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Effects of Nonnative Fishes on Commercial Seine Fisheries: Evidence from a Long-Term Data Set

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Abstract: Dozens of introduced exotic freshwater fish species inhabit the state of Florida. These nonnative fishes interact with freshwater commercial fisheries in a variety of ways, influencing catch abundance, composition, and revenue. Using a 22-year data set collected from a commercial haul seine fishery, we aimed to explore the dynamics of yield and revenue in relation to nonnative fishes, with emphasis on the suckermouth armored catfishes (*Pterygoplichthys* spp.). Using profit index metrics and the inverse Simpson's diversity index, we found that non-native tilapia (*Oreochromis* spp.) and brown hoplo (*Hoplosternum littorale*) provided economic benefits while suckermouth armored catfishes seemed to disrupt catch consistency and lower profit index values. To reduce the negative impacts of the suckermouth armored catfishes and subsequently exert pressure on their population, we suggest marketing these edible fishes for human and/or animal consumption.

Keywords: fisheries economics; invasive species; *Pterygoplichthys*; suckermouth armored catfishes; tilapia; diversity; profit index; Simpson's diversity

1. Introduction

Introductions of nonnative species can have impacts on the ecology, biodiversity, human and non-human health, and economies of the novel geographic range, e.g., [1] and papers therein. Such impacts may manifest as either positive, negative, or mixed outcomes [1]. Due to its island-like geography, large population, major ports of entry, and diversity of sub-tropical habitats, the state of Florida, USA has become a hotbed of both intentional and accidental species introductions [2,3]. Aquatic habitats are not immune, with at least 42 exotic fish species having been reported as established in Florida freshwater systems [4].

Among these are the South American suckermouth armored catfishes of the genus *Pterygoplichthys* (Siluriformes: Loricariidae). Members of this genus have been introduced to at least five continents and 21 countries, likely via the aquarium trade [5]. Multiple *Pterygoplichthys* species and their presumed hybrids are established throughout peninsular Florida and can form dense clusters in lakes and rivers. These fishes have been implicated in numerous negative ecological and economic impacts in their novel ranges, including, for example, competing with native fishes, inducing altered behaviors in endangered manatees (*Trichechus manatus*), causing erosion and sedimentation via nest excavation, and generating biogeochemical hotspots (e.g., [6–9]).

In Florida, members of the genus *Pterygoplichthys* are largely considered "trash" fish and unmarketable bycatch. Recent anecdotal reports from numerous commercial freshwater fishing operations have suggested a shift in catch composition and revenue in response to the presence of *Pterygoplichthys* spp. (A. Orfinger personal communications; e.g., Figure 1).

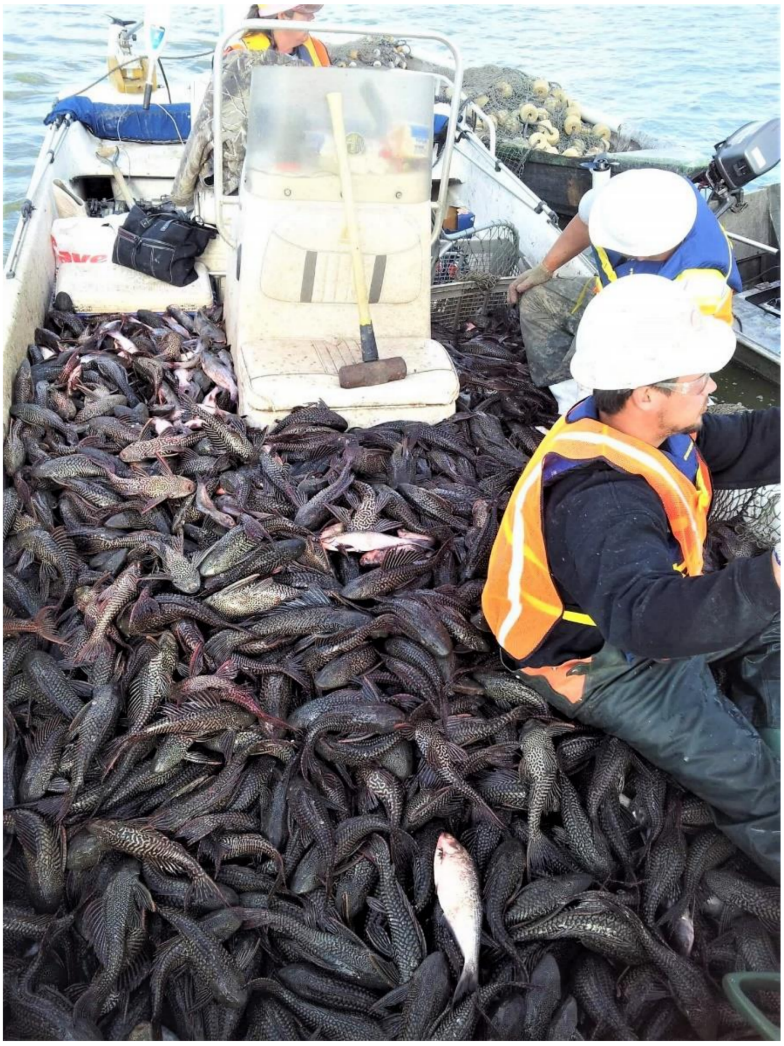

Figure 1. A representative catch illustrating the dominance of *Pterygoplichthys* spp. (dark fishes composing bulk of image) in some seining hauls. Photography by Taren Wadley.

In the present study, we aimed to explore the influence of *Pterygoplichthys* spp. and other nonnative fishes on catch composition and economic output using a long-term data set from a commercial haul seine fishery. Specifically, we anticipated that an increase in *Pterygoplichthys* spp. would correspond to a proportional decrease in marketable fish yield. Likewise, we also expected that another nonnative fish genus, tilapia, *Oreochromis* spp., would constitute the most profitable taxon. By investigating the interactions of *Pterygoplichthys* spp. and other nonnative fishes on freshwater net fisheries, we hope to provide insight into the relationships between native and nonnative fishes and the fishery operations that rely on these fish communities and make management recommendations, as appropriate.

2. Materials and Methods

2.1. Study Area

The seine fishery evaluated in this study operates out of Winter Haven, Polk County, FL, USA. Winter Haven is home to an extensive chain of natural lakes at the headwaters of the Peace River–Charlotte Harbor watershed (Figure 2). The commercial operation in question fishes in 14 of the 25 lakes. Most of the lakes (18/25) are considered impaired in terms of water quality [10]. Lake Hancock is one of the largest and the primary target of fishing activity (27°58′6.52′′ N, 81°50′20.12′′ W). Lake Hancock spans 1851 ha and reaches a maximum depth of 4.9 m, with an average depth of 1.2 m [11].

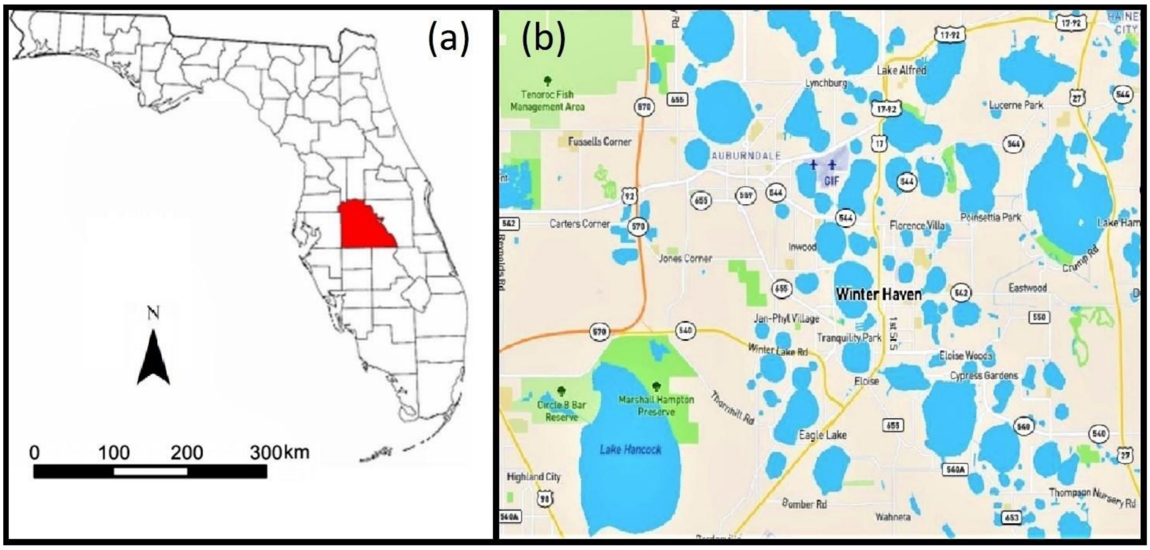

Figure 2. (**a**) Polk County (red), Florida, USA. (**b**) The Winter Haven chain of lakes where data were collected. The primary lake targeted, Lake Hancock, is in the southwest corner of the map.

2.2. Sampling and Data Set

The fishery-dependent data set was generated based on collection efforts between 1995 and 2018. Fishes were collected using a haul seine with dimensions 914.4 m length, 5.2 m depth, and 7.6 cm nylon mesh. Five variables were included in the analysis: (1) year, (2) lake representation (percent overall catch), (3) taxon, (4) estimated harvest (kg), and (5) market value of harvest (USD).

Data were not collected in 1996 and 2007, resulting in a total of 22 years of data collection. Lake representation is described as percent harvest from each of the 14 lakes in relation to the overall catch each year. Lake representation also likely shifted concerning fishing efforts to the most profitable lake to optimize the harvest each year. Average total fishing effort was 57 days/year. Taxa reported (n = 6) include tilapia (nonnative *Oreochromis* spp.), catfishes (native *Ictalurus* spp.), American shad (native *Alosa sapidissima*), gar (native *Lepisosteus* spp.), suckermouth armored catfishes (nonnative *Pterygoplichthys* spp.), and the brown hoplo (nonnative *Hoplosternum littorale*). Harvest was reported for species each year. A missing harvest value of brown hoplo in 2018 was treated as zero. Market value reported was the wholesale value at dock side. Tilapia and catfishes were heavily marketable. Shad and brown hoplo were partially marketable. Gar and suckermouth armored catfishes were not marketable.

2.3. Analysis

The suckermouth armored catfishes were first recorded in the fishery operation as bycatch in 1999. We compared the impact of the suckermouth armored catfishes to the yield and economic outcomes of the fishery operation. The data set from 1995 to 1998 and from 1999 to 2018 were referred to pre-invasion and post-invasion, respectively.

The ratio of suckermouth armored catfishes is the proportion of these fishes in total yield ranging from 0 to 1. An estimate of relative catch per unit effort (CPUE) of marketable fish was calculated by dividing total yield of these fish (tilapia, native catfishes, shad, and brown hoplo) each year to the average fishing effort of 57 days/year. We used average CPUE of pre-invasion as a benchmark (hereafter referred to as CPUE-pre) in order to elucidate the impact of the suckermouth armored catfishes on the CPUE post-invasion (hereafter referred to CPUE-post).

To evaluate how the suckermouth armored catfishes' presence impacted revenue, we used the profit index to compare the revenue pre- and post-*Pterygoplichthys* invasion in Winter Haven, FL.

The profit index was calculated by dividing total revenue (in USD) to total fish caught (in kg, both marketable and undesirable fish). The average profit index pre-invasion was used as a benchmark to compare the impact of the suckermouth armored catfishes on subsequent profit. Increasing the ratio of undesirable/unmarketable fish (gar, suckermouth armored catfishes) in the catch will reduce the revenue to fishers with subsequent reductions in the profit index. To further evaluate the impact of suckermouth armored catfishes in bycatch and to reduce the sensitivity of the profit index to market price, we used \$0.60, \$0.60, \$0.10, and \$2.20 kg^{-1} as the average market prices of tilapia, catfishes, shad and brown hoplo, respectively, to estimate the profit index (indicated when applied).

Next, the relationship between diversity (i.e., inverse Simpson's diversity index) and the ratio of suckermouth armored catfishes versus the profit index was assessed by using ordinary least-squares linear regression in R [12]. We calculated lake representation diversity and evenness indices to evaluate trends through time, as well as to understand the relationship of lake diversity and species diversity of the catch. Changes in catch diversity as a result of variation in the fishing effort among lakes over time could have management implications for targeted harvesting.

3. Results

3.1. Yield Impacts of *Pterygoplichthys spp*

Tilapia, a nonnative taxon, and native catfishes contributed most to the total yield. The commercial fishery relied mainly on the harvest of these two taxa for revenues. Prior to the invasion of the suckermouth armored catfishes in 1999, the yield of tilapia and native catfishes was 72,824 ± 10,169 kg/year and 8986 ± 5755 kg/year, respectively. Following the introduction of the suckermouth armored catfishes, the production of tilapia and native catfishes became highly variable at 77,454 ± 47,122 kg/year and 20,102 ± 26,020 kg/year, respectively, with large increases in standard deviation values relative to pre-invasion levels. The ratio of suckermouth armored catfishes bycatch ranged from 0 to 0.44 in the total harvest (Figure 3). The CPUE-pre was 1640 ± 542 kg/day; lower CPUE-post compared to CPUE-pre was observed in 1999, 2000, 2001, 2005, 2009, 2010, and 2011 when the ratio of the suckermouth armored catfishes in the harvest ranged from 0.15 to 0.44 (Figure 4). However, except for tilapia, the total yield of native fishes (catfishes, gar, and shad) was still higher than suckermouth armored catfish bycatch and dominated the harvest in some years (Figure 5).

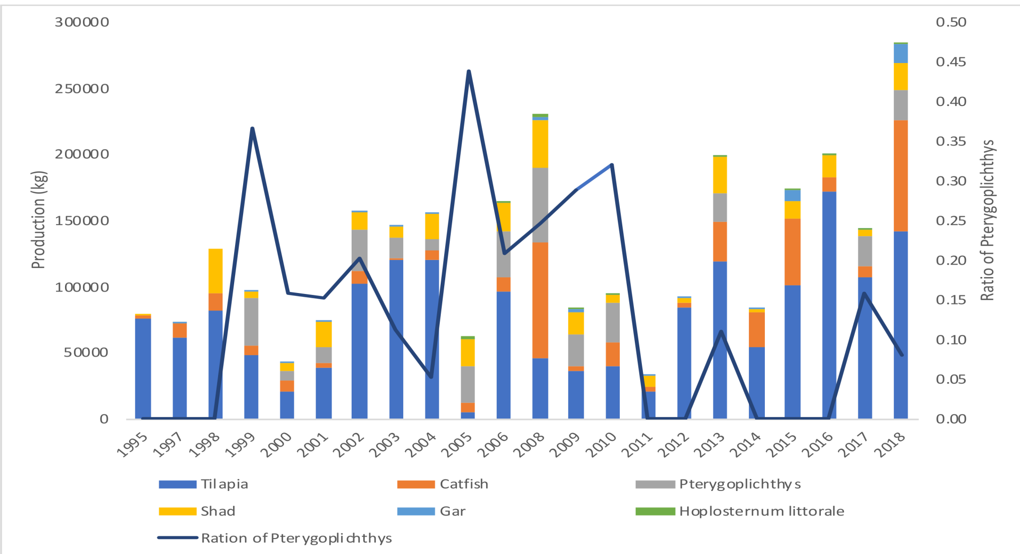

Figure 3. Total fish harvest and ratio of the suckermouth armored catfishes through the study period. The stacked bar for each year represents the production (in kg, left-hand vertical axis) represented by each taxonomic group, while the right-hand vertical axis tracks the ratio of suckermouth armored catfishes in the catch over time.

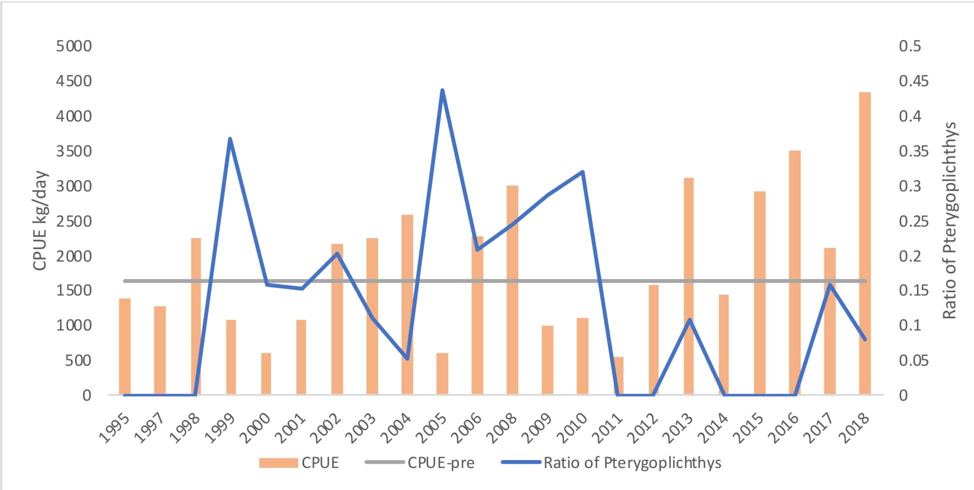

Figure 4. CPUE of marketable fish relative to CPUE-pre and ratio of suckermouth armored catfishes. Generally, years with a high ratio of *Pterygoplichthys* spp. in the catch (right-hand vertical axis) are associated with depressed CPUE values of marketable fish.

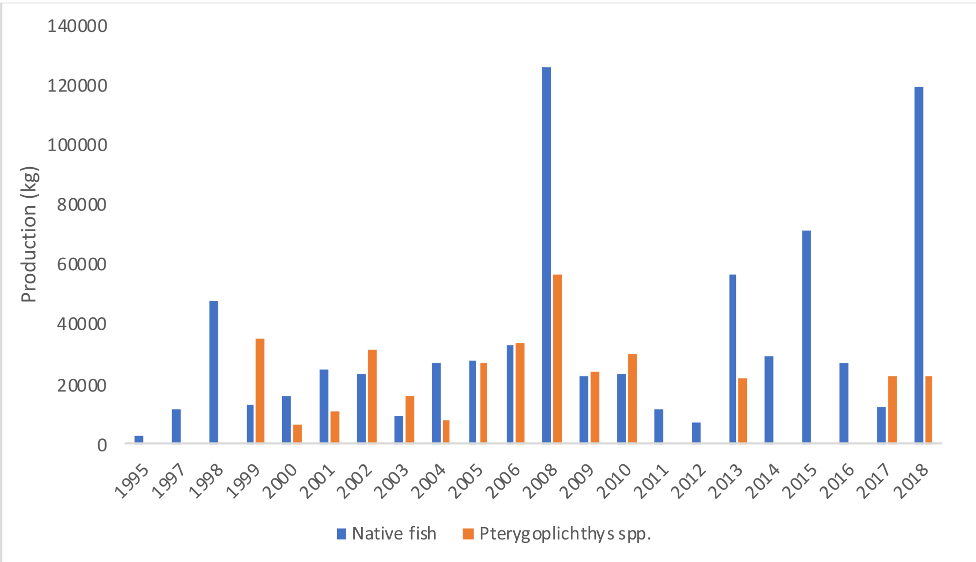

Figure 5. Yield of native fish versus suckermouth armored catfishes per year.

3.2. *Economic Impact of the Pterygoplichthys Invasion*

Fishing revenue stemmed mostly from tilapia and native catfishes. Shad was somewhat marketable. Nonnative brown hoplo was introduced in 2005 and is also somewhat marketable (Figure 6). The profit index benchmark was \$0.66 kg^{-1}; the lowest profit index post-invasion was \$0.19 kg^{-1} in 2005, while the highest was \$0.93 kg^{-1} in 2012 and 2015 (Figure 7). During the 1999–2018 post-invasion, there were 13 years during which the profit index was lower than the benchmark.

The profit index is driven by both fish yield and market price. However, the profit index of fishery operation in Winter Haven is driven more by market value than by yield. This is demonstrated well by data in 2018, when the highest CPUE-post was 4345 kg day^{-1} and the ratio of the suckermouth armored catfishes was 0.08 (Figure 4), but the prices of tilapia and native catfishes were just half of their pre-invasion period values (Figure 6), making the profit index in 2018 67% lower than the benchmark (Figure 7). A similar trend was observed in 2004 and 2013 with higher CPUE and a low ratio of suckermouth armored catfishes (i.e., <0.15), but also a lower unit price per marketable fish (Figures 4, 6 and 7).

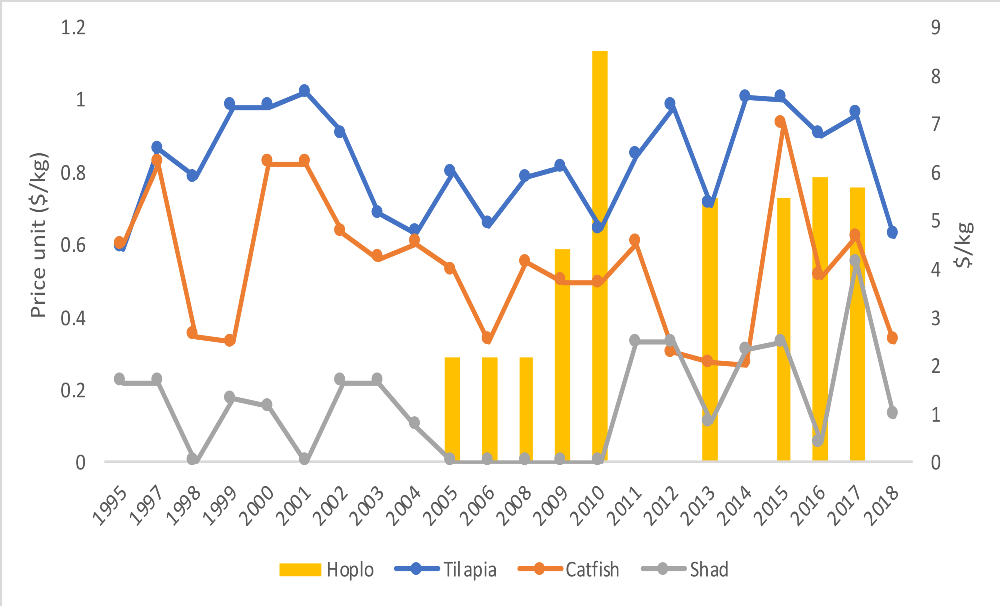

Figure 6. Price unit per marketable fish each year. Lines represent price unit ($/kg) of tilapia, catfish, and shad (left-hand vertical axis). Bars represent price unit ($/kg) of brown hoplo (right-hand vertical axis).

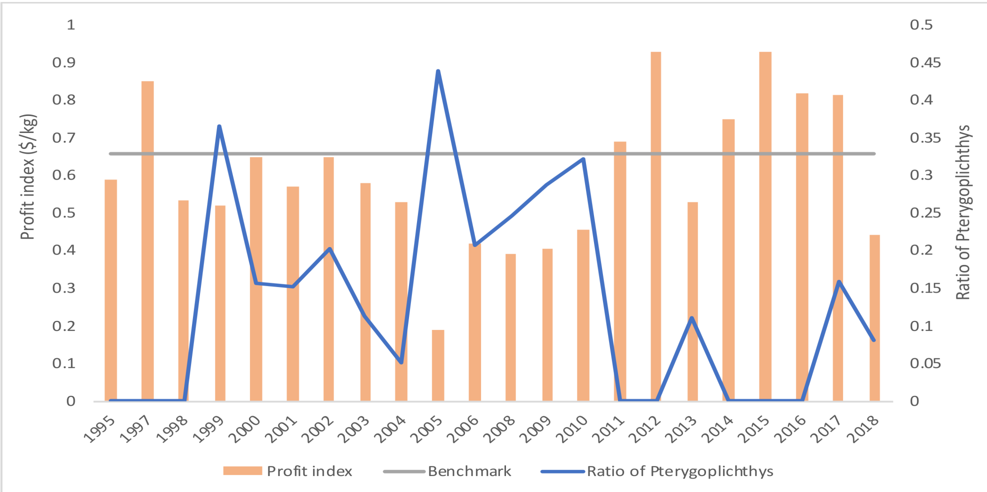

Figure 7. Profit index benchmark and post-invasion of armored catfishes.

3.3. *Profit Index versus Species Diversity and Ratio of Pterygoplichthys spp*

A significant negative correlation existed between the inverse Simpson's diversity index and profit index ($r^2 = 0.62$, $p = 1.497 \times 10^{-5}$; Figure 8), and also between the ratio of suckermouth armored catfishes and profit index ($r^2 = 0.60$, $p = 1.665 \times 10^{-8}$; Figure 9). As species diversity in the catch increased, there was a subsequent decrease in the profit index. Although some of this negative influence of increased species diversity is likely attributable to other unprofitable harvested species (e.g., gar), most is certainly a result of the inclusion of armored catfishes in the catch given its greater relative contribution (Figure 9). The highest profit index was associated with pre-invasion and years without suckermouth armored catfish bycatch.

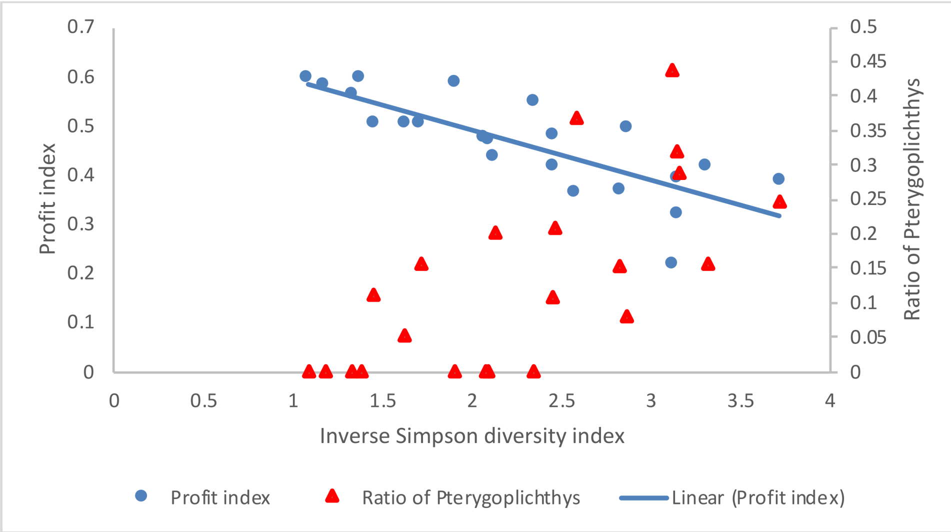

Figure 8. Negative linear correlation between diversity index and profit index (average market price applied).

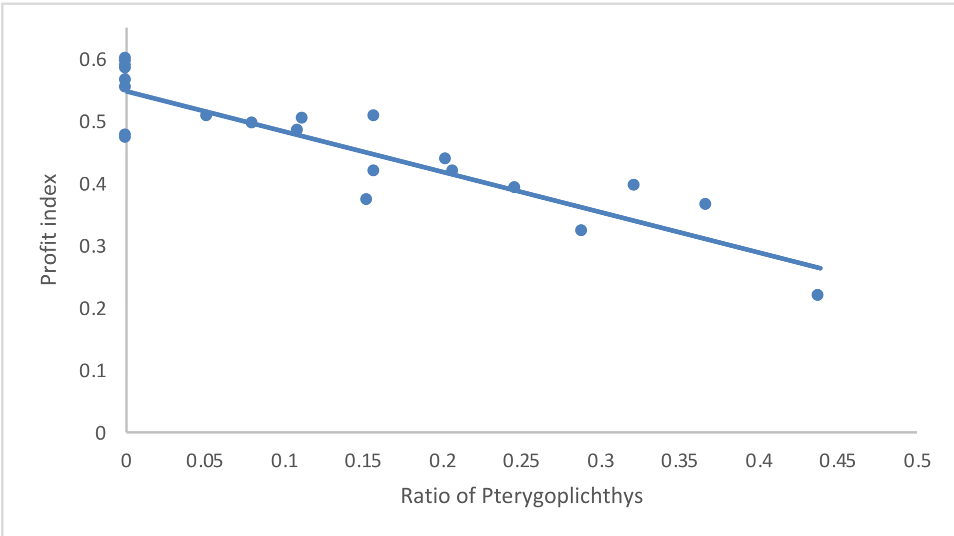

Figure 9. Negative linear correlation between the ratio of suckermouth armored catfishes in the catch and profit index (average market price applied).

3.4. Lake Representation

Except for five years (i.e., 1999, 2000, 2001, 2005, and 2008), the majority of fish were harvested from Lake Hancock with the yield ranging from 16 to 117 kg/ha. Years with a high ratio of suckermouth armored catfishes in the catch often coincided with high representation of Lake Hancock in harvests (Figure 5; Figure 10). Increases in the "spreading out" of fishing effort across multiple lakes (i.e., 1999, 2001, 2005; Figure 10) did not increase total yield or reduce the ratio of the suckermouth armored catfishes in the harvest. Primary harvest of both marketable and undesirable fish was still from Lake Hancock. No evident pattern exists between lake diversity and species diversity at low levels of lake diversity. However, high levels of species diversity were associated with high levels of lake diversity (Figure 11).

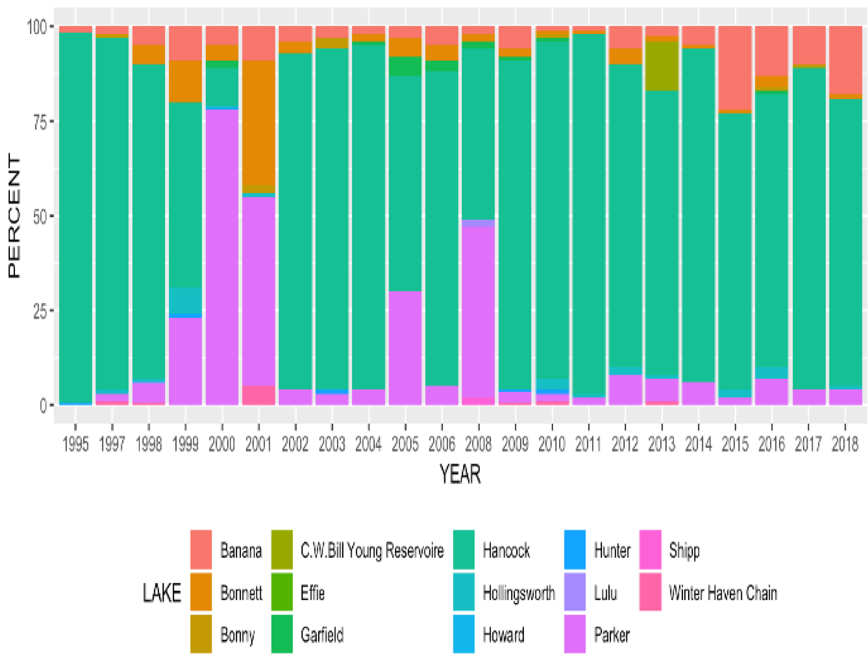

Figure 10. Lake representation of harvest per year.

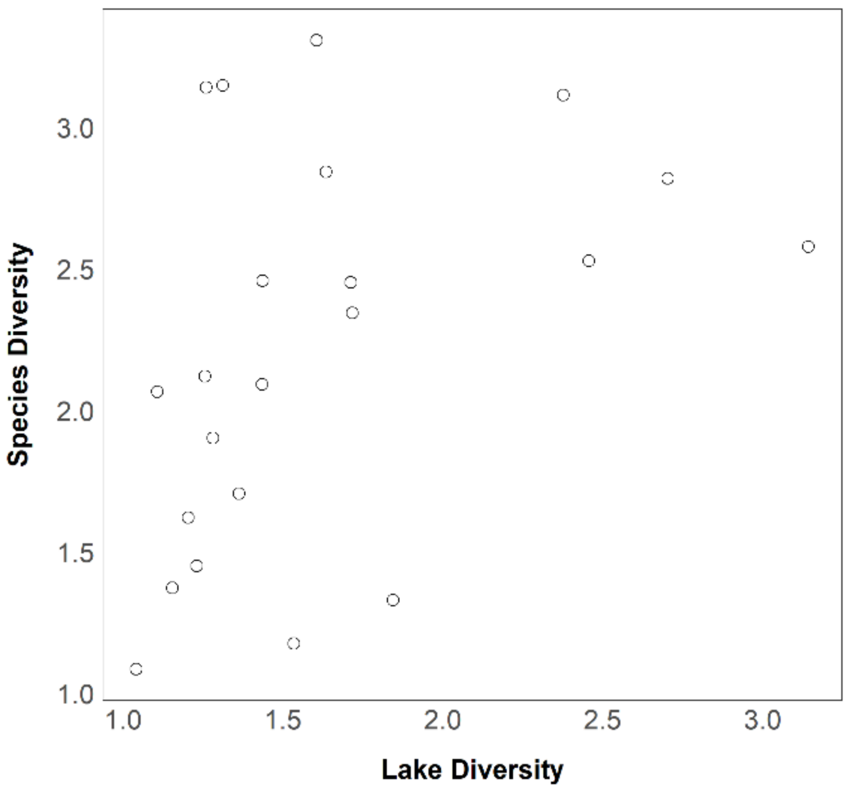

Figure 11. The relationship between lake diversity in sampling effort and species diversity of the catch. High levels of lake diversity were associated with high levels of species diversity.

4. Discussion

4.1. Observed Trends in Nonnative Taxa

Despite possible adverse ecological impacts, tilapia are of clear economic importance to Florida's freshwater haul seine industry. Brown hoplo shows slight marketability, while the data here suggest that the suckermouth armored catfishes are economically harmful to an appreciable extent. Despite constituting a large proportion of each catch annually post-invasion, the suckermouth armored catfishes did not consistently dominate the overall yield. However, the profit index through time suggests that these exotic catfishes disrupt catch consistency and lower revenue relative to pre-invasion years. This conclusion is supported to by the inverse Simpson's diversity values which demonstrate a decreasing profit index with increased species diversity (Figure 8). The increased diversity (a measure of relative abundance and richness) post-invasion can be directly attributed to the introduction of the suckermouth armored catfishes. These negative economic effects are consistent with the geographically and categorically broader findings of [4] that *Pterygoplichthys* spp. exert low to moderate negative impacts.

4.2. Recommendations

The results presented here provide implications for targeting lakes for fish harvest. Of note, broadening fishing efforts to include multiple lakes was ineffective in increasing revenue relative to fishing a primary lake (i.e., Lake Hancock). Based on the current data, then, it seems pertinent to target only the most productive lake. Further supporting this notion is the fact that high levels of lake diversity correspond to higher species diversity. When coupled with the finding that higher species diversity is negatively correlated with profit index, spreading out catch efforts among lakes could possibly contribute to a lower profit index. Therefore, targeting fewer, more productive lakes would likely result in higher revenue per unit effort.

Steps should be taken to mitigate the ongoing issues presented by the suckermouth armored catfishes. First and foremost, a concerted effort should be undertaken to market these catfishes. Eaten widely throughout the Neotropics, the suckermouth armored catfishes are readably edible and demonstrably easy to harvest. Indeed, efforts to market these fishes are already underway by some private firms. For example, in parts of Mexico, where *Pterygoplichthys* spp. are also introduced, fishermen have embraced the previous nuisance fish and now market and sell its meat locally and internationally (Acari Fish Co., Personal Communication). However, the campaign of marketing these fishes is still in its infancy, with no peer-reviewed literature to evaluate consumer acceptability beyond the fishes' native South America. Fisheries economists should seek to work with companies and consumers to better understand marketing potential of *Pterygoplichthys* spp. In addition, *Pterygoplichthys* spp. has proven a valuable commercial fish meal replacement [13], a source of antioxidants for nutrition supplements [14], and even shows promise for use in biodiesel production [15].

Government subsidization, through a bounty program or incentivization for commercial fishers, is another option for mitigation. Such programs have been employed with varying degrees of success and for various taxa globally, including in Florida [16]. For example, commercial and recreational fisheries of invasive red lionfish (*Pterois volitans*) are underway in the United States and seem to inhibit local lionfish populations [17]. Given the dense groupings formed by *Pterygoplichthys* spp., it is reasonable to suggest that at least some degree of population inhibition could be imparted by harvest-based mitigation efforts. While unlikely to eliminate the Florida populations, harvesting suckermouth armored catfishes provides an economically-sound option that bears little environmental tradeoffs compared to other options (e.g., rotenone poisoning, [18]).

5. Conclusions

Nonnative species are a double-edged sword for Florida freshwater seine fisheries. While exotic tilapia are highly marketable, other species such as the suckermouth armored catfishes are not currently marketed and seem to be negatively impacting fishery revenue. A growing body of research also suggests other negative ecological and economic impacts imparted by the genus *Pterygoplichthys* [4]. Given that large-scale eradication of these hardy and widespread fishes is unfeasible once established [4], we recommend marketing the edible suckermouth armored catfishes for consumption. In doing so, fisheries that otherwise suffer can potentially turn a profit while simultaneously exerting some degree of pressure on the introduced populations. Continued research is needed to better characterize the mechanisms of ecological and fisheries impacts of the suckermouth armored catfishes. Ongoing efforts to do so are currently underway in Florida and Vietnam.

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