Hindawi
Journal of Applied Ichthyology
Volume 2024, Article ID 6668857, 14 pages
https://doi.org/10.1155/2024/6668857

Research Article

Analysis of Migratory Catfish Production from Artisanal Fishing in the Middle Madeira Sub-Basin Using New Monitoring Methods, Southwestern Amazon

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Received 31 January 2023; Revised 23 January 2024; Accepted 29 January 2024; Published 23 February 2024

Academic Editor: Hamed Ghafarifarsani

Studies on the production of *Pimelodidae* catfish in the Amazon are generally carried out in large fishing centers. However, the data referring to small-scale fisheries have gaps that can represent a risk to the activity. This study evaluated the volume produced and the revenue obtained from migratory catfish of the *Pimelodidae* family of commercial interest landed in Humaitá, Amazonas, Brazil, from May 2018 to April 2019. Daily monitoring was carried out with the Z-31 Fishermen's Colony through questionnaires to fishermen for each vessel docked. The total production was 6013.93 kg, with 1,689 fish counted and 13 species. A total of 186 landings by 122 fishermen in 24 fishing sites characterized as rivers, lakes, and "igarapés" were evaluated. The average selling price was R$5.57/kg, and the highest volumes were obtained from July to September, mainly with gillnets, where the "Surubim" *Pseudoplatystoma punticfer* had the highest volume and revenue. Low productivity was verified in most localities, characterizing the fishing as artisanal. The lack of adequate conditions for storing and transporting fish, the local hydrological variations, and the presence of hydroelectric plants on the Madeira River are major factors limiting the fishing expansion in southern Amazonas.

1. Introduction

Due to the richness of species found in the Amazon region, the fishing activity stands out compared to other neotropical regions, whether by the number of explored species or the dependence of riverine communities and urban populations on the activity [1]. However, according to the Food and Agriculture Organization of the United Nations (FAO), much of the data from artisanal/small-scale fisheries is still unknown [2].

Amazonian fish species adapt to seasonal changes in the environments they occupy. Therefore, knowing these changes is fundamental to understanding the abundance and composition of fish resources and, consequently, defining assertive management policies [3–6].

The ecological function of the *Siluriform* order, more specifically from the *Pimelodidae* family, and their inter- or intraspecific interactions are fundamental for environmental balance [7–9]. Also known as "catfish," they are responsible for dispersing seeds throughout the basin through zoochory, evidencing the important ecological role played by aquatic biota when using the flooded forests as habitat and source of food [10–13].

During the upstream journey of migratory catfish (flooding season), while recruiting for reproduction, some species are a target of intense fishing, characterizing a period known as "piracema." During this period, which usually extends from July to November [14, 15], the percentage of captures increases in some regions of the Madeira River basin. However, the beginning of the migration comprises the months of November, December, and January, with the spawning season usually occurring during the flood period (which comprises the months of February, March, and April) and adapting to each region's hydrological cycles [16].

The fishing activity developed in the middle Madeira River sub-basin presents small-scale/artisanal characteristics due to the use of simple fishing gear, short fishing trips of low catch, and multispecific captures [17, 18]. From 2001 to 2017, an estimated average of 213 tons of fish/year was captured in the municipality of Humaitá, but these numbers, especially in the lower portion of the Madeira River, have continually decreased over the years [19, 20]. Some authors attribute this decrease in catch to demographic expansion and higher demand for fish [21], while others attribute it to the construction of hydropower dams [20].

Given the sizes that some *Pimelodidae* species can reach, they have excellent market acceptance. Also known as "large migratory catfish," some species, such as the *Pseudoplatystoma punticfer*, *P. tigrinum*, *Brachyplatystoma rousseauxii*, and *B. filamentosum*, figure as one of the most important commercial freshwater fish species in South America [10, 22, 23]. This good market acceptance, consequently, generates pressure over the exploration of some species of this family, explaining part of the decreases in catch observed in the last decades.

Parallelly, starting in 2008, the Jirau and Santo Antônio hydroelectric plants (UHE) were built upstream from Humaitá, Amazonas, in Porto Velho, Rondônia, and inaugurated in 2012, creating a physical barrier and flooding a considerable area. Evidence shows that the *Pimelodidae* family suffers strong influence from the hydrological cycles [12, 20, 24], which coordinates the migration cycles, telling them when and where to go [10, 25]. Based on that, recent studies suggest that the construction of hydropower dams along the Madeira basin has occasioned a dramatic decrease in migrations and possible local extinctions in some parts of the basin [20, 26, 27].

Reliable catch data are essential to understand these processes better [28]. However, the growing demand for fish, associated with the lack of information from artisanal/small-scale fisheries, hampers the production of reliable datasets and, consequently, weakens the policies of the sector, occasioning fish stock overexploitation and indirectly changing the structure and functioning of freshwater ecosystems in medium and long term [29, 30]. In addition, climatic effects, pollution, and habitat degradation can also cause changes in fish stock abundance and capture dynamics [31, 32].

The effectiveness of fisheries' good economic performance and profitability relies on the exploited environments' productivity, the exploited species' value, and the fisheries' duration over time [33]. Thus, understanding the dynamics of small-scale fisheries, the activity potential risks, and adopting prophylactic management decisions based on reliable data are the key steps to define how to exploit this resource appropriately [34]. According to Castello [35], however, artisanal/small-scale systems require a differentiated management approach adapted to each region's social and ecological specificity.

In this light, this study uses the data produced by a new and more refined fisheries monitoring method [18]—based on a social technology under a "citizen science" perspective, where the researchers daily monitor the fish landings with the aid of the involved fishermen, photographing, taking biometric measures, and quantifying each of the landed species—in the municipality of Humaitá, Amazonas, Brazil, to characterize the migratory catfish commercial production of the *Pimelodidae* family landed in the Z-31 Fishermen's Colony Dr. Renato Pereira Gonçalves, bringing new and more reliable information over the fisheries dynamics of pimelodids in inland artisanal/small-scale systems.

2. Materials and Methods

2.1. Study Area. The study area includes the middle Madeira River sub-basin region, between the Aripuanã and the Machado rivers. Almost entirely distributed in the southern portion of the Amazonas state and a small part located in the state of Mato Grosso [22], the Aripuanã, Manicoré, Mataurá, and Marmelos rivers stand out as its main tributaries. It covers rivers, streams, and lakes located near the municipality of Humaitá, Amazonas, Brazil, compressed between the coordinates (7°53′17.06″S and 62°52′51.5 2″W and 6°46′12.6″S and 62°27′34 0.0″W) (Figure 1).

The middle Madeira region already has some generic ongoing fishing management policies in place, which consists of a closed season that aims to protect the reproduction of some fish species, including some pimelodids, as established by the Normative Instruction MMA No. 18, from October 14th, 2004 (Hypophthalmus spp.); IBAMA Ordinance No. 48 from November 5th, 2007 (Hypophthalmus spp.); CEMAAM Resolution No. 18, from September 16th, 2014, and amended by CEMAAM No. 21, from October 27th, 2015 (*Pseudoplatystoma tigrinum* and *Pseudoplatystoma punticfer*), which prohibits the fishing of certain species of commercial interest from November 15th until March 15th. Although prohibited, the fishing of migratory catfish did not stop in this period.

2.2. Data Collection. We gathered the data used in this study by monitoring the artisanal fishing production of the Fishermen's Colony Z-31 Dr. Renato Pereira Gonçalves—which counts 1,500 members and is located in the middle Madeira basin, in the Humaitá municipality, Southeast Amazonas, Brazil—landed from May 2018 to April 2019, using the low-cost social technology applied to the monitoring of the artisanal fishing proposed by Lourenço et al. [18]—a protocol based on the daily monitoring of the fisheries landings with structured questionnaires, adapted to the multispecies captures present in the region [19, 30]. The method consists of four steps, described as follows:

Step 1. When the embarkation arrives, the technician must head to the landing point, present the work, and ask for authorization to take the biometric measures of

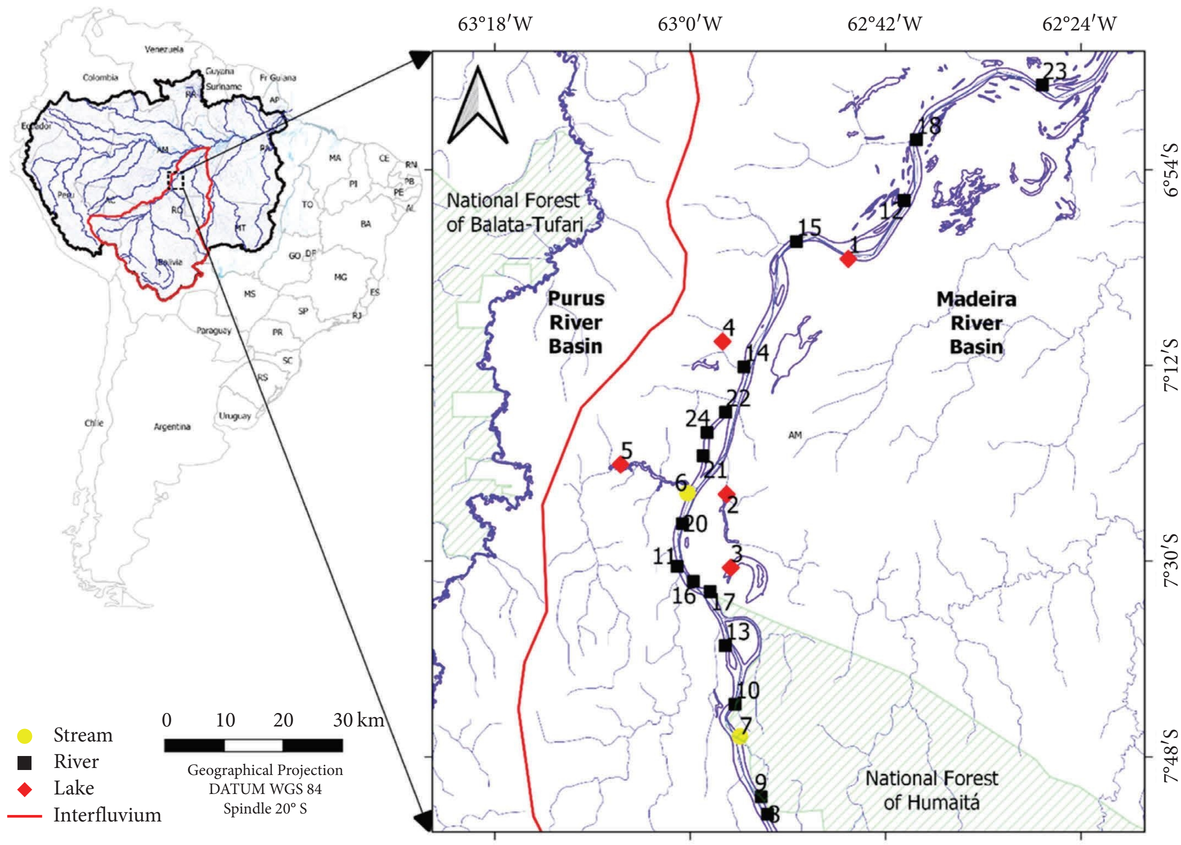

Figure 1: Capture areas and characterization of different types of environments recorded for fishing landings made in the municipality of Humaitá, Amazonas, of migratory catfish (*Siluriformes*: *Pimelodidae*) registered in artisanal fishing in the middle Madeira sub-basin, between 2018 and 2019.

each species. The technician then positions himself close to the transfer point and keeps track of how many and which species are being landed. In this part of the process, having a good relationship with the fishermen is essential once they can separate the species in different boxes during the landings, making the work easier.

Step 2. Technician is responsible for taking note of every new species landed and taking its biometric measures in consonance with the information provided instep 1 (e.g., species 1, species 2, and species *n*).

Step 3. Technician is responsible for filing the identification card according to the information provided insteps 1 and 2 and photographing one individual of each species for taxonomic identification.

Step 4. Technician is responsible for interviewing the fisherman and collecting information like when, where, and how the fish were captured, along with other socioeconomic information, such as investments and profit.

By the end of each landing, all technicians must reunite and cross information to fill out the landing form. These pieces of information allow us to identify the following in each landing: the fishing grounds, communities, effort variables (fisherman.days fishing^{-1}), type of environment, species, individual and total mass, length, type of embarkation, and fishing gear used. Finally, using the available literature, we use the photographs to identify the landed species at the lowest possible taxonomic level [36].

During the monitoring, approved by the Brazilian Ethics Committee, we collected the following variables: total number of captured individuals and their respective species; weight; length; captured volume (kg); commercialization price of each species; days spent fishing; the number of fishermen per boat; type of vessel; where they captured it; and type of environment (e.g., stream, river, and lake). The coordinates of each fishing ground and community were taken with *in loco* visits using a GPS (Global Position System).

2.3. Data Analyses. To analyze the pimelodids captures' relation with the regional hydrological cycles, we collected the average quotas data from the fluviometric station "15630000 Humaitá" and defined the minimum and maximum hydrological values for each period. These values allowed the visualization of how the average monthly quotes of the Madeira River levels changed during the analyzed period and to delimitate the following periods: flooding (from August to October), flood (from November to

January), ebb (from February to April), and drought (from May to July).

We analyzed the landings' catch (kg) per species using descriptive statistics to obtain the following parameters: mean, standard deviation, minimum, maximum, coefficient of variation, and kurtosis. To verify the distribution of the captured volumes (kg), we used Shapiro–Wilk's normality test [37]. For the homogeneity of variances analysis, we used Levene's test [38, 39]. To verify the existence of significant differences in the landed volume between the Pimelodidae species, we applied the nonparametric Kruskal–Wallis [40] and Dunn's post hoc test of multiple comparisons, which allowed us to visualize the differences expressed by p values.

We adopted ordering and classification analyses to assess the spatial-temporal fishing dynamics, reducing the amount of interpreted information to obtain an interpretive grouping. The two multivariate techniques applied in this study intended to search for emerging interpretable patterns, namely: (i) nonmetric multidimensional scaling (NMDS), which produces orderings from distance matrices, but instead of using the real distances, it only considers the distance "ranks" [41–43], and (ii) cluster analysis for indicating the aggregation of the most similar data and, through this, allowing comparisons of the data [44].

We also used nonmetric multidimensional scaling (NMDS) to define the fishing seasonality as well as the spatial-temporal dynamics of the analyzed *Pimelodidae* species, uncovering the solution for a certain number of dimensions by ordering it to minimize the STRESS function (standardized residual sum of squares). To do that, we elaborated a quantitative matrix of the captured volumes (kg) for each species, using the Euclidean measure to determine the geometric distance in the multidimensional space. Ordering patterns differ according to the number of ordering axes; for the validation of the evidenced structure, we used a significance test based on the "null model" of the Monte Carlo permutation method [42, 45], present in the PAST 4.05 statistical package [46].

To determine the similarity of the captured volumes between the capture sites, we used a classification analysis, where we created a quantitative matrix of the captured volumes (kg) using the Bray–Curtis index [47], along with an agglomerative method based on the group means (UPGMA) indicated for decreasing the distortion of the original matrix during the construction of the dendrogram [48]. We also used the cophenetic correlation coefficient to validate the dendrogram with the original matrix [49].

To assess the effect of the monotonic relationships between the descriptor variables, we applied Spearman's correlation coefficient (r_s) for the following variables: hydrological level, type of environment, days spent fishing, number of support vessels, and distance between the capture sites and the landing site [50]. Finally, we used the canonical correspondence analysis (CCA) to verify the influence of each variable on the distribution of captured volumes (kg) of the thirteen analyzed fish species [51, 52].

3. Results

The total production of catfish species of the *Pimelodidae* family addressed in this study was 6013.93 kg for the entire period, totaling around 1,689 fish from 10 genera and 13 species. We evaluated a total of 186 landings from 122 fishermen, from which 98 were motorized canoes and 24 fishing boats, from 24 different fishing grounds; the total captured volume (kg) was distributed between rivers (71%), lakes (18.8%), and streams (10.2%). The identified species are available in Table 1.

The average production of pimelodids in this sample was 32.33 ± 89.84 kg (0.27 min–980.00 max) per fishing trip, which lasted an average of 3 days. The average sale value in each landing was R$5.57/kg (2.00 min–12.00 max) paid by the "magarafes," who resale the products after processing for up to R$20.00/kg.

The highest volumes of migratory catfish landings occurred between July and September, corresponding to the region's transition period from the ebb to the drought period. The fishing gears most commonly used were stationary gillnets (96.72%), followed by throwing nets (1.64%), and "espinhéis" (stationary longlines with several hooks) (1.64%). The gillnets mesh sizes varied from 45 mm to 190 mm, and the 70 mm mesh was the most used.

Descriptive analyses showed variation in the volume caught (Table 2) and revenue (Table 3) per fishing trip for the thirteen species of migratory catfish analyzed. For the period studied, the highest values observed for each fishing trip, both in volume caught and in revenue (R$), were for the "surubim" fish, *Pseudoplatystoma punticfer*.

The values obtained from the Kruskal–Wallis nonparametric analysis of variance, used to test the differences in volumes captured for each trip, were represented by $H = 73.48$ and $p = 1.83E^{-28}$, demonstrating that the medians for the analyzed samples presented significant differences, and represented by the multiple comparisons posterior Mann–Whitney test (Table 4).

Through nonparametric multidimensional scaling (NMDS), we ordered the captured volumes (kg) according to the location, type of capture environment, and seasonality. The groupings were arranged according to the amount of biomass registered for the different months of the year (Figure 2). Through NMDS, it was possible to verify that the highest production for the analyzed locations occurred between the ebb and drought periods, with low production during the flood period, a fact possibly linked to the beginning of the closed-season period. It was possible to observe that the volumes varied spatiotemporally due to the availability of different environments during different periods of the year. Most of the monitored fishing grounds presented low captures, evidencing the artisanal/small characteristics of the studied region. Linear adjustment of NMDS for the captured volumes in kilograms (kg) presented a determination coefficient (R^2) of 0.8262 for dimension 1 and 0.492 for dimension 2, with a residual sum of squares equal to STRESS of 0.1269.

Through the similarity dendrogram (Figure 3), we identified five groups with adjustments higher than 55%

Table 1: Recorded *Pimelodidae* catfish captured during the artisanal fisheries monitoring in the middle Madeira sub-basin, Amazonas, Brazil, between 2018 and 2019.

Species	Popular name	Frequency (%)
Brachyplatystoma filamentosum (Lichtenstein, 1819)	Filhote/piraíba	2.7
Brachyplatystoma platynemum (Boulenger, 1898)	Babão	1
Brachyplatystoma rousseauxii (Castelnau, 1855)	Dourada	4.2
Brachyplatystoma vaillantii (Valenciennes, 1840)	Piramutaba	0.2
Hypophthalmus marginatus (Valenciennes, 1840)	Mapará	2.1
Leiarius marmoratus (Gill, 1870)	Jandiá	3.4
Phractocephalus hemioliopterus (Bloch and Schneider, 1801)	Pirarara	3.9
Pinirampus pirinampu (Spix and Agassiz, 1829)	Barba-chata	0.7
Pseudoplatystoma punticfer (Linnaeus, 1766)	Surubim/cachara	69.7
Pseudoplatystoma tigrinum (Valenciennes, 1840)	Caparari	8.4
Sorubim lima (Bloch and Schneider, 1801)	Bico de pato	1
Sorubimichthys planiceps (Spix and Agassiz, 1829)	Peixe lenha	2.6
Zungaro zungaro (Humboldt, 1821)	Jau	0.2

The frequency of species occurrence (presence/absence) is expressed as a percentage.

Table 2: Descriptive statistics of biomass production (kg) of migratory catfish (*Siluriformes*: *Pimelodidae*) recorded in artisanal fishing in the Madeira River sub-basin, between 2018 and 2019, according to location and hydrological period.

	M	SD	MinV	MaxV	CV%	K
Brachyplatystoma filamentosum	5.07	±31.22	1	255	615.3	63.84
Brachyplatystoma platynemum	1.02	±4.02	1.3	24	392.15	22.71
Brachyplatystoma rousseauxii	5.43	±18.21	0.3	104	335.17	16.54
Brachyplatystoma vaillantii	0.12	±0.59	0.5	4	476.83	31.21
Hypophthalmus marginatus	0.24	±0.94	0.27	5.6	391.97	21.97
Leiaurius marmoratus	1.41	±3.25	1	19	230.34	13.39
Phractocephalus hemioliopterus	7.33	±20.51	4	117	279.64	16.9
Pinirampus pirinampus	0.19	±0.67	0.64	3.8	349.74	16.49
Pseudoplatystoma punticfer	56.47	±153.07	0.45	1094	271.06	32.14
Pseudoplatystoma tigrinum	8.79	±32.85	4	243	373.44	39.88
Sorubim lima	0.09	±0.70	0.48	5.84	762.73	67.01
Sorubimichthys planiceps	2.11	±7.42	0.51	56	351.25	42.32
Zungaro zungaro	0.14	±0.81	0.65	6	571.38	43.85

M: mean; SD: standard deviation; MinV: minimum value; MaxV: maximum value; CV%: coefficient of variation in percentage; K: kurtosis.

Table 3: Descriptive statistics of financial income (R$) of migratory catfish (*Siluriformes*: *Pimelodidae*) recorded in artisanal fisheries in the middle Madeira sub-basin, between 2018 and 2019, for each fishing landing.

	M	SD	MinV	MaxV	CV%	K
Brachyplatystoma filamentosum	42.07	±251.22	0.18	377.07	596.9	62.19
Brachyplatystoma platynemum	5.52	±23.40	0.96	26.61	423.75	26.36
Brachyplatystoma rousseauxii	35.43	±117.90	0.66	103.51	332.69	11.64
Brachyplatystoma vaillantii	0.61	±3.52	0.53	5.17	575.67	56.4
Hypophthalmus marginatus	1.52	±8.40	0.14	12.47	552.66	58.87
Leiaurius marmoratus	5.35	±12.79	0.56	10.53	239.07	8.68
Phractocephalus hemioliopterus	38.83	±128.32	2.95	173.01	330.05	36.88
Pinirampus pirinampus	0.73	±2.45	0.36	2.10	334.59	10.77
Pseudoplatystoma punticfer	371.4	±1036.7	0.50	1415.52	279.11	37.2
Pseudoplatystoma tigrinum	66.13	±254.30	14.22	359.33	384.53	45.78
Sorubim lima	0.27	±2.12	0.98	3.23	781.66	67.56
Sorubimichthys planiceps	9.47	±31.83	2.04	41.40	335.98	31.89
Zungaro zungaro	0.56	±3.24	2.6	4.43	571.38	43.85

M: mean; SD: standard deviation; MinV: minimum value; MaxV: maximum value; CV%: coefficient of variation in percentage; K: kurtosis.

Table 4: Dunn's post hoc test of multiple comparisons highlights the differences observed for the captured volumes (kg) between the different species, represented by p values, for the analyzed period.

	Pse fas	*Pse tig*	*Phr hem*	*Bra rou*	*Bra fil*	*Sor pla*	*Lei mar*	*Bra pla*	*Hyp mar*	*Pir pir*	*Zun zun*	*Bra vai*	*Sor lim*
Pse fas		$^*8.24E^{-11}$	$^*1.87E^{-09}$	$^*1.98E^{-14}$	$^*1.08E^{-17}$	$^*8.70E^{-13}$	$^*4.74E^{-09}$	$^*5.06E^{-18}$	$^*1.45E^{-18}$	$^*1.25E^{-18}$	$^*1.12E^{-21}$	$^*6.16E^{-21}$	$^*1.48E^{-22}$
Pse tig	$^*8.24E^{-11}$		0.626	0.248	*0.039	0.514	0.522	*0.031	*0.022	*0.021	*0.002	*0.004	*0.001
Phr hem	$^*1.87E^{-09}$	0.626		0.101	*0.011	0.254	0.879	*0.008	*0.005	*0.005	*0.001	*0.001	*0.001
Bra rou	$^*1.98E^{-14}$	0.248	0.101		0.362	0.615	0.073	0.317	0.254	0.247	0.056	0.083	*0.034
Bra fil	$^*1.08E^{-17}$	*0.039	*0.011	0.362		0.157	*0.007	0.930	0.819	0.806	0.317	0.411	0.227
Sor pla	$^*8.70E^{-13}$	0.514	0.254	0.615	0.157		0.196	0.133	0.101	0.097	*0.016	*0.025	*0.009
Lei mar	$^*4.74E^{-09}$	0.522	0.879	0.073	*0.007	0.196		*0.005	*0.003	*0.003	*0.001	*0.001	$^*8.99E^{-05}$
Bra pla	$^*5.06E^{-18}$	*0.031	*0.008	0.317	0.930	0.133	*0.005		0.888	0.875	0.361	0.462	0.263
Hyp mar	$^*1.45E^{-18}$	*0.022	*0.005	0.254	0.819	0.100	*0.003	0.888		0.987	0.440	0.553	0.328
Pir pir	$^*1.25E^{-18}$	*0.021	*0.005	0.247	0.806	0.097	*0.003	0.875	0.987		0.450	0.564	0.336
Zun zun	$^*1.12E^{-21}$	*0.002	*0.001	0.056	0.317	*0.016	*0.001	0.361	0.440	0.450		0.859	0.836
Bra vai	$^*6.16E^{-21}$	*0.004	*0.001	0.083	0.411	*0.025	*0.001	0.462	0.553	0.564	0.859		0.701
Sor lim	$^*1.48E^{-22}$	*0.001	*0.001	*0.034	0.227	*0.009	$^*8.99E^{-05}$	0.263	0.328	0.336	0.836	0.700	

Significant values are marked with an asterisk (*); *Pse faz*: *Pseudoplatystoma punticfer*; *Pse tig*: *Pseudoplatystoma tigrinum*; *Phr hem*: *Phractocephalus hemioliopterus*; *Bra rou*: *Brachyplatystoma rousseauxii*; *Bra fil*: *Brachyplatystoma filamentosum*; *Sor pla*: *Sorubimichthys planiceps*; *Lei mar*: *Leiarius marmoratus*; *Bra pla*: *Brachyplatystoma platynemum*; *Hyp mar*: *Hypophthalmus marginatus*; *Pir pir*: *Pinirampus pirinampu*; *Zun zun*: *Zungaro zungaro*; *Bra vai*: *Brachyplatystoma vaillantii*; *Sor lim*: *Sorubim lima.*

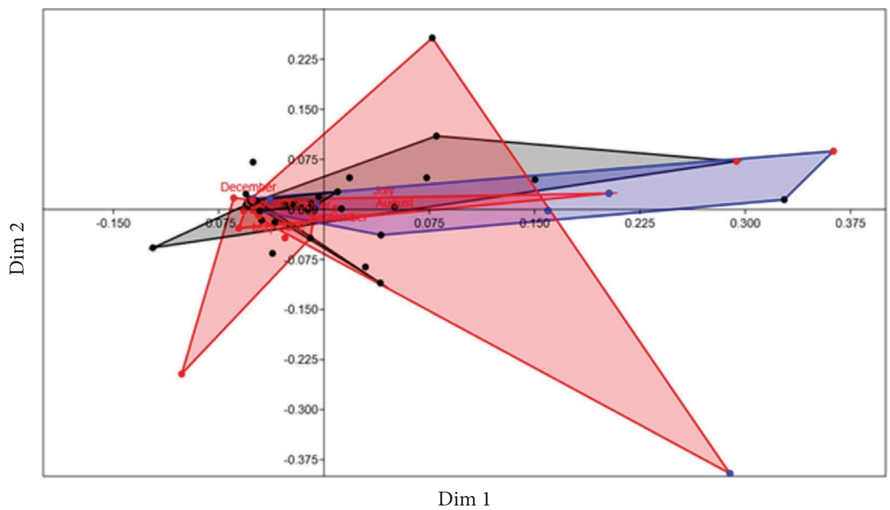

Figure 2: Nonparametric multidimensional scaling for fish catch volumes (kg) for each fishing trip in different types of environments and catch months for *Pimelodidae* species recorded in artisanal fisheries in the middle Madeira sub-basin, between 2018 and 2019, in relation to localities (dots correspond to locations and capture environments; black dots represent rivers; red dots represent lakes; blue dots represent "igarapés" or stream).

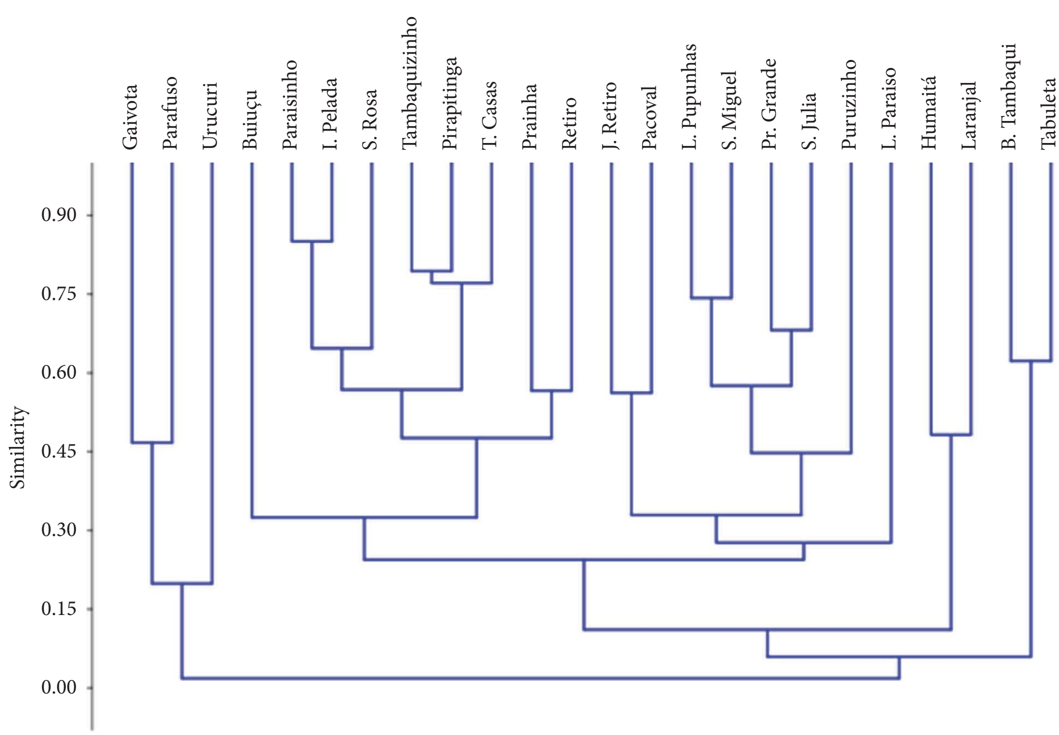

Figure 3: Similarity dendrogram generated through cluster analysis of captured volumes (kg) of *Pimelodidae* species, for each location, using the Bray–Curtis index as a function of months and capture locations (cophenetic correlation coefficient = 0.8849).

compared to the original highest capture volumes (kg) in the considered locations. The cophenetic correlation coefficient was >0.8.

The monotonic relationships tested for Spearman's correlation coefficient (r_s) between the descriptor variables presented significant values for nonlinear associations (Table 5; Figure 4). Spearman's correlation coefficient (r_s) allowed us to detect the monotonic relationships between the descriptor variables pair by pair, highlighting the uncorrelated variables.

The canonical correspondence analysis (Figure 5) presents the influence of environmental descriptors (months, hydrological level, type of environment, number of days fished, number of support vessels, and distance between

Table 5: Scores of statistical values and two-tailed probabilities for nonexistent correlations among those described considered for the analysis.

	Months	HidrLev	Envir.	NDF	SupBoa	Loc X Unl
Months		$1.19E^{-20*}$	0.62425	0.52478	0.00352*	0.66814
HidrLev	−0.85674		0.50785	0.07061*	0.04424*	0.86489
Envir.	0.06047	−0.08168		0.21529	0.25246	0.0115*
NDF	−0.07846	−0.22063	0.15221		0.85532	0.73153
SupBoa	0.34914	−0.24478	0.14069	0.02253		0.82973
Loc X Unl	−0.05293	0.02102	0.30473	0.04237	−0.02657	

*Significant value if $\alpha \leq 0.05$; HidLev: hydrological level; Envir.: environment; NDF: number of days fished; SupBoat: support boats; Loc X Unl: locations vs unloading.

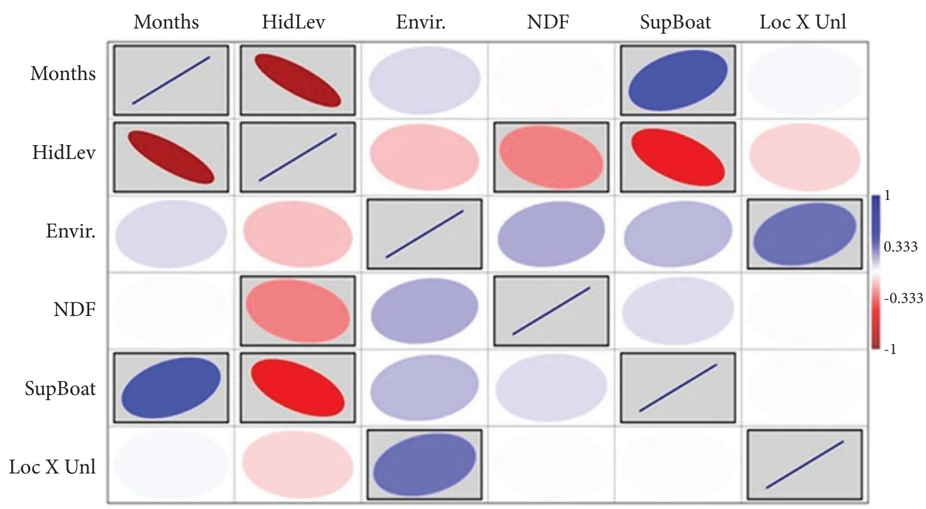

Figure 4: Graphic representation of Spearman's correlation coefficient (rs) between descriptive variables demonstrating the significant values for nonlinear associations and uncorrelated two-tailed probabilities (HidLev: hydrological level; Envir.: environment; NDF: number of days fished; SupBoat: support boats; Loc X Unl: locations vs unloading).

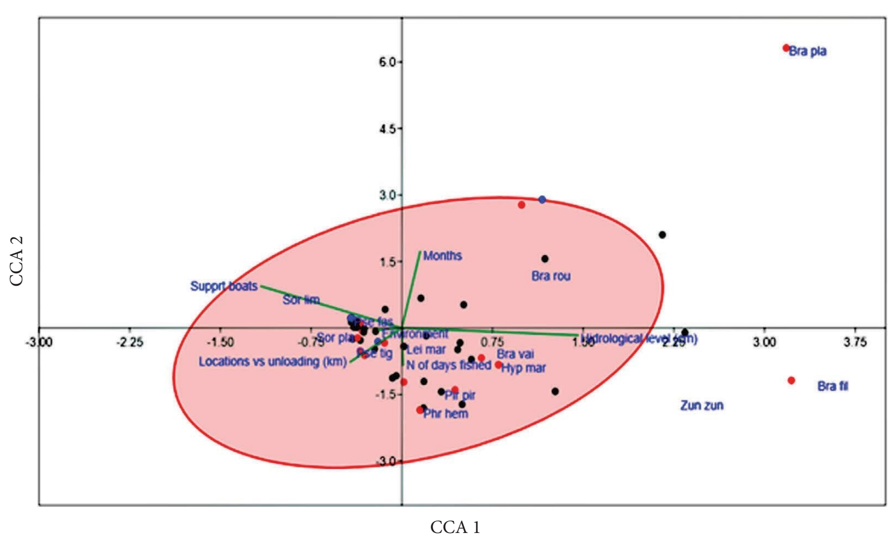

Figure 5: Canonical correspondence analysis (CCA) of volumes captured in kilograms (kg) for *Pimelodidae* species registered in artisanal fisheries in the middle Madeira River subbasin, according to fishing excursions and types of capture environment (2018 to 2019), in relation to the variables: hydrological level, environment, number of days fished, number of support vessels, and distance between capture and landing sites (*Pse faz*: *Pseudoplatystoma punticfer*; *Pse tig*: *Pseudoplatystoma tigrinum*; *Phr hem*: *Phractocephalus hemioliopterus*; *Bra rou*: *Brachyplatystoma rousseauxii*; *Bra fil*: *Brachyplatystoma filamentosum*; *Sor pla*: *Sorubimichthys planiceps*; *Lei mar*: *Leiarius marmoratus*; *Bra pla*: *Brachyplatystoma platynemum*; *Hyp mar*: *Hypophthalmus marginatus*; *Pir pir*: *Pinirampus pirinampu*; *Zun zun*: *Zungaro zungaro*; *Bra vai*: *Brachyplatystoma vaillantii*; *Sor lim*: *Sorubim lima*) (dots correspond to locations and capture environments; black dots represent rivers; red dots represent lakes; blue dots represent "igarapés" or stream).

the capture sites and the landing site) on the volume captured in kilograms of *Pimelodidae* catfish for the analyzed area. *Leiarius marmoratus*, *B. vaillantii*, *P. pirinampus*, *H. marginatus*, and *Phractocephalus hemioliopterus* positively responded to changes in the hydrological level and the number of days fished. While the production of *P. punticfer*, *S. lima*, *P. tigrinum*, and *S. planiceps* was positively influenced by the environment and the number of support boats, the distance between the capture sites and the landing site negatively influenced the observed catches, reinforcing the observed higher production values found in "Igarapé do Buiçú," "Tambaquizinho," and "Três Casas lake."

The first two axes of the canonical correspondence analysis explained 67.87% of the variation in the catch distribution of *Pimelodidae* species. The descriptors considered to be significant in the distribution of abundances in the catch of the species were the month, hydrological level, type of environment, number of days fished, number of support vessels, and the distance between the capture sites and the landing site (Table 6).

Table 6: Canonical correspondence analysis (CCA) score for the influence of descriptor variables on the volume of fish caught (kg) of *Pimelodidae* species for the middle Madeira River region between 2018 and 2019.

Descriptors	Axis 1	Axis 2	Eigen value
Months	0.03	0.34	0.38
Hydrological level (cm)	0.29	−0.03	0.26
Environment	−0.04	−0.01	0.15
Number of days fished	0.00	−0.17	0.10
Support boats	−0.23	0.19	0.03
Locations vs unloading (km)	−0.09	−0.15	0.02
Variation explained (%)	40.73	27.14	—

4. Discussion

The characteristics present in the gathered data, such as multispecific exploration, diversity of equipment used, limited types of environments, and variations in flood pulses, in addition to the ecological conditions of the populations, influence fishing strategies, abundances, and composition [53–57], characterizing the fishing of migratory catfish in the middle Madeira River sub-basin region as a multispecific and subsistence commercial fishery.

Pseudoplatystoma punticfer, popularly known as "surubim," "pintado," or "cachara," is one of the *Pimelodidae* species with the highest commercial value and the one with the higher proportion in landings for the analyzed region. This species was responsible for 69.7% of the total production among *Pimelodidae* species, with approximately 4 tons and 8.3% of the 46.7 tons landed in the region, ranking fifth in total production, corroborating other studies [58, 59]. According to Goulding [22], the genus *Pseudoplatystoma* Bleeker, 1862, was the most important among those exploited in fisheries on the Guaporé and Mamoré rivers in the 1970s. According to Payne [60], 95% of fish landed in Trinidad and Bolivia were composed of four main species, two of which are within the *Pimelodidae* family: *P. punticfer* and *P. tigrinum*. Santos [61], describing the composition and situation of fishing in the state of Rondônia, mentions that in 1984, the production of *P. tigrinum* was 41.2% of the total 104.5 t landed in Vila Pimenteira on the banks of the Guaporé river. Petrere Jr. [62] estimated *P. tigrinum* as 48% of the captures in the Mamoré River. More recently, Lopes et al. [30] observed that *Pseudoplatystoma* spp accounted for more than 10% of the fish landed in Boca do Acre, Amazonas, in 2012.

The main differences observed in production and travel revenue for each *Pimelodidae* species were analyzed using exploratory techniques and multivariate statistics for interpretation purposes [63, 64]. Thus, the descriptive analyses showed significant differences when analyzed separately for each species, where *P. punticfer* had the highest captured volume and revenue values. The Kruskal–Wallis nonparametric analysis of variance detected the differences observed for the production of the evaluated species, and their values were represented by the multiple comparisons post hoc Dunn's test, pointing once again to *P. punticfer* as having the most significant production and revenue, unlike the other *Pimelodidae* species analyzed. This fact can be explained by the great flexibility of the species *P. punticfer* in occupying diversified environments throughout their entire ontogenetic development [12, 65], which in turn justifies that their production is seven times greater than that of *P. tigrinum*, which is the second most frequently captured large catfish species in the study area.

Regarding the parties involved, we identified three production agents working in the landings of commercial fishing in the middle Madeira River region: fishing boats (who focus their catches on the mainstream of the rivers), motorized canoes (which explore lakes and streams), and the "magarefes" [19, 22].

A peculiar feature is the fishing in stream environments during the drought season, an environment frequently explored by fishermen in motorized canoes [19]. This modality presents great expressiveness in production, reaching the highest values and surpassing, in some cases, the production of periods expected to be more productive for migratory catfish. On the other hand, during this period, shoals are more frequent in the main channel of large rivers, and the fishing effort of the fleet is mainly concentrated in these types of environments [15, 22] with trips lasting on average less than one day [19]. However, for the studied region, these trips last around three days.

Another factor that explains the differences observed in production between fishing trips is due to the numerous reproductive strategies that exist among *Pimelodidae* species, such as other migratory species from tropical environments, which have developed mechanisms that enable them to optimize the environment [66–69]. Spawning occurs at the head of rivers during the rainy season when the rivers are full of turbulent and oxygenated running water. Young and adult individuals of species such as *P. punticfer* are found in adjacent flooded areas during the flood period [70]. During the ebb and drought seasons, the distribution is different. Young fish are found in streams and marginal lakes, while adults are found only in the main riverbeds

[71, 72]. This difference explains the high capture rates of *P. punticfer* throughout the period but with the highest relative frequencies during the ebb and drought periods, thus corroborating the data observed in the present study.

Nonparametric multidimensional scaling analysis showed that capture volume for different *Pimelodidae* species varied spatiotemporally as a function of the types of environment and months. This tendency for variation in catch volumes is caused by the preference of some species for certain types of habitats during different times of the year, which consequently leads fishermen to undertake a higher capture effort in environments such as lakes and small adjacent streams [11, 15]. The period considered most productive was during the ebb and drought season, comprising the months from May to October, with the highest values of capture per trip occurring in May and September, respectively.

Cluster analysis showed the formation of groups defined by the similarity of volumes captured for the considered fishing grounds, demonstrating the effect of the types of environments for each location (Figure 3). It was possible to observe that the capture volumes varied among the different locations, influenced by fluctuations in hydrological level, which interfered with the capture dynamics for the analyzed area.

Studies on *Pimelodidae* have shown that the highest revenues revolve around the species *B. rousseauxii* and *B. vaillantii* due to the greater demand for these species, as well as a higher fishing effort [34, 73], mainly in the river mouth region [74]. However, artisanal fishing, especially in the middle Madeira River subbasin region, does not have a fleet of boats with the proper characteristics to capture these species. Generally, specific equipment and vessels with a large storage capacity (tons) are necessary to capture larger catfish species [75].

Based on the local reality, although Barthem and Goulding [23] describe the capture of species of the *Pimelodidae* family as occurring from July onward, in the middle Madeira region, captures of *P. punticfer* and *P. tigrinum* were observed occurring from April onwards, which for the study area corresponds to the final period of reproduction for these species when individuals find themselves with a low accumulation of reserves and depleted gonads [76, 77].

It is essential to consider that fish assemblages can be directly affected by changes in environmental conditions, such as the increase and/or reduction of flooded areas, food availability, and harbor areas [78]. The results showed that for the analyzed period, the Buiuçú stream was the most productive, with a total capture of 1,333 kg, followed by the Tambaquizinho with 618 kg and, in third place, Três Casas Lake with a production of 573 kg. These numbers highlight the importance of adjacent lakes and streams for fishing activity in the region, especially during drought periods when these environments present higher captures [79].

Some authors, when dealing with the production of catfish, observed that the greatest catchability occurs during the flood period due to the beginning of recruitment to carry out the reproductive migration. However, shoals form during the ebb, with the decrease in the supply of environments, increasing their catch [34]. This study corroborates with our data, where the highest production recorded occurred in August, September, and October, respectively, during the lowest water level recorded [80].

We can observe that *P. punticfer* and *P. tigrinum* are responsible for the highest abundances in captured volume when considering production per trip and total biomass, reflecting the observed revenue. However, it is noteworthy that the region's fisheries are nontargeted hybrids. Fishermen catch whatever gets trapped in the mesh, which explains the low number of species and individuals captured when analyzed separately [18, 81].

Another critical factor is that during fishing trips, vessels do not have adequate conditions for fish storage and transport, which, in turn, also limits the captures and consequently generates low values in revenue due to the effect of underexploration. Most boats used in catfish fishing in the studied area are motorized canoes with expanded polystyrene (Styrofoam) boxes [82]. Studies report that motorized canoes, popularly called "rabeta," represent the majority of vessels and are responsible for more than 90% of the storage and transport capacity of fisheries in the region [83].

Vessels like motorized canoes limit fishermen to shorter and more frequent trips, usually to places close to the landing areas, which demands a low cost for fisheries, leading to a higher number of fishing trips, but with fewer days fished, increasing the number of records [55, 84, 85]. In this way, fishermen adapt fishing techniques to exploit abundance cycles and local market demands [34]. The information generated with the data obtained can explain the values observed for the revenues in relation to the evaluated locations and species. In addition, the precariousness and lack of infrastructure during the capture's landing compromise the fishing activity's development, increasing costs for its execution, which may reflect in the price of commercial fish.

Thus, catfish have a higher commercial value when compared to the other species that come from this study area [18], whether because of their commercial appeal as well as the difficulties imposed by the specific catches observed for the group, with emphasis on the minimum lengths and weights allowed established by ordinance No. 48/2007 and some state legislations [1]. Other difficulties include the lack of access to ice for fish conservation, the lack of guarantees of access to closed-season insurance, and the lack of necessary inputs to manufacture equipment, preventing the development of fishing activity in the region [86].

Due to the requirements imposed by local commercial consumption, as well as the limitations in storage space for large volumes of fish, some species of catfish have the head and viscera removed before being brought to the landing site; these body parts represent between 20 and 30% of the individual fish's volume, adding to the total weight and thus influencing the final total weight of fish caught. This practice occurs in several regions, involving the fishing of *Pimelodidae* catfish [87]. Undoubtedly, this factor may have contributed to the low production observed for some species when considering the weight obtained.

5. Conclusions

The *Pimelodidae* catfish production in the middle Madeira River subbasin region is a small-scale fishery and plays a vital role by providing food and a source of income for local populations. When analyzing the catfish production expressed as volume and the type of capture environments, we found that, despite being partially organized, fishing in the region needs investments concerning the acquisition of vessels with greater transport capacity and storage, improvements in the floating platform where the fish are landed, improvements in working conditions, better access to ice, and necessary supplies for the development of this type of fishing, in addition to updating public policies aimed at this sector, based on local realities.

The presence of large hydroelectric projects in the region may represent one of the causes of low productivity found in this study, especially when considering that these types of projects consist of artificial barriers that can interfere with the reproductive dynamics of the analyzed group, and the registered mean productions presented here are lower when compared to other similar studies that cover periods before the installation of the hydroelectric dams.

Finally, despite the short history dataset available in this study, the refined data produced by the monitoring method allowed us to characterize the pimelodids' production dynamics in the region. This characterization is the first step to circumvent the lack of systematic and continuous information available about artisanal fishery production in Amazon's inland waters and highlights the importance of the expansion of more refined monitoring methods adapted to each region's specific realities.

Data Availability

The authors will make the dataset used to support the results of this study available upon reasonable request made through the e-mail: liop@ufam.edu.br. Additionally, a visualization of the database is available in the following link: https://app.powerbi.com/view?r=eyJrIjoiYzE0NTcyZGMtNThiMi00YzVmLWI2Y2MtYWRlMWUzZDE0MWFjIiwidCI6ImUxZTlmNWYzLTZlNGUtNDY0Zi1hZDU2LWFmMzBhMzlkMDlhNiJ9.

Additional Points

Highlights. The available fisheries data in the Humaitá region are generic and do not cover the multispecific captures present in small-scale/artisanal fisheries, limiting the use of the data in more robust analyses. This, associated with the hydropower dam construction in the region, makes it challenging to evaluate its effects on fish assemblages and the fisheries resources. New fisheries monitoring methods have been implemented in the region, bringing new light to the part of the "occult data" from inland fisheries. This study presents data prevenient from one of these new methods and compares it with the available data produced in the region, bringing new perspectives and discussions.

Ethical Approval

The information obtained from fishermen in this study was duly registered with Plataforma Brasil under registration number 31850120.0.000.5020.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Igor Hister Lourenço and Larissa Sbeghen Pelegrini investigated the study, proposed the methodology, supervised the study, performed project administration, wrote the original draft, and reviewed and edited the article. Victoria Judith Isaac investigated the study and reviewed and edited the article. Marcelo Rodrigues dos Anjos conceptualized the study, performed formal analysis, investigated the study, performed project administration, proposed the methodology, supervised the study, wrote the original draft, and reviewed and edited the article.

Acknowledgments

The authors would like to thank the Alianza Aguas Amazónicas (AAA); the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq); the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES); and Arthur Oslund and his wife Susan Oslund for the final English revision. This research was funded by the 2020 to 2021 Biodiversa and Water JPI joint call for research projects, under the BiodivRestore ERA-NET Cofund (GA no. 101003777), with the EU and the funding organisations ANR, FCT, DFG, FUNDECT, and FAPEAM (through the Chamada Transnacional Conjunta BiodivRestore 2020-2021, "Conservação e restauração de ecossistemas degradados e sua biodiversidade, incluindo o foco nos sistemas aquáticos"–Resolução FAPEAM no. 016/2020), through the profect Forest Fisher," and by the CNPq, through the projects BACIAS (CNPq/MCTI/FNDCT no. 39/2022 call), and Banzeiro da Educação (CNPq/MCTI no. 55/2022 call). The authors would also like to thank Mastereing Degree Grant provided by FAPEAM to the first author through the Resolução No. 003/2019—POSGRAD UFAM—Edição 2019, developed in the Programa de Pós-Graduação em Ciências Ambientais (PPGCA), at the Instituto de Educação, Agricultura e Ambiente (IEAA) from the Universidade Federal do Amazonas (UFAM). Finally, the authors would like to thank the Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio), for funding the field trip to collect the coordinates of the fishing grounds.

References

[1] G. M. Santos and A. C. M. Santos, "Sustentabilidade da pesca na Amazônia," *Estudios Avanzados*, vol. 19, no. 54, pp. 165–182, 2005.

[2] S. J. Funge-Smith, "Review of the state of world fishery resources: inland fisheries," *Rome: FAO Fisheries and Aquaculture Circular*, vol. 3, 2018.

[3] R. B. Barthem and N. N. Fabré, "Biologia e diversidade dos recursos pesqueiros da Amazônia," in *Ruffino ML. A pesca e os recursos pesqueiros na Amazônia Brasileira*, pp. 11–55, Springer, Berlin, Germany, 2004.

[4] C. R. D. C. Doria, M. L. Ruffino, N. C. Hijazi, and R. L. Cruz, "A pesca comercial na bacia do rio Madeira no estado de Rondônia, Amazônia brasileira," *Acta Amazonica*, vol. 42, no. 1, pp. 29–40, 2012.

[5] H. M. V. Espírito-Santo, M. A. Rodríguez, and J. Zuanon, "Reproductive strategies of Amazonian stream fishes and their fine-scale use of habitat are ordered along a hydrological gradient," *Freshwater Biology*, vol. 58, no. 12, pp. 2494–2504, 2013.

[6] L. E. Hurd, R. G. C. Sousa, F. K. Siqueira-Souza, G. J. Cooper, J. R. Kahn, and C. E. C. Freitas, "Amazon floodplain fish communities: habitat connectivity and conservation in a rapidly deteriorating environment," *Biological Conservation*, vol. 195, pp. 118–127, 2016.

[7] T. M. P. Braga, C. R. Anjos, H. D. B. Anjos, and E. S. Silva, "Diversidade e composição da ictiofauna em dois sistemas de lagos de várzea, com acordo de uso integrado, município de Manacapuru, Amazônia central," in *Sociobiodiversidade e conservação da várzea amazônica. Manaus*, N. N. Fabré, V. B. Silva, and A. V. Waichman, Eds., pp. 161–169, Springer, Berlin, Germany, 2007.

[8] R. B. Barthem, M. Goulding, R. G. Leite et al., "Goliath catfish spawning in the far western Amazon confirmed by the distribution of mature adults, drifting larvae and migrating juveniles," *Scientific Reports*, vol. 7, no. 1, Article ID 41784, 2017.

[9] K. M. Formiga, J. D. S. Batista, and J. A. Alves-Gomes, "The most important fishery resource in the Amazon, the migratory catfish *Brachyplatystoma vaillantii* (Siluriformes: Pimelodidae), is composed by a unique and genetically diverse population in the Solimões-Amazonas River System," *Neotropical Ichthyology*, vol. 19, no. 1, Article ID e200082, 2021.

[10] M. Goulding, "Ecology and management of migratory foods fishes of the Amazon basin," in *Tropical Rainforests: Diversity and Conservation*, F. Almeida and C. M. Pringle, Eds., pp. 71–85, California Academy of Sciences, San Francisco, CA, USA, 1988.

[11] W. J. Junk, M. G. M. Soares, and U. Saint-Paul, "The fish," in *The Central Amazon Floodplain: Ecology of a Pulsing System*, W. J. Junk, Ed., pp. 386–408, Springer, Berlin, Germany, 1997.

[12] R. B. Barthem, J. R. M. Petrere, V. J. Isaac, M. C. L. B. Ribeiro, D. G. Mcgrath, and I. J. A. Vieira, "A pesca na Amazônia: problemas e perspectivas para seu manejo," in *Manejo e conservação de vida silvestre no Brasil. Tefé: Sociedade Civil Mamirauá/CNPq*, C. Valladares-Padua, R. E. Bodmer, and L. Cullen, Eds., pp. 173–185, Springer, Berlin, Germany, 1997.

[13] M. H. Horn, S. B. Correa, P. Parolin et al., "Seed dispersal by fishes in tropical and temperate fresh waters: the growing evidence," *Acta Oecologica*, vol. 37, no. 6, pp. 561–577, 2011.

[14] M. L. Ruffino and R. B. Barthem, "Perspectivas para el manejo de los bagres migradores de la Amazonia," *Boletim Cientifico del INPA*, vol. 15, no. 4, pp. 19–28, 1996.

[15] R. S. Cardoso and C. E. C. Freitas, "Desembarque e esforço de pesca da frota pesqueira comercial de Manicoré (Médio rio Madeira), Brasil," *Acta Amazonica*, vol. 37, no. 4, pp. 605–612, 2007.

[16] G. M. Santos, J. G. F. Efrem, and A. S. Z. Jansen, *Peixes comerciais de Manaus*, INPA, Manaus, Brazil, 2009.

[17] C. R. C. Doria and M. A. L. Lima, *Rio Madeira: seus peixes e sua pesca*, EDUFRO, Rondônia, Brazil, 2015.

[18] I. H. Lourenço, M. R. Anjos, and J. P. Barreiros, "Low-cost technology for fish monitoring applied to the fishing of two species of pacu in Amazonas, Brazil," *Bol Inst Pesca*, vol. 46, no. 2, p. e585, 2020.

[19] M. Lima, C. Freitas, S. Moraes, and C. Doria, "Pesca artesanal no municí--pio de Humaitá, médio rio Madeira, Amazonas, Brasil," *Bol Inst Pesca*, vol. 42, no. 4, pp. 914–923, 2016.

[20] R. E. Santos, R. M. Pinto-Coelho, R. Fonseca, N. R. Simões, and F. B. Zanchi, "The decline of fisheries on the Madeira River, Brazil: the high cost of the hydroelectric dams in the Amazon Basin," *Fisheries Management and Ecology*, vol. 25, no. 5, pp. 380–391, 2018.

[21] V. J. Isaac-Nahum, "Explotação e manejo dos recursos pesqueiros do litoral amazônico: um desafio para o futuro," *Ciencia e Cultura*, vol. 58, no. 3, pp. 33–36, 2006.

[22] M. Goulding, *Ecologia da pesca do rio Madeira*, CNPq/INPA, Manaus, Brazil, 1979.

[23] R. B. Barthem and M. Goulding, *Os bagres balizadores: Ecologia, migração e conservação de peixes amazônicos*, Sociedade Civil Mamirauá/CNPq, Manaus, Brazil, 1997.

[24] H. C. P. De Freitas, C. R. D. C. Doria, and R. G. C. Sousa, "Hydroelectric dams from Madeira River seasonally impacts the fisheries production in the Guaporé basin (Rondônia, Brazil)," *Bol Inst Pesca*, vol. 46, no. 4, pp. 1–11, 2021.

[25] J. Carosfeld, B. Harvey, C. Ross, and A. Baer, *Migratory Fishes of South America. Canada: World Fisheries Trust, the World Bank*, International Development Research Centre, Ottawa, Canada, 2003.

[26] P. M. Fearnside, "Brazil's Amazon forest in mitigating global warming: unresolved controversies," *Climate Policy*, vol. 12, no. 1, pp. 70–81, 2012.

[27] K. D. Das Neves Barros, M. F. Brabo, and A. C. Ferreira, "Impactos de usinas hidrelétricas sobre os recursos pesqueiros amazônicos: os casos de Tucuruí e Belo Monte," *Gaia Scientia*, vol. 14, no. 4, pp. 1–15, 2020.

[28] A. M. V. Santos, C. L. D. B. R. Wongtschowski, and J. L. Figueiredo, "Recursos pesqueiros compartilhados: bioecologia, manejo e aspectos aplicados no Brasil," *Bol Inst Pesca*, vol. 33, no. 2, pp. 273–292, 2007.

[29] M. L. Ruffino, *A pesca e os recursos pesqueiros na Amazônia brasileira*, Brasília: Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis (IBAMA), Brasília, Brazil, 2004.

[30] G. C. D S. Lopes, M. F. Catarino, Á. C. Lima, and C. E. D C. Freitas, "A pesca de pequena escala na bacia Amazônica: padrões gerais e diversidade pelos desembarques de cinco sub-bacias," *Bol Inst Pesca*, vol. 42, no. 4, pp. 889–900, 2016.

[31] S. E. Bunn and A. H. Arthington, "Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity," *Environmental Management*, vol. 30, no. 4, pp. 492–507, 2002.

[32] Fao, *Strengthening the Science-Policy Nexus*, FAO Headquarters, Rome, Italy, 2020.

[33] M. Goulding, E. Venticinque, M. L. D. B. Ribeiro et al., "Ecosystem-based management of Amazon fisheries and wetlands," *Fish and Fisheries*, vol. 20, no. 1, pp. 138–158, 2018.

[34] R. E. A. Cruz, V. J. Isaac, and E. T. Paes, "A pesca da dourada *Brachyplatystoma rousseauxii* (Castelnau, 1855) na região do Baixo Amazonas, Brasil," *Bol Inst Pesca*, vol. 43, no. 4, pp. 474–486, 2017.

[35] L. Castello, "Re-pensando o estudo e o manejo da pesca no Brasil," *PANAMJAS*, vol. 3, no. 1, pp. 17–22, 2008.

[36] L. J. Queiroz, G. Torrente-Vilara, W. M. Ohara, T. H. S. Pires, J. Zuanon, and C. R. C. Doria, *Peixes do Rio Madeira*, Dialeto Latin American Documentary, São Paulo, 2013.

[37] S. S. Shapiro and M. B. Wilk, "An analysis of variance test for normality (complete samples)," *Biometrika*, vol. 52, no. 3-4, pp. 591–611, 1965.

[38] J. L. Romeu and A. Ozturk, "A comparative study of goodness-of-fit tests for multivariate normality," *Journal of Multivariate Analysis*, vol. 46, no. 2, pp. 309–334, 1993.

[39] C. J. Mecklin and D. J. Mundfrom, "A Monte Carlo comparison of the Type I and Type II error rates of tests of multivariate normality," *Journal of Statistical Computation and Simulation*, vol. 75, no. 2, pp. 93–107, 2005.

[40] W. H. Kruskal and W. A. Wallis, "Use of ranks in one-criterion variance analysis," *Journal of the American Statistical Association*, vol. 47, no. 260, pp. 583–621, 1952.

[41] N. C. Kenkel and L. Orlóci, "Applying metric and nonmetric multidimensional scaling to ecological studies: some new results," *Ecology*, vol. 67, no. 4, pp. 919–928, 1986.

[42] P. G. N. Digby and R. A. Kempton, *Multivariate Analysis of Ecological Communities*, Chapman and Hall, London, UK, 1996.

[43] C. E. M. Bicudo and D. C. Bicudo, "Amostragem em limnologia," *São Carlos: RiMa*, vol. 1, 2007.

[44] J. R. J. F. Hair, R. E. Anderson, R. L. Tatham, and W. C. Black, *Análise multivariada de dados. Porto Alegre*, Bookman, New York, NY, USA, 2009.

[45] K. R. Clarke, "Non-parametric multivariate analyses of changes in community structure," *Australian Journal of Ecology*, vol. 18, no. 1, pp. 117–143, 1993.

[46] O. Hammer, *Paleontological Statistics Version 3.15. Reference Manual*, Natural History Museum, University of Oslo, Oslo, Norway, 2017.

[47] J. R. Bray and J. T. Curtis, "An ordination of the upland forest communities of southern Wisconsin," *Ecological Monographs*, vol. 27, no. 4, pp. 325–349, 1957.

[48] J. L. Valentin, *Ecologia numérica: uma introdução à análise multivariada de dados ecológicos*, Interciência, Rio de Janeiro, Brazil, 2000.

[49] K. Mcgarigal, S. Cushman, and S. Stafford, *Multivariate Statistics for Wildlife and Ecology Research*, Springer-Verlag, New York, NY, USA, 2000.

[50] W. H. Press, S. A. Teukolsky, W. T. Vetterling, and B. P. Flannery, *Numerical Recipes in C: The Art of Scientific Computing*, Cambridge University Press, Cambridge, UK, 1992.

[51] C. J. F. Ter-Braak, "Canonical correspondence analysis: a new eigenvector technique for multivariate direct gradient analysis," *Ecology*, vol. 67, no. 5, pp. 1167–1179, 1986.

[52] P. Legendre and L. Legendre, *Numerical Ecology*, Elsevier, Amsterdam, Netherlands, 2012.

[53] M. Petrere Jr, "Pesca e esforço de pesca no Estado do Amazonas. II: locais, aparelhos de captura e estatísticas de desembarque," *Acta Amazonica*, vol. 8, no. 2, pp. 5–54, 1978.

[54] M. Petrere Jr, "A pesca comercial no rio Solimões-Amazonas e seus afluentes: análise dos informes do pescado desembarcado no mercado municipal de Manaus (1976-1978)," *Ciencia e Cultura*, vol. 37, no. 12, pp. 1987–1999, 1985.

[55] V. J. Isaac and R. B. Barthem, "Os recursos pesqueiros da Amazônia Brasileira," *Boletim do Museu Paraense Emilio Goeldi Serie Antropologia*, vol. 11, no. 2, pp. 295–339, 1995.

[56] J. R. M. Petrere, V. S. Batista, C. T. A. Freitas, O. T. Almeida, and A. C. S. Surgik, "Amazônia: ambientes, recursos e pescam," *Science and Culture*, vol. 15, pp. 11–17, 2007.

[57] W. H. D. Pinaya, F. J. Lobon-Cervia, P. Pita, R. Buss de Souza, J. Freire, and V. J. Isaac, "Multispecies fisheries in the lower Amazon river and its relationship with the regional and global climate variability," *PLoS One*, vol. 11, no. 6, Article ID e0157050, 2016.

[58] M. L. Ruffino and V. J. Isaac, "The Fisheries of the Lower Amazon: questions of management and development," *Acta Biologica Venezuelica*, vol. 15, no. 2, pp. 37–46, 1994.

[59] M. L. Ruffino and V. J. Isaac, "Dinâmica populacional de surubim-tigre, *Pseudoplatystoma tigrinum* (Valenciennes, 1840) no Médio Amazonas (Siluriformes, Pimelodidae)," *Acta Amazonica*, vol. 29, no. 3, pp. 463–476, 1999.

[60] A. I. Payne, *The Ecology of Tropical Lakes and Rivers*, John Wiley and Sons, New York, NY, USA, 1986.

[61] G. M. Santos, "Composição do pescado e situação da pesca no Estado de Rondônia," *Acta Amazonica*, vol. 17, no. suppl 1, pp. 43–84, 1987.

[62] M. Petrere Jr, "Pesca na amazônia," in *Secretaria de Estado de Ciência, Tecnologia e Meio Ambiente-Pará. SIMDA-MAZÔNIA, Seminário Internacional Sobre Meio Ambiente, Pobreza e Desenvolvimento da Amazônia*, pp. 72–78, John Wiley and Sons, New York, NY, USA, 1992.

[63] S. A. Mingoti, *Análise de dados através de métodos estatística multivariada: uma abordagem aplicada*, John Wiley and Sons, New York, NY, USA, 2007.

[64] H. A. Bakke, A. S. D. M. Leite, and L. B. Silva, "Estatística multivariada: aplicação da análise fatorial na engenharia de produção," *Revista Gestão Industrial*, vol. 4, no. 4, pp. 01–14, 2008.

[65] G. Loubens and J. Panfili, "Biologie de *Pseudoplatystoma fasciatum* et *P. tigrinum* (Teleostei: Pimelodidae) dans le bassin du Mamoré (Amazonie Bolivienne)," *Ichthyological Exploration of Freshwaters*, vol. 11, no. 1, pp. 13–34, 2000.

[66] J. E. Santos, G. E. V. Padilha, O. Bomcompagni-Júnior, G. B. Santos, E. Rizzo, and N. Bazzoli, "Ovarian follicle growth in the catfish *Iheringichthys labrosus* (Siluriformes: Pimelodidae)," *Tissue and Cell*, vol. 38, no. 5, pp. 303–310, 2006.

[67] J. E. Santos, V. C. Veloso-Júnior, D. A. Andrade Oliveira, and R. E. S. Hojo, "Morphological characteristics of the testis of the catfish *Pimelodella vittate* (Lütken, 1874)," *Journal of Applied Ichthyology*, vol. 26, no. 6, pp. 942–945, 2010.

[68] M. L. Santos, N. G. Sales, F. P. Arantes, T. C. Pessali, N. Bazzoli, and J. E. Santos, "Anatomical and histological organization of the testes of the inseminating catfish *Trachelyopterus striatulus* (steindachner, 1877) (siluriformes: auchenipteridae)," *Anatomia Histologia Embryologia*, vol. 43, no. 4, pp. 310–316, 2013.

[69] J. E. dos Santos, L. Marcon, M. F. Guedes Brito, N. G. Sales, E. Rizzo, and N. Bazzoli, "Reproductive biology of the Neotropical catfish *Iheringichthys labrosus* (Siluriformes: Pimelodidae), with anatomical and morphometric analysis of gonadal tissues," *Animal Reproduction Science*, vol. 209, Article ID 106173, 2019.

[70] R. G. Leite, C. Cañas, B. Forsberg, R. Barthem, and M. Goulding, *Larvas dos Grandes Bagres Migradores. Manaus: Instituto Nacional de Pesquisas da Amazônia-INPA, Asociación para la Conservación de la Cuenca Amazónica-ACCA*, Elsevier, Amsterdam, Netherlands, 2007.

[71] C. A. R. M. Araujo-Lima and E. C. Oliveira, "Transport of larval fish in the Amazon," *Journal of Fish Biology*, vol. 53, no. sA, pp. 297–306, 1998.

[72] F. Duponchelle, M. Pouilly, C. Pécheyran et al., "Trans-Amazonian natal homing in giant catfish," *Journal of Applied Ecology*, vol. 53, no. 5, pp. 1511–1520, 2016.

[73] M. M. Ramos and H. D. S. Pereira, "Os ambientes, a pesca e a gestão das pescarias da piramutaba (*Brachyplatystoma vaillantii*) no Estuário Amazônico-PA," *Novos Cadernos NAEA*, vol. 14, no. 1, pp. 115–129, 2011.
[74] N. N. Fabré and R. B. Barthem, *O manejo da pesca dos grandes bagres migradores: piramutaba e dourada no eixo Solimões-Amazonas*, Elsevier, Amsterdam, Netherlands, 2005.
[75] V. J. Isaac, C. O. Silva, and M. L. Ruffino, "A pesca no Baixo Amazonas," in *Ruffino ML. A pesca e os recursos pesqueiros na Amazônia brasileira. Manaus: Edições ProVarzea/IBAMA*, pp. 185–211, Elsevier, Amsterdam, Netherlands, 2004.
[76] A. Garcia, V. Montreuil, and R. Rodriguez, "Talla de la primera maduracion y epoca de desova de la "doncella," *Pseudoplatystoma fasciatum* (Linnaeus), Y el "tigre zungaro," *Pseudoplatystoma tigrinum* (Valanciennes), en la Amazonia Peruana," *Boletim do Museu Paraense Emílio Goeldi*, vol. 17, no. 1, pp. 3–13, 2001.
[77] A. Barbarino, "Aspectos biológicos y pesqueros de los bagres rayados *Pseudoplatystoma fasciatum* (Linnaeus, 1766) y *P. tigrinum* (Valenciennes, 1840) (Siluriformes: Pimelodidae) en la parte baja de los ríos Apure y Arauca, Venezuela," *Mem Fund La Salle Cien Nat*, vol. 163, pp. 71–91, 2005.
[78] R. R. Ota, H. J. Message, W. J. da Graça, and C. S. Pavanelli, "Neotropical siluriformes as a model for insights on determining biodiversity of animal groups," *PLoS One*, vol. 10, no. 7, Article ID e0132913, 2015.
[79] E. U. Faria, S. C. Loebens, K. C. Yamamoto, F. K. Siqueira-Souza, C. E. C. Freitas, and H. B. Anjos, "Assembleia de peixes em lagos do rio Quiuini, um tributário do rio Negro, Amazonas, Brasil," *Biota Amazônia*, vol. 7, no. 1, pp. 74–81, 2017.
[80] R. E. A. Cruz, D. A. Kaplan, P. B. Santos, A. O. Ávila-da-Silva, E. E. Marques, and V. J. Isaac, "Trends and environmental drivers of giant catfish catch in the lower Amazon River," *Marine and Freshwater Research*, vol. 72, no. 5, pp. 647–657, 2021.
[81] G. C. S. Lopes and C. E. C. Freitas, "Avaliação da pesca comercial desembarcada em duas cidades localizadas no rio Solimões-Amazonas," *Biota Amazônia*, vol. 8, no. 4, pp. 36–41, 2018.
[82] M. Oetterer, L. K. Savay-da-Silva, and J. A. Galvão, *Uso Do Gelo É Peça-Chave Na Conservação Do Pescado*, Visão agrícola no11, Piracicaba, Brazil, 2012.
[83] C. H. Hanry Faria junior and V. D. S. Da Silva Batista, "Frota pesqueira comercial na Amazônia central: composição, origem, espécies exploradas e mercado," *Agroecossistemas*, vol. 11, no. 1, pp. 146–168, 2019.
[84] P. R. Abdallah and C. J. C. Bacha, "Evolução da atividade pesqueira no Brasil: 1960- 1994," *Revista Teoria e Evidência Econômica*, vol. 7, no. 13, pp. 9–24, 1999.
[85] R. V. Espírito-Santo and V. J. Isaac, "Desembarques da pesca de pequena escala no município de Bragança – PA, Brasil: esforço e produção," *Boletim do Laboratório de Hidrobiologia*, vol. 25, no. 1, pp. 31–48, 2012.
[86] T. S. D. C. Magno, A. C. F. Saraiva, K. C. D. A. Silva, and H. A. Cintra, "Infraestrutura da atividade pesqueira em áreas de barragem na Amazônia: o caso do reservatório da usina hidrelétrica de Tucuruí, Pará, Brasil," *Boletim Tecnico-Cientifico do Cepnor*, vol. 17, no. 1, pp. 29–38, 2018.
[87] A. R. Correia, C. R. Musis, J. P. N. Filho, M. V. B. R. Ribeiro, S. E. M. Leite, and V. H. M. Danelichen, "Análise de Pescado sem cabeça," *Revista Brasileira de Criminalística*, vol. 9, no. 2, pp. 22–29, 2020.
[88] O. J. Dunn, "Multiple comparisons using rank sums," *Technometrics*, vol. 6, no. 3, pp. 241–252, 1964.
[89] C. E. C. Freitas and A. A. F. Rivas, "A pesca e os recursos pesqueiros na Amazônia Ocidental," *Ciencia e Cultura*, vol. 58, no. 3, pp. 30–32, 2006.
[90] G. M. Santos and A. B. Oliveira Jr, "A pesca no reservatório da Hidrelétrica de Balbina (Amazonas, Brasil)," *Acta Amazonica*, vol. 29, no. 1, pp. 145–163, 1999.
[91] M. G. M. Soares and W. J. Junk, "Commercial fishery and fish culture of the state of Amazonas: status and perspectives," in *The central Amazon Floodplain: Actual Use and Options for a Sustainable Management*, W. J. Junk, J. J. Ohly, M. T. F. Piedade, and M. G. M. Soares, Eds., pp. 433–461, Backhuys Publishers, Netherlans, Europe, 2000.
[92] J. H. Zar, *Biostatistical Analysis*, Prentice-Hall International Editions, New Jersey, NJ, USA, 2009.