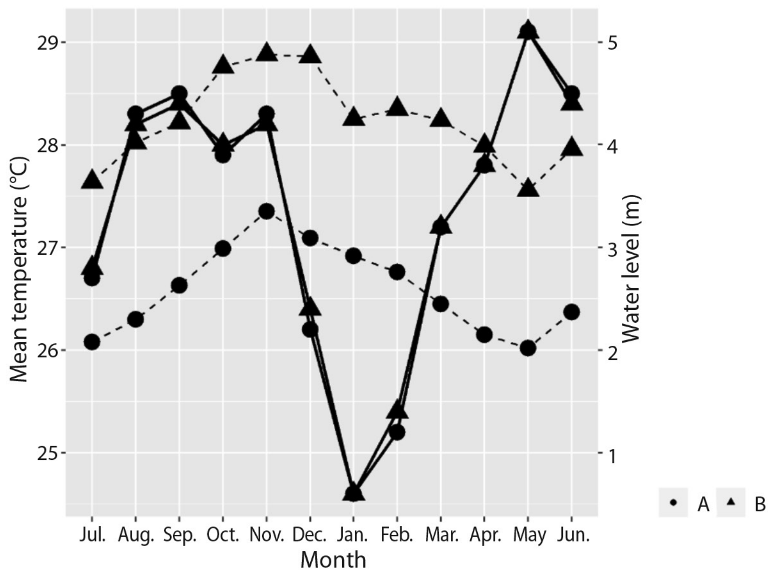

Fig. 6. Surface temperature and average water level at two sites (A and B) in the Southeast of Lake Nicaragua measured with a Garmin echosounder, from July 2017 to June 2018. The thick continuous line corresponds to surface temperature data in degrees Celsius and the dashed line to water level in meters. The geometric figures differentiate from the sites.

environment, due to the increase in water speed and volume. In Southern Lake Nicaragua this could influence, with the increase of the flow of Frío River (Fig. 1), the Pleco have to spend more energy, so it may seek for nearby deep areas in Lake Nicaragua where the water speed and energy consumption is lower.

However, *Hypostomus* species do not always show a preference for deep habitats. Teresa & Casatti (2013), when evaluating two species of this genus, found that they did not show a clear preference for these types of environments, and instead could opt for shallow environments, suggesting that water velocity could be significant factor in habitat selection. Therefore, it is important that, in the case of the species of the genus *Hypostomus*, evaluated in Lake Nicaragua, there was found a positive correlation with depth, and a greater abundance during periods and at the site where the water level was greater. In addition, it has been found that some species of the genus *Hypostomus* (Celestino et al., 2017) are more active during the night and when the flow increases. These data are of great importance for the effective control of *Hypostomus* in Lake Nicaragua, since, as activity increases, they move more and, therefore, make them more vulnerable to encountering gill nets. This is likely the case in the present work, where gillnets were used during the night and large numbers of specimens of the invasive species were captured.

Cook-Hildreth et al. (2016), observed that in loricariids species the non-reproductive period was less evident and shorter in the introduced habitat than in their native habitat. These authors argue that the photoperiod is the main proximate factor in the reproduction of these species, the non-reproductive period (quiescence) being less and less evident in places where the variation of the photoperiod is less. This, integrated with what was observed in this work (Fig. 4), could support the idea that the quiescence period will decrease as the photoperiod variation decreases, and that in areas where the duration of the day is relatively constant throughout the year, the quiescence period for these loricariid species may not be evident.

Rueda-Jasso et al. (2013) found mature gonads of *Pterygoplichthys disjunctivus* throughout the year at the Infiernillo dam in Mexico.

The authors argued that in the Infiernillo dam the population of *P. disjunctivus* has found a situation in which the lack of predators and a surplus of food is conducive to an extended reproductive period. Additionally, Gibbs et al. (2017) showed that when *P. disjunctivus* is introduced in a place where the environmental conditions are stable and there is great availability of food, as the years progress, its period of reproductive inactivity will become less and less evident as in Florida (United States).

The results of GSI showed mature females throughout the year in lake Nicaragua. This may relate to the fact that Lake Nicaragua also has stable conditions because it is in a tropical zone, perhaps even more stable than in Florida (Gibbs et al., 2017), with few variations in environmental conditions during the year. Therefore, is prudent to complement the GSI value with more information to determine a period in which capture efforts should be concentrated in the area, such as the number of females that are captured each month. This can help the selection of a capture period that helps reduce reproductive output. So, the months of September, October, March, and April, where we have high values of GSI, as well as large numbers of females, would be important months to concentrate capture and decrease the future recruitment of the species. However, considering the months when the impact to native species would be reduced, it seems that, based on the COI number (Table 2), the best months to concentrate catching efforts in Nicaragua, would be the months with the highest rainfall: September and October.

When making decisions for the management of a non-native species, there are three possible actions: (i) act quickly to find it, (ii) eradicate it or (iii) control it (Britton et al., 2011). In the case of Pleco in Nicaragua, the first option is no longer viable because it has been more than ten years since they were first recorded. In terms of eradicating it, there are few reported cases where this method has been successful, and these are restricted to small and closed water bodies and invariably requiring substantial expenditure of funds (Britton et al., 2011; Kolar et al., 2010). As a result of the unviability of action (i) and the unlikelihood of success from action (ii), control methods try to minimize the impact and dispersion of the invasive fish seems more viable in this case.

Selective removal is a common method for managing invasive species, but finding gear that effectively targets non-native fish without harming native species remains challenging (Britton et al., 2011; Kolar et al., 2010). Some successful cases involve systems with few or no native species, such as the use of gillnets to control introduced trout in parts of the U.S. and Canada (Knapp & Matthews, 1998; Parker et al., 2001). In contrast, Lake Nicaragua supports 23 fish species, of which only Tilapia and Pleco are non-native, increasing the risk of bycatch and complicating selective removal.

Nevertheless, other studies suggest selective removal can work even in diverse systems. For instance, Lozano-Vilano et al. (2006) eliminated an invasive African cichlid using traps in the San José del Anteojo Well, Mexico. Native species had declined dramatically, but after removing the invasive, they were successfully reintroduced from nearby rivers. However, San José del Anteojo Well covers less than 1 km², whereas Lake Nicaragua spans 8 264 km² and contains numerous inflowing rivers, making management far more complex in scale and logistics.

Although this study was not designed to compare fishing gear, gillnets used in deep areas (Net 2) showed promising results, capturing large numbers of adult Plecos (Fig. 5) with limited bycatch and within legal mesh size (MARENA & INPESCA, 2013). This aligns with the findings of Wickramaratne et al. (2020), who studied gillnet selectivity for *P. disjunctivus* in Sri Lanka, concluding that smaller mesh nets were ineffective for juveniles. In our case, juveniles may occupy cryptic habitats like burrows or submerged debris along lake and river shores, making them less accessible to nets. Gibbs et al. (2013) also observed this pattern in Florida, linking it to predation pressure on smaller individuals.

Catch composition by Net type in other countries where introduced loricariids species have been found, the approach has been to encourage their consumption, and / or to look for ways to take advantage of the species. This is the case in Mexico, where it has been used in the manufacture of meal for lamb and tilapia feed, as well as possible use as a crop fertilizer (Escalera-Gallardo et al., 2012; Filigrana, 2016; Monares-Gallardo et al., 2012; Tejeda-Arroyo et al., 2015).

In the Southeast of Lake Nicaragua, as well as most fisheries worldwide, the introduction of invasive species has resulted in substantial declines in catches of species of commercial interest. In the Southeast of this lake, species such as Garfish (*Atractosteus tropicus*), Snook (*Centropomus* spp.) and Rainbow Bass (*Parachromis dovii*), that were once of great commercial importance and frequently caught by fishers, are now rarely captured.

The biological findings of this study suggest that Pleco in Lake Nicaragua reproduce throughout the year, but with peaks of reproductive activity and female abundance during specific months, particularly September, October, March, and April. This information is key for designing targeted control strategies aimed at reducing recruitment, especially if capture efforts are aligned with the rainy season (September-October), when impacts on native species may also be minimized. While this study did not aim to evaluate fishing gear effectiveness per se, the observed success of legal gillnets in deeper areas provides useful insights into the feasibility of selective removal. As a result, switching to target the loricariid species in the area could provide an opportunity for local fishers to extract an abundant resource (Fig. 3) and avoid the extraction of local species, as long as viable markets are developed. This study provides a basis for local governments, and managers from countries in the area to start establishing policies to control this invasive species.

Ethical statement: The author declares that he agrees with this publication; that there is no conflict of interest of any kind; and that he followed all pertinent ethical and legal procedures and requirements. All financial sources are fully and clearly stated in the acknowledgements section. A signed document has been filed in the journal archives.

ACKNOWLEDGMENTS

I extend my gratitude to Juan Bosco Mendoza and INPESCA for their invaluable assistance and collaboration in data collection and organization. Thanks to Rosa Soto and Marcus Sheaves for their insightful advice on data analysis and manuscript preparation. I also thank Keylin Gómez for her help with reviewing and editing the final version of the manuscript. I wish to acknowledge the Guadamuz family members and Moisés Arana for their crucial support in the field during data collection efforts. We thank IDEA WILD for providing equipment that contributed to this research.

REFERENCES

Armbruster, J. W. (2004). Phylogenetic relationships of the suckermouth armoured catfishes (Loricariidae) with emphasis on the Hypostominae and the Ancistrinae. *Zoological Journal of the Linnean Society*, *141*(1), 1–80. http://dx.doi.org/10.1111/j.1096-3642.2004.00109.x

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), 401–409. https://doi.org/10.1590/s1679-62252006000400003

Armbruster, J. W., Werneke, D. C., & Tan, M. (2015). Three new species of saddled loricariid catfishes, and a review of Hemiancistrus, Peckoltia, and allied genera (Siluriformes). *Zookeys*, *480*, 97–123. https://doi.org/10.3897/zookeys.480.6540

Britton, J. R., Gozlan, R. E., & Copp, G. H. (2011). Managing non-native fish in the environment. *Fish and Fisheries, 12*(2), 256–274. https://doi.org/10.1111/j.1467-2979.2010.00390.x

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*, 90–94.

Bussing, W. A. (2002). *Peces de las aguas continentales de Costa Rica*. Editorial de la Universidad de Costa Rica.

Celestino, L. F., Sanz-Ronda, F. J., Kashiwaqui, E. A. L., Celestino, E. F., Makrakis, M. C., & Makrakis, S. (2017). Daily movement behavior of two Neotropical armored catfish species (Ancistrus aff. cirrhosus Valenciennes, 1836 and *Hypostomus* ancistroides Ihering, 1911) at a road-stream crossing culvert. *Journal of Applied Ichthyology*, *33*(6), 1092–1099. https://doi.org/10.1111/jai.13446

Clavero, M., & Garcia-Berthou, E. (2005). Invasive species are a leading cause of animal extinctions. *Trends in Ecology and Evolution*, *20*(3), 110. http://dx.doi.org/10.1016/j.tree.2005.01.003

Cook-Hildreth, S. L., Bonner, T. H., & Huffman, D. G. (2016). Female reproductive biology of an exotic suckermouth armored catfish (Loricariidae) in the San Marcos River, Hays Co., Texas, with observations on environmental triggers. *BioInvasions Records*, *5*(3), 173–183. https://doi.org/10.3391/bir.2016.5.3.09

Escalera-Gallardo, C., Arroyo-Damián, M., Moncayo-Estrada, R., & Zarazúa, J. A. (2012). Pesquería sustentable y desarrollo local. Uso y aprovechamiento potencial del pez diablo. En L. P. Carrete-Lucero, M. R. Cota-Yañéz, M. L. Martín-Carbajal, J. Martínez-Aparicio, M. C. Mejía-Argote, A. Ortega-Hernández, & A. Solari-Vicente (Eds.), *Desarrollo local y empresa* (pp. 39–58). Universidad de Guanajuato.

Fialho, A. P., Oliveira, L. G., Tejerina-Garro, F. L., & De Mérona, B. (2008). Fish-habitat relationship in a tropical river under anthropogenic influences. *Hydrobiologia*, *598*(1), 315–324. https://doi.org/10.1007/s10750-007-9165-3

Filigrana, G. (2016). *Uso de la harina de pez diablo (Pterygoplichthys* spp*) en la alimentación de tilapia nilótica (Oreochromis niloticus)* [Tesis de maestría, El Colegio de la Frontera Sur]. Repositorio Institucional ECOSUR. https://ecosur.repositorioinstitucional.mx/jspui/bitstream/1017/1424/1/100000057617_documento.pdf

Gadea, V. (2003). *Estudio Biológico pesquero de las especies comerciales en la zona de San Carlos y Solentiname. Río San Juan, Nicaragua*. Asociación de Cooperación Rural en África y América Latina (ACRA).

Gallardo, B., Clavero, M., Sánchez, M. I., & Vilà, M. (2015). Global ecological impacts of invasive species in aquatic ecosystems. *Global Change Biology*, *22*(1), 151–163. https://doi.org/10.1111/gcb.13004

Gerhard, P., Moraes, R., & Molander, S. (2004). Stream fish communities and their associations to habitat variables in a rain forest reserve in southeastern Brazil. *Environmental Biology of Fishes*, *71*(4), 321–340. https://doi.org/10.1007/s10641-004-1260-y

Gibbs, M., Futral, T., Mallinger, M., Martin, D., & Ross, M. (2010). Disturbance of the Florida Manatee by an invasive catfish. *Southeastern Naturalist*, *9*(4), 635–648. https://doi.org/10.1656/058.009.0401

Gibbs, M., Watson, P., Johnson-Sapp, K., & Lind, C. (2017). Reproduction revisited - a decade of changes in the reproductive strategies of an invasive catfish, *Pterygoplichthys disjunctivus* (Weber, 1991), in Volusia Blue Spring, Florida. *Aquatic Invasions*, *12*(2), 225–239. https://doi.org/10.3391/ai.2017.12.2.10

Gibbs, M. A., Kurth, B. N., & Bridges, C. D. (2013). Age and growth of the loricariid catfish *Pterygoplichthys disjunctivus* in Volusia Blue Spring, Florida. *Aquatic Invasions*, *8*(2), 207–218. http://dx.doi.org/10.3391/ai.2013.8.2.08

Härer, A., Torres-Dowdall, J., & Meyer, A. (2017). The imperiled fish fauna in the Nicaragua Canal zone. *Conservation Biology*, *31*(1), 86–95. https://doi.org/10.1111/cobi.12768

Hoover, J. J., Killgore, K. J., & Cofrancesco, A. F. (2004). Suckermouth catfishes: threats to aquatic ecosystems of the United States? *Aquatic Nuisance Species Research Program*, *4*(1), 1–10.

Instituto Nicaragüense de la Pesca y Acuicultura. (2018). Anuario pesquero y acuícola de Nicaragua. http://www.inpesca.gob.ni/images/Anuarios%20Pesqueros/Anuario%20Pesquero%20y%20Acuicola%202018.pdf

Jayaratne, R., & Surasinghe, T. (2010). General ecology and habitat selectivity of fresh water fishes of the Rawan Oya, Kandy, Sri Lanka. *Sabaragamuwa University Journal*, *9*(1), 11–43. https://doi.org/10.4038/suslj.v9i1.3732

Karunarathna, D. M. S. S., Amarasinghe, A. T., & Ekanayake, E. M. K. B. (2008). Observed predation on a suckermouth catfish (*Hypostomus* plecostomus) by a water monitor (Varanus salvator) in Bellanwila-Attidiya Sanctuary. *Biawak*, *2*(1), 37–39.

Knapp, R. A., & Matthews, K. R. (1998). Eradication of nonnative fish by gill netting from a small mountain lake in California. *Restoration Ecology*, *6*(2), 207–213. https://doi.org/10.1046/j.1526-100X.1998.06212.x

Kolar, C. S., Courtenay, W. R., & Nico, L. G. (2010). Managing undesired and invading species. En W. A, Hubert, & M. C. Quist (Eds.), *Inland fisheries management in North America* (3th ed., pp. 213–259). American Fisheries Society.

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*, *25*(4), 474–476.

Lowe, S., Browne, M., Boudjelas, S., & De Poorter, M. (2000). *100 of the world's worst invasive alien species: A* *selection from the global invasive species database*. The Invasive Species Specialist Group (ISSG).

Lozano-Vilano, M. L., Contreras-Balderas, A. J., & García-Ramírez, M. E. (2006). Eradication of spotted jewelfish, *Hemichromis guttatus*, from Poza San José Del Anteojo, Cuatro CiéNegas Bolsón, Coahuila, Mexico. *Southwestern Naturalist*, *51*(4), 553–555. https://doi.org/10.1894/0038-4909(2006)51[553:EOSJHG]2.0.CO;2

Maradiaga, J. E. (2009). *Alerta temprana y detección precoz del pez diablo en lago Cocibolca. (Informe de Resultados)*. Instituto Nicaragüense de la Pesca y Acuicultura (INPESCA), Ministerio del Ambiente y Recursos Naturales (MARENA).

Ministerio del Ambiente y de los Recursos Naturales, & Instituto Nicaragüense de la Pesca y Acuicultura. (2013, 13 de noviembre). *Acuerdo interinstitucional AC-INT N°001.11.13*. Gobierno de la República de Nicaragua. http://www.inpesca.gob.ni/images/Acuerdos%20Interinstitucionales/Acuerdo%20Interinstitucional%20AC-INT%20%20No.%20001.11.13.pdf

Matamoros, W. A., Mcmahan, C. D., Mejia, C. R., House, P. H., Armbruster, J. W., & Chakrabarty, P. (2016). First record of the non-native suckermouth armored catfish *Hypostomus cf. niceforoi* (Fowler 1943) (Siluriformes: Loricariidae) from Central America. *Occasional Papers of the Museum of Natural Science, Louisiana State University*, *87*(1), 1–12.

Mazzoni, R., de Souza Lemos, F., & Iglesias-Rios, R. (2009). Spatial variation of five co-existing siluriformes in an atlantic rain forest drainage. *Brazilian Archives of Biology and Technology*, *52*(1), 127–133. https://doi.org/10.1590/S1516-89132009000100017

McKaye, K. R., Ryan, J. D., Stauffer, J. R., Lopez Perez, L. J., Vega, G. I., & Van Den Berghe, E. P. (1995). African tilapia in Lake Nicaragua - Ecosystem in transition. *Bioscience*, *45*(6), 406–411. https://doi.org/10.2307/1312721

Mendoza, J., Sánchez, R., Barnutti, R., (2008). *Diagnóstico de la presencia del* Hypostomus plecostomus *(Pez Diablo) basado en la literatura consultada y en la participación de personas involucrados en la actividad pesquera del Gran Lago de Nicaragua*. Instituto Nicaragüense de la Pesca y Acuicultura (INPESCA), Centro de Investigaciones Pesqueras (CIPA).

Monares-Gallardo, I., Ceja-Torres, L. F., Escalera-Gallardo, C., Vázquez-Gálvez, G., & Ochoa-Estrada, S. (2012). Tamaño de partícula y tiempo de aplicación presiembra de harina de pescado (*Plecostomus* spp.) en producción de calabacita. *Terra Latinoamericana*, *30*(2), 147–155.

Nelson, J. S. (2006). *Fishes of the World* (4th ed). John Wiley & Sons.

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. https://doi.org/10.1590/S1679-62252010005000014

Nico, L. G., Jelks, H. L., & Tuten, T. (2009). Non-native suckermouth armored catfishes in Florida: description of nest borrows and burrow colonies with assessment of shoreline conditions. *Aquatic Nuisamce Species Research Program*, *9*(1), 1–30.

Parker, B. R., Schindler, D. W., Donald, D. B., & Anderson, R. S. (2001). The effects of stocking and removal of a nonnative salmonid on the plankton of an alpine lake. *Ecosystems*, *4*, 334–345. https://doi.org/10.1007/s10021-001-0015-2

R Core Team. (2018). *R: A language and environment for statistical computing* [Software]. R Foundation for Statistical Computing. Vienna, Austria.

Ríos-Muñoz, C. A. (2015). Depredación de pez diablo (Loricariidae : *Pterygoplichthys*) por el cormorán oliváceo (*Phalacrocorax brasilianus*) en Villahermosa, Tabasco, México. *Huitzil Revista Mexicana de Ornitología*, *16*(2), 62–65. http://dx.doi.org/10.28947/hrmo.2015.16.2.68

Rueda-Jasso, R. A., Campos-Mendoza, A., Arreguín-Sánchez, F., Díaz-Pardo, E., & Martínez-Palacios, C. A. (2013). The biological and reproductive parameters of the invasive armored catfish *Pterygoplichthys disjunctivus* from Adolfo López Mateos El Infiernillo Reservoir, Michoacán-Guerrero, Mexico. *Revista Mexicana de Biodiversidad*, *84*(1), 318–326. https://doi.org/10.7550/rmb.26091

Sierra, J. C. (2012). *Nicaragua: División administrativa, cuencas hidrográficas, precipitaciones, hidrognosia, uso del suelo, pendientes, etc*. http://juanchosierrar.blogspot.com/2012/10/descarga-shapefiles-de-nicaragua.html.

Simberloff, D., Martin, J. L., Genovesi, P., Maris, V., Wardle, D. A., Aronson, J., Courchamp, F., Galil, B., García-Berthou, E., Pascal, M., Pyšek, P., Sousa, R., Tabacchi, E., & Vilà, M. (2013). Impacts of biological invasions: What's what and the way forward. *Trends in Ecology and Evolution*, *28*(1), 58–66. https://doi.org/10.1016/j.tree.2012.07.013

Tejeda-Arroyo, E., Cipriano-Salazar, M., Camacho-Díaz, L. M., Salem, A. Z. M., Kholif, A. E., Elghandour, M. M. M. Y., DiLorenzo, N., & Cruz-Lagunas, B. (2015). Diet inclusion of devil fish (*Plecostomus* spp.) silage and its impacts on ruminal fermentation and growth performance of growing lambs in hot regions of Mexico. *Tropical Animal Health and Production*, *47*, 861–866. https://doi.org/10.1007/s11250-015-0800-0

Teresa, F. B., & Casatti, L. (2013). Development of habitat suitability criteria for Neotropical stream fishes

Revista de Biología Tropical, ISSN: 2215-2075 Vol. 73: e20252701, enero-diciembre 2025 (Publicado Nov. 04, 2025)

and an assessment of their transferability to streams with different conservation status. *Neotropical Ichthyology*, *11*(2), 395–402. https://doi.org/10.1590/S1679-62252013005000009

Víquez, R. (2017). *Abundancia relativa de la especie exótica pez diablo (Hemiancistrus aspidolepis), en el Humedal Ramsar Caribe Noreste, como complemento a la línea base elaborada durante mayo y junio de 2016, para disponer de información anual que consolide la toma de decisiones respecto a esta especie* [Informe técnico]. Sistema Nacional de Áreas de Conservación (SINAC), Ministerio del Ambiente y Energía (MINAE).

Wickramaratne, I. U., Wijenayake, H. K., & Jayakody, D. S. (2020). gill net selectivity of vermiculated sailfin catfish *Pterygoplichthys disjunctivus* (Weber 1991; Family Loricariidae) and coexisting fish species in Victoria and Kalawewa reservoirs in Sri Lanka. *Journal of Technology and Value Addition*, *2*(2), 65–84.