

Characterization of an Artisanal Multigear Fishery in the Core Zone of La Encrucijada Biosphere Reserve, Mexican Pacific

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Abstract

Artisanal fisheries operating within protected coastal systems play a critical role in sustaining local livelihoods while interacting closely with ecologically sensitive environments. This study provides an integrated assessment of a multigear artisanal fishery operated by a cooperative society in Barra Zacapulco, located within the core zone of La Encrucijada Biosphere Reserve on the southern Pacific coast of Mexico. Catch data derived from cooperative landing records and monitored fishing trips were used to analyze catch composition, catch per unit effort (CPUE), relative biomass, by-catch, and seasonal patterns across different fishing gears. In addition, socio-economic surveys were conducted to characterize fishers' profiles and perceptions of fishery trends and environmental change. Results revealed a multispecific fishery strongly structured by fishing gear and hydrological seasonality. Finfish catches were concentrated during the dry season, whereas shrimp exploitation was closely linked to the rainy season, when increased freshwater discharge enhances lagoon productivity and connectivity. Cast nets emerged as the most widely used and comparatively balanced gear, while stow nets exhibited higher shrimp efficiency but

generated substantially greater by-catch, including species of conservation concern. Socio-economic findings highlighted a locally rooted and experienced fishing community, but also pointed to challenges related to aging fishers, limited formal education, and the underrepresentation of women in capture activities. Fishers' perceptions of declining catches and environmental degradation—particularly mangrove loss, sedimentation, pollution, and reduced fishing areas—were consistent with empirical and historical evidence. These findings underscore the need for integrated and participatory management strategies that incorporate seasonal dynamics, promote selective fishing practices, mitigate by-catch, and strengthen local capacities to ensure the sustainability of artisanal fisheries within protected areas.

Keywords

By-Catch, Catch per Unit Effort, Environmental Perceptions, Fisherwomen, Natural Protected Area

1. Introduction

Artisanal fisheries represent a key socio-ecological system in many tropical coastal regions, providing food security, employment, and cultural identity to millions of people worldwide [1]. In Mexico, this sector contributes significantly to national fishery production, particularly along the Pacific coast, where lagoon-estuarine systems support diverse small-scale fishing practices [2]. These fisheries are typically multispecific and rely on a variety of gear types, each with distinct operational characteristics and ecological implications. Despite their importance, artisanal fisheries often face multiple challenges, including declining fish stocks, habitat degradation, limited institutional support, and increasing socio-economic vulnerability among fishing communities [3].

The productivity and sustainability of coastal fisheries are closely tied to the condition of critical habitats such as mangroves [4]. These ecosystems serve as essential nursery, feeding, and refuge areas for numerous species of commercial interest. Growing evidence indicates a positive correlation between the extent of mangrove cover and the productivity of adjacent fisheries, as mangrove ecosystems support the early life stages and habitat requirements of a wide range of economically valuable aquatic species [5]. However, these habitats are under growing pressure due to land use change, pollution, and hydrological alterations, leading to a decline in their ecological functionality [6]. This degradation not only affects biodiversity but also undermines the ecosystem services that sustain artisanal fisheries. Consequently, evaluating the interaction between fishing practices and habitat conditions becomes essential for informing effective management strategies [7].

In the coastal lagoon systems of the southern Pacific coast of Mexico, artisanal fishing is deeply embedded in the livelihoods, culture, and identity of local com-

munities. The use of gears such as cast nets, gillnets, handlines, and stow nets reflects a high degree of adaptability among fishers operating under variable environmental conditions and pronounced seasonal fluctuations in resource availability [8] [9]. However, the efficiency and selectivity of these gears vary substantially, influencing both the composition of target catches and the magnitude of by-catch, including non-target and protected species. Understanding gear-specific catch patterns is therefore essential for assessing the ecological impacts of artisanal fisheries and identifying opportunities to improve selectivity and reduce by-catch [10].

The social dimension of artisanal fisheries further shapes harvesting strategies and responses to environmental change. Factors such as age structure, gender participation, educational level, and livelihood diversification influence how fishing communities interact with coastal ecosystems and adapt to resource variability [11]. In this context, fishers' local ecological knowledge—often accumulated over decades of experience—provides valuable insight into long-term changes in fish availability and habitat quality. Perceptions of declining catches, frequently linked to observable stressors such as mangrove loss and lagoon sedimentation, align with broader patterns of ecosystem degradation and underscore the need for integrated and socially informed management approaches [12].

Chiapas, a southern Mexican state with a Pacific coastline and bordering Guatemala, is notable for its extensive marine-coastal conservation framework. The state hosts two federally protected areas—the Puerto Arista Beach Sanctuary and La Encrucijada Biosphere Reserve—as well as two state-level protected areas (Cabildo-Amatal and Gancho-Murillo), which together encompass at least 153,847 ha of terrestrial and continental aquatic environments under legal protection. Despite Mexico's vast marine and coastal extent, and the importance of fisheries within these environments, relatively few studies have undertaken comprehensive characterizations of fishing units operating within protected areas, particularly in southern Mexico [13].

At the time of its designation in 1995, La Encrucijada Biosphere Reserve supported approximately 26,992 inhabitants engaged primarily in agriculture, livestock production, and fishing, with 16 fishing cooperatives holding active concessions within the reserve [14]. Under the Mexican system of Natural Protected Areas, biosphere reserves operate under a zoning framework that allows regulated artisanal fishing by authorized cooperatives, even within core zones, provided that these activities comply with specific regulations regarding the number of fishers, fishing sites, gear types, and seasonal restrictions. Although the core zone represents the most restrictive management category, economic activities deemed compatible with conservation objectives are legally permitted, making these areas particularly relevant for evaluating the balance between resource use and ecosystem protection.

Within this context, characterizing catch composition, fishing effort, CPUE, by-catch, and the social dimensions of artisanal fisheries operating inside the core

zone of La Encrucijada Biosphere Reserve is critical for informing management strategies that reconcile conservation goals with the livelihoods of local fishing communities. Against this background, the present study examines the structure and dynamics of the artisanal multigear fishery in Barra Zacapulco, a cooperative society that operates within the core zone of La Encrucijada Biosphere Reserve. Adopting an interdisciplinary approach, the research integrates ecological, technological, and social dimensions to provide a comprehensive assessment of local fishing practices. Specifically, it quantifies gear-specific catch composition, relative biomass, and catch per unit effort (CPUE), evaluates by-catch, and incorporates socio-economic data and fishers' perceptions regarding fishing practices and their relationship with surrounding ecosystems. The findings aim to generate evidence that supports sustainable fisheries management and highlights the ecosystem services provided by mangrove-associated habitats in sustaining coastal livelihoods.

2. Material and Methods

2.1. Study Area

Barra Zacapulco (BZ) is located within the core zone of La Encrucijada Biosphere Reserve (**Figure 1**), a federally Protected Natural Area on the southern coast of Chiapas, designated in 1995 to conserve approximately 144,868 ha of mangroves, swamps, and flooded forests characteristic of the southernmost Mexican Pacific coast [14].

The BZ fishing cooperative was founded in 1977 and has historically focused on the capture of shrimp and finfish within a network of tidal creeks locally known as “esteros”, located northwest of the main inlet (Boca de San Juan), entirely within the core zone of the reserve, comprised by the Chantuto-Panzacola lagoon system. Other fishing cooperatives—including La Palma, Los Cerritos, Las Lauras, El Castaño, and Unión Santa Isabel—established between 1941 and 1993, also operate within what is currently designated as the core zone of La Encrucijada Biosphere Reserve, highlighting the long-standing coexistence of artisanal fisheries and conservation-oriented land use in this area [15].

The region has a warm sub-humid climate, with a mean annual temperature of 28.2°C and an average annual precipitation of 1567 mm. Seasonal variability, characterized by a rainy season (May-October) and a dry season (November-April), strongly influences hydrological conditions, which range from limnetic (≈ 0.5 PSU) to polyhaline (>20 PSU). The fishing grounds of BZ are shallow with depths that vary between 0.5 and 4.5 m [16] [17]. The cooperative's fleet is composed of 126 fiberglass dugout canoes (≈ 19.7 ft) equipped with 5 - 15 hp outboard motors.

2.2. Data Collection

Catch data were obtained from landing reports submitted by fishers to the BZ cooperative between January 2015 and October 2016. These reports characterize

the activity of virtually the entire regulated fleet, and the information was curated to include the total daily catch weights reported per fisher for the target groups—shrimps, snappers, snooks, mojarras, and mullets—as recorded under the commercial categories used in the cooperative landing reports, caught with cast nets, gill-nets, and handlines. Reported weights of organisms not belonging to these target groups were classified as by-catch for each gear.

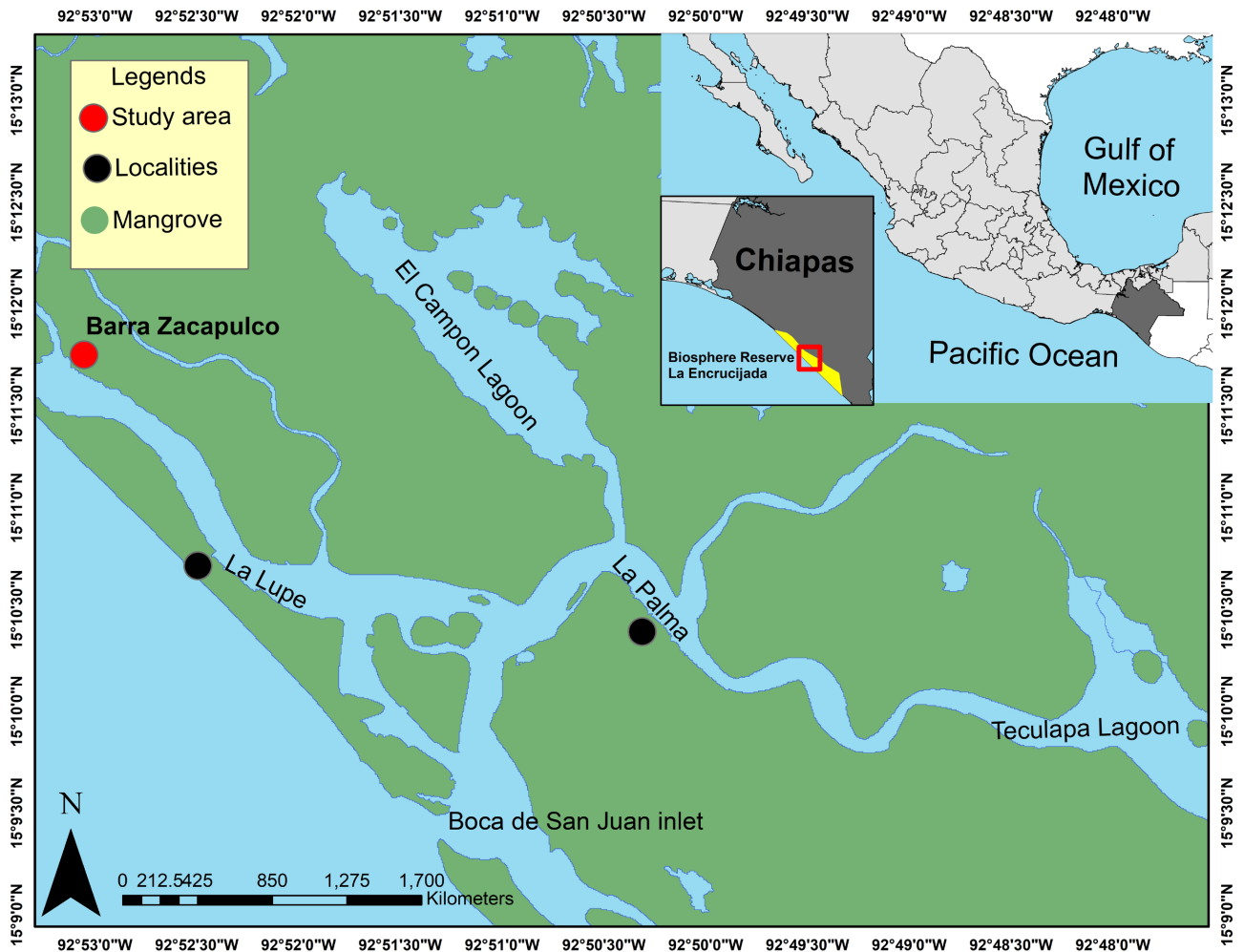


Figure 1. Localization of the study area.

In the case of the stow net, an unregulated gear used for shrimp harvesting, nine fishing trips carried out by local fishers between August and November 2024 were accompanied and monitored to characterize the activity, recording both the total shrimp catch and the associated by-catch in each trip. All fishing gears were measured, and their materials and mode of operation were verified *in situ* to refine their characterization. Stow net monitoring was conducted in collaboration with local fishers who regularly operate this gear within the lagoon system. The accompanied trips were selected opportunistically based on fishers' availability during the shrimp fishing season and are considered representative of the typical operational conditions of this gear in the area. During each monitored trip, the total shrimp

catch was recorded and the associated by-catch was sorted immediately after gear retrieval. When necessary, quarter subsamples of the by-catch were collected to characterize the taxonomic composition of the associated fauna. These subsamples were also used to estimate the approximate biomass relationship between shrimp catch and by-catch for each fishing operation.

Cooperative landing records were reviewed and curated prior to analysis. Reported catch weights correspond to the quantities delivered by individual fishers to the cooperative at the end of each fishing trip and were measured using a mechanical hanging dial scale at the landing site. Catches were recorded under the categories used in the cooperative landing reports (e.g., shrimps, snappers, snooks, mojarras, and mullets). The dataset was reviewed for internal consistency between fishing gear, reported catch category, and catch weight, and records with incomplete information were excluded from the analysis. Because landing records were reported under commercial group categories rather than species-level identifications, some degree of taxonomic aggregation may occur; therefore, CPUE estimates and catch composition values are interpreted at the target-group level rather than at the species level.

Although stow net data correspond to a later monitoring period (2024) than the cooperative landing records (2015-2016), CPUE comparisons were conducted to explore potential differences in gear performance. Artisanal fisheries in the lagoon system have historically relied on a limited set of traditional fishing gears—including cast nets, gillnets, handlines, and stow nets—which have been consistently documented in previous studies of the region [18]. Because the datasets originate from different monitoring periods and collection approaches, these comparisons should nevertheless be interpreted cautiously and considered indicative of gear-specific catch efficiency rather than strict cross-period statistical contrasts.

Specimens from all reported target groups were examined *in situ* to confirm their taxonomic identity. Subsamples of the by-catch obtained during stow net trips were fixed and preserved for later taxonomic identification. Fish and shrimps were identified using taxonomic keys for the Eastern Pacific and Mexico [19] [20], while other faunal groups were identified using additional descriptions and regional field guides relevant to each taxonomic group. The taxonomic nomenclature of shrimp species in this study follows the World Register of Marine Species [21]. For finfish, scientific names were updated and standardized according to Eschmeyer's Catalog of Fishes [22].

2.3. Data Analysis

Catch data were obtained from landing reports submitted by fishers to the BZ cooperative between January 2015 and October 2016. For the cooperative's regulated fisheries (cast nets, gillnets, and handlines), total catch was obtained as the sum of all biomass categories per trip, representing the landings of the entire active fleet. For stow nets, total catch values correspond exclusively to the observed

catches from the monitored gears (three to five nets) and were not extrapolated to the total number of nets operated.

$$\text{Relative biomass}_i = (B_i / \sum B_{\text{total}}) \times 100,$$

where B_i is the biomass (kg) of group i , and $\sum B_{\text{total}}$ is the total biomass recorded in the trip.

CPUE was calculated as the ratio of total catch to fishing time. For each gear type, the number of fishing hours was standardized to the mean number of hours recorded per fishing trip:

$$CPUE_i = B_i / H,$$

where B_i is the biomass (kg) of group i and H is the number of hours fished per trip, as reported or observed. This standardization allows for direct comparison of extraction intensity across different fishing gears with distinct operational times and modes. These calculations followed protocols for catch standardization commonly applied in small-scale fisheries [23]-[25], and were implemented using Microsoft Excel for post-processing and visualization.

In this study, fishing time refers to the effective time during which the fishing gear was actively deployed in the water. Travel time between the landing site and fishing grounds, as well as search time for fishing locations, was not included in the effort calculation. Fishing hours were estimated based on the average duration of gear operation reported by fishers during structured interviews and field observations. In some fishing trips, vessels operated more than one fishing gear (e.g., cast nets in combination with gillnets or handlines). In such cases, fishing effort was estimated separately for each gear according to the time actively devoted to its operation. This procedure allowed the calculation of gear-specific CPUE values while maintaining comparability among fishing methods with different operational characteristics.

As a complementary step, inferential analyses were applied to evaluate whether significant differences in CPUE existed among fishing gears for each target group and by-catch category. Prior to the analyses, data distributions were tested for normality (Shapiro-Wilk test) and homogeneity of variances (Levene's test). When assumptions were met, one-way ANOVA was used to compare CPUE across gears, followed by Tukey's HSD post-hoc tests. When assumptions were not satisfied, the non-parametric Kruskal-Wallis test was applied [26], with Dunn's post-hoc pairwise comparisons using Bonferroni adjustment. This procedure allowed us to determine whether observed differences in catch efficiency among gears reflected consistent statistical patterns rather than sampling variability. Effect sizes were interpreted in terms of the magnitude of differences in mean CPUE among gears. All tests were performed in PAST 5 [27].

Additionally, in May 2025, a total of 42 structured interviews were conducted during a cooperative assembly and through household visits to fishers. The purpose of these interviews was to complement and calibrate the quantitative records of fishing effort and catch. Information was gathered on the average number of

hours dedicated to fishing, the frequency of net deployments per day, seasonality and further details on the composition of the by-catch. The interviews also explored fishers' perceptions regarding long-term trends in fishing activity and their relationship with surrounding ecosystems, particularly mangroves. This information provided a socio-ecological context to the landing data and contributed to validating the estimates of effort and catch derived from cooperative reports and monitored trips.

3. Results

3.1. Fishing Effort, Catch Composition, and CPUE

From January 2015 to October 2016, a total of 5,364 fishing trips carried out by 147 vessels were characterized in BZ. All vessels used cast nets as the primary fishing gear, while 50% also operated handlines and 47% gillnets. Between August and November 2024, five stow nets were recorded in BZ, although only three were regularly operated during the evaluated period. Information on the characterization of fishing units by gear is summarized in **Table 1**. The main fishing gears—cast nets, gill nets, handlines, and stow nets—differ in operation, dimensions, and the commercially important species they capture in coastal lagoon systems.

Table 1. Characterization of fishing units by gear in the artisanal fishery of Barra Zacapulco, Chiapas, Mexico.

Fishing gear	Number of fishing units (vessels/nets)	Total number of trips	Mean hours per trip \pm S.D.
Cast net ^a	147	3822	6 \pm 1
Gill net ^a	69	406	8 \pm 1.5
Handline ^a	73	1136	4.8 \pm 1.2
Stow net ^b	5	9	5.3 \pm 2

^aCharacterization conducted between January 2015 and October 2016. ^bCharacterization conducted between August and November 2024.

The cast net is a circular multifilament nylon net, manually deployed from canoes or the shoreline to maximize coverage. After settling on the bottom, the drawline is pulled, closing the net and preventing the escape of captured organisms. Two types are commonly used: the shrimp cast net (7.39 m diameter, 1-inch mesh) and the fish cast net (2.5-inch mesh). Operations are typically conducted by one or two fishers, with travel times to fishing sites averaging 30 minutes.

The gill net is constructed of nylon with floats along the upper edge and weights along the lower, forming a horizontal barrier fixed to mangroves or stakes near the surface or bottom. Standard nets measure approximately 200 m in length and 5 m in depth, remain deployed for nine hours, and are checked every three hours. They primarily capture finfish, which are of commercial importance.

Handline fishing employs a monofilament nylon line with a baited hook, targeting primarily predatory finfish. The line is manually handled, allowing direct detection of bites, with static or dynamic manipulation to stimulate fish activity.

This method is widely used in lagoon environments to capture commercially important fish species.

The stow net—locally known as “copo”—is a conical or cylindrical bottom net positioned against the current. Fishers deploy stow nets approximately five hours per day and inspect them every 45 minutes. In lagoon systems, stow nets primarily target shrimp, while also capturing a diverse array of by-catch species of commercial importance.

Total catches in the general sampling of the fishery at BZ varied according to the target group and fishing gear. Shrimps accounted for 54% of the total catch, followed by mullets (21.1%), snooks (13.3%), snappers (5.1%), and mojarras (2.4%). The by-catch, both discarded and retained, represented 3.8% of the overall catch. Regarding the highest relative biomass values by fishing gear, shrimps in BZ accounted for 68.66% of the total biomass captured with cast nets; snappers contributed 61.15% of the biomass recorded with handlines, and snooks 53.39% of the biomass obtained with gillnets. The stow net exhibited the highest relative by-catch values, representing 56.3% of its total catch. **Table 2** summarizes the fishing effort by target group in BZ for the study periods.

The results revealed clear differences in gear selectivity toward target groups (**Figure 2**). In the case of shrimp, the highest catch rates were obtained using the stow net ($9.69 \text{ kg}\cdot\text{h}^{-1}$), significantly greater than those recorded with cast nets ($1.6 \text{ kg}\cdot\text{h}^{-1}$) ($t = 1.63$, $df = 9$, $p = 0.03$). Snappers were caught using cast nets, gillnets, and handlines, with the highest yield from gillnets ($0.87 \text{ kg}\cdot\text{h}^{-1}$) and the lowest from handlines ($0.68 \text{ kg}\cdot\text{h}^{-1}$), although the differences were not statistically significant [ANOVA: $F(df = 2, 25) = 2.32$, $p = 0.12$]. A similar pattern was observed for snooks, with the gillnet yielding the highest catch rate ($1.15 \text{ kg}\cdot\text{h}^{-1}$) and the cast net the lowest ($0.79 \text{ kg}\cdot\text{h}^{-1}$), with no significant differences among gears [ANOVA: $F(df = 2, 25) = 0.52$, $p = 0.59$]. Mulletts were captured using cast nets and gillnets with similar catch rates (1.76 and $1.61 \text{ kg}\cdot\text{h}^{-1}$, respectively), with no significant difference between gears ($t = 0.83$, $df = 17$, $p = 0.41$).

Regarding by-catch, the stow net yielded substantially higher rates ($12.5 \text{ kg}\cdot\text{h}^{-1}$) compared to the cast net ($0.6 \text{ kg}\cdot\text{h}^{-1}$), with significant differences between gears (Kruskal-Wallis: $H = 6.87$, $df = 2$, $p = 0.03$). These findings highlight the contrasting efficiency and selectivity among the evaluated fishing gears: the stow net was the most effective for shrimp harvest but also produced the largest amount of by-catch, while the cast net showed broader selectivity across multiple groups with relatively low levels of by-catch (**Figure 2**).

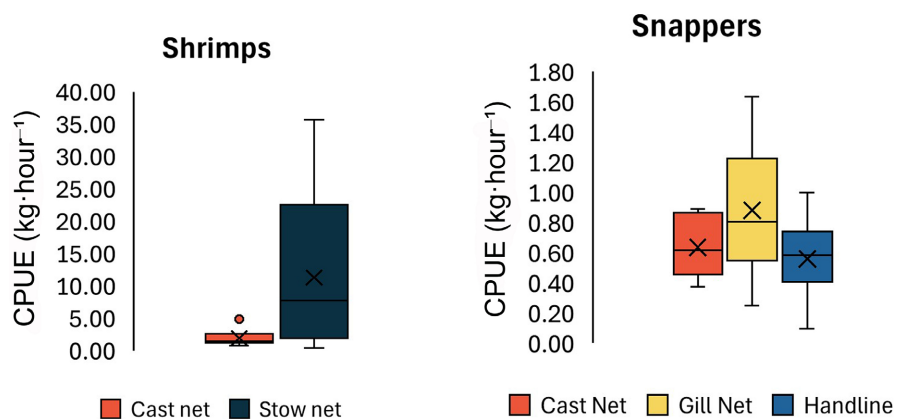
In this study, 18 species belonging to five target groups were identified (**Table 3**). The group of shrimps captured comprised three Pacific penaeids: *Penaeus californiensis*, *P. stylirostris*, and *P. vannamei*, the latter being the most abundant. In the case of target fishes, four different species were identified within each group of snappers (Lutjanidae) and snooks (Centropomidae). For mojarras, four species belonging to two families (Gerreidae and Cichlidae) were recorded, while three species were recognized among mullets (Mugilidae).

Table 2. Fishing effort characterization by gear and target group in the artisanal fishery of Barra Zacapulco, Chiapas, Mexico.

Fishing gear	Target group and by-catch	Fishing effort		Predominant season of catches	Mean CPUE \pm S.D. (kg·h ⁻¹)
		Total catch (kg)	Relative biomass (%)		
Cast net ^a	Shrimps	26330.7	68.66	Dry (88.55%)	1.60 \pm 1.55
	Snappers	552.5	1.44	Dry (65.10%)	0.71 \pm 0.53
	Snooks	646.2	1.69	Dry (68.99%)	0.79 \pm 1.03
	Mojarras	916.4	2.39	Dry (76.67%)	0.54 \pm 0.45
	Mulletts	9501.9	24.78	Dry (64.71%)	1.76 \pm 1.47
	By-catch	400.7	1.04	Dry (76.34%)	0.60 \pm 0.45
Gillnet ^a	Snappers	333.7	6.29	Dry (85.95%)	0.87 \pm 1
	Snooks	2832.4	53.39	Dry (82.31%)	1.15 \pm 1.09
	Mojarras	246.1	4.64	Dry (81.88%)	0.46 \pm 0.57
	Mulletts	1084.2	20.44	Dry (78.35%)	1.61 \pm 2.22
	By-catch	808.8	15.25	Dry (53.45%)	0.81 \pm 0.81
Handline ^a	Snappers	1645.1	61.15	Dry (69.70%)	0.68 \pm 0.60
	Snooks	3064	32.83	Dry (59.09%)	0.84 \pm 0.82
Stow net ^b	Shrimps	276.5	43.7	Rainy (100%)	9.69 \pm 12.08
	By-catch	351.5	56.3	Rainy (100%)	12.5 \pm 17.47

^aCharacterization conducted between January 2015 and October 2016. ^bCharacterization conducted between August and November 2024.

The by-catch generated by the four fishing gears was composed of four groups: invertebrates (four taxa), fishes (20 taxa), herpetofauna (five taxa), and birds (one taxon). When fishers in BZ consider that some by-catch organisms are of marketable size or suitable for self-consumption, up to 40% of the taxa (fishes and invertebrates) may be retained, while the remaining taxa are usually discarded at the fishing site. Four herpetofaunal species recorded as part of the by-catch (mainly from the stow net) are listed under risk categories by the Mexican Official Norm for Environmental Protection (NOM-059-SEMARNAT-2010) and/or as threatened in the IUCN Red List: *Caiman crocodylus*, *Crocodylus acutus*, *Eretmochelys imbricata*, and *Kinosternon mexicanum*.



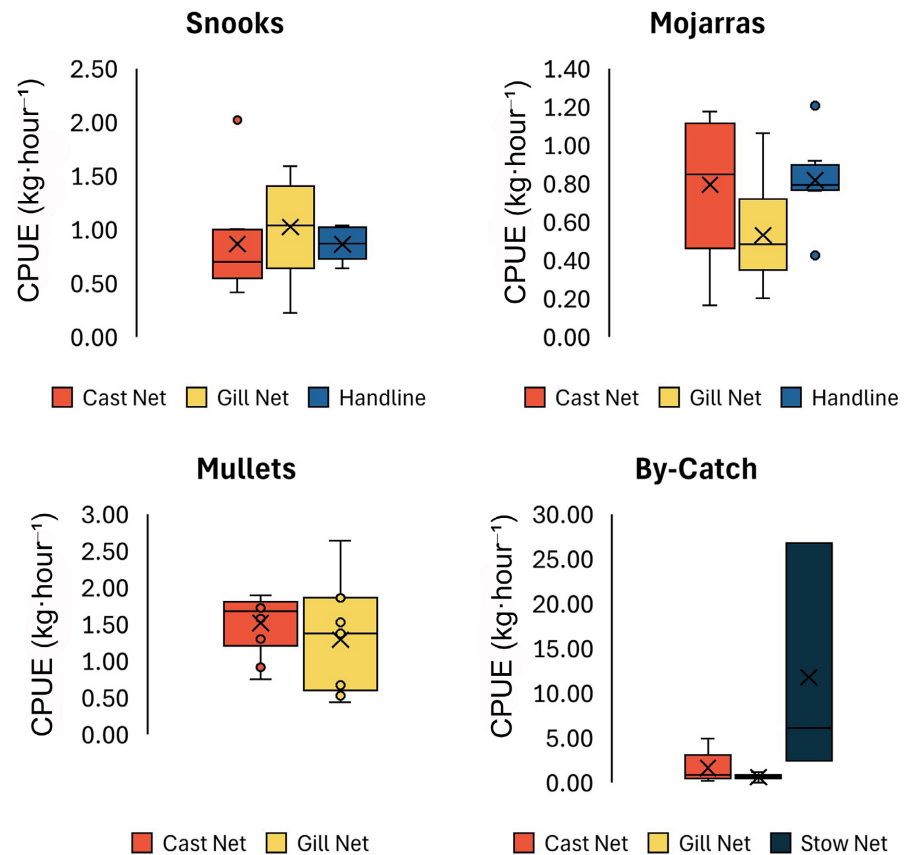


Figure 2. Catch per unit effort (CPUE, kg·hour⁻¹) by target group and fishing gear type in an artisanal fishery of Barra Zacapulco, Chiapas, Mexico. Boxplots show the median, interquartile range, mean (×), and outliers for each gear.

Table 3. Composition of target groups and by-catch in the artisanal fishery of Barra Zacapulco, Chiapas, Mexico.

Taxa		Cast net	Gill net	Handline	Stow net
Target group					
Shrimps	<i>Penaeus californiensis</i> , <i>Penaeus stylirostris</i> , <i>Penaeus vannamei</i>	×			×
Snappers	<i>Hoplopagrus guntherii</i> , <i>Lutjanus argentiventris</i> , <i>Lutjanus colorado</i> , <i>Lutjanus novemfasciatus</i>	×	×	×	
Snooks	<i>Centropomus medius</i> , <i>Centropomus nigrescens</i> , <i>Centropomus robalito</i> , <i>Centropomus viridis</i>	×	×	×	
Mojarras	<i>Amphilophus trimaculatus</i> , <i>Astatheros macracanthus</i> , <i>Diapterus brevirostris</i> , <i>Gerres simillimus</i>	×	×		
Mulletts	<i>Mugil cephalus</i> , <i>Mugil hospes</i> , <i>Mugil setosus</i>	×	×		
By-catch					
	Alpheidae				×
Invertebrates	<i>Callinectes arcuatus</i> *	×	×		×
	Coleoptera				×
	<i>Macrobrachium tenellum</i> *				×

Continued

	Achiridae			×
	Albulidae*	×		
	Ariidae*	×	×	×
	<i>Astyanax aeneus</i>			×
	<i>Atractosteus tropicus</i> *		×	×
	Centropomidae*			×
	Cichlidae*			×
	Clupeidae	×		×
	Eleotridae*	×		×
Fishes	<i>Elops affinis</i> *			
	Engraulidae			×
	Gerreidae*			×
	Gobiidae			×
	Hemiramphidae			×
	Mugilidae*			×
	Poeciliidae			×
	Sciaenidae*			×
	<i>Scomberomorus sierra</i> *			
	Serranidae*		×	
	<i>Strongylura exilis</i>	×		
	<i>Caiman crocodylus</i>		×	×
	<i>Crocodylus acutus</i>		×	
Herpetofauna	<i>Eretmochelys imbricata</i>			×
	<i>Kinosternon mexicanum</i>			×
	<i>Leptodactylus melanonotus</i>			×
Birds	<i>Phalacrocorax brasilianus</i>		×	

*The asterisk indicates by-catch species that can be retained for consumption or sale.

3.2. Profile and Fishers' Perceptions

Regarding the age structure of the fishermen, it was observed that 28.26% of them are between 15 and 34 years old, 19.57% are between 35 and 54 years old, 30.43% belong to the 55 to 74 age group, and 21.74% correspond to the 75 to 84 age group. Ninety-eight percent of the fishermen originate from local coastal communities, while only 2.38% come from other regions of the country, specifically the state of Veracruz. With respect to educational level, 38.10 % of the fishermen have completed primary education, followed by 21.43 % with high school and 19.05 % with secondary education. A total of 14.29 % have no formal education, while only 7.14 % have completed undergraduate studies. The fishermen's experience varied consid-

erably. Only 7.3 % of them have less than 5 years of experience, 31.7 % have between 10 and 15 years of experience, and the majority, 61.0 %, have been fishing for more than 20 years. So, all the fishermen belong to the BZ Fishing Cooperative.

Among the individuals interviewed with links to fishing activities within the BZ cooperative society, 17% were women and 83% were men. In terms of fishing gear usage by gender, cast nets were the most widely used gear among both men and women, with usage rates ranging from 85% to 100%. Gillnets represented the second most frequently reported gear (29% - 41%). Notably, 38.24% of men reported using handlines, compared to only 14.29% of women. Regarding economic dependency, 61.9% of fishers reported combining fishing with other livelihood activities such as agriculture, live-stock, or small-scale trade, while 38% stated that they rely solely on fishing as their primary source of income. In terms of perceived trends in fishing productivity, 60% of respondents indicated a gradual decline in catches over time. This decline was attributed to observable environmental problems such as mangrove loss, pollution, and sedimentation of water bodies, all of which were identified as factors contributing to reduced fish stocks (Table 4).

Table 4. Fishing gear use by gender, categorization of fishers by level of economic dependence on fishing, and perceptions regarding fishery trends, according to artisanal fishers from Barra Zacapulco, Chiapas, Mexico.

Variable	Characteristic	N	Fishing gears				Perceptions	
			Cast net*	Gill net*	Stow net*	Handline*	Fishing trends %	Environmental concerns (%)
Sex	Female	7	100	28.57	14.29	14.29	Gradual decline: 60 Sharp decline: 40	Siltation (16.67)
	Male	35	85.29	41.18	14.71	38.24		Water pollution (22.92)
Fishing activity status	Full-time fisher	16	81.25	31.25	6.25	56.25	Gradual decline: 60 Sharp decline: 40	Catch reduction (32.64)
	Part-time fisher	26	92	32	20	20		Mangrove loss (27.78)

*The percentage represents the proportion of fishermen who use each fishing gear, not an exclusive part of the total.

4. Discussion

4.1. Fishing Effort and CPUE

The results of this study provide a detailed overview of the operational characteristics of artisanal fishing within the BZ cooperative, highlighting patterns that are consistent with the broader dynamics of small-scale fisheries in Mexican coastal lagoons. Artisanal fishing activity is concentrated primarily in coastal lagoon systems, where shrimp (Penaeidae) represent the main target species. This prominence is closely linked to the amphibiotic life cycle of penaeid shrimps, which enter brackish environments as postlarvae and juveniles and later migrate back to marine waters, where they complete their growth, reach sexual maturity, and reproduce. Artisanal fishers exploit these continental-marine migratory movements using a variety of traditional gears, resulting in a strong functional linkage between lagoonal and marine shrimp fisheries [28].

Over the assessed period, cast nets were identified as the dominant fishing gear in terms of both frequency of use and contribution to overall catch, reflecting their

versatility, accessibility, and compatibility with small-scale lagoon operations. This predominance is consistent with the historical role of the cast net as the principal artisanal gear used in continental coastal systems throughout Mexico [29]. According to the current national fisheries regulation in Mexico (NOM-002-SAG/PESC-2013), cast nets must be constructed with a minimum mesh size of 37.5 mm; however, this technological measure is rarely complied with in practice. In BZ, most cast nets were manufactured with smaller mesh sizes (≤ 25.4 mm), a practice that likely increases catch efficiency but also enhances the capture of juvenile shrimp and non-target species.

Despite this, shrimp catches obtained with cast nets in this study were characterized by low levels of by-catch (< 0.6 kg·h⁻¹), suggesting that this gear maintains relatively high selectivity for the target species under local operating conditions. This feature contrasts with the stow net, which, although more efficient in terms of shrimp CPUE, generated substantially higher amounts of accompanying fauna [30] [31]. Because stow net observations were collected in a later monitoring period than the cooperative landing records, comparisons involving this gear should be interpreted as indicative of relative gear performance rather than as strict cross-period contrasts. The relatively reduced by-catch associated with cast net fishing supports its characterization as a comparatively less disruptive artisanal gear in coastal lagoon environments, particularly when evaluated in terms of incidental impacts on non-target taxa.

In this study, shrimp CPUE obtained with cast nets averaged 1.60 ± 1.55 kg·h⁻¹, reflecting high short-term variability in catch rates. Similar patterns of high variability have been documented in other coastal lagoon systems. For instance, in the La Pampita-Joya-Buenavista system, on the northern coast of Chiapas, Ramos-Cruz [32] reported annual CPUE values ranging from 0.09 to 0.90 t·year, and described a gradual decline in CPUE over time. These findings collectively indicate that shrimp CPUE in continental coastal systems is inherently variable and subject to long-term decreasing trends, likely driven by changes in fishing effort, gear selectivity, and recruitment dynamics associated with lagoon-marine connectivity [33].

Marked differences in gear selectivity were also observed for finfish groups. Mulletts, snooks, and snappers contributed substantially to the overall biomass but exhibited clear gear-specific associations, reflecting differences in behavior, habitat use, and vulnerability to each fishing method. However, relatively few studies have addressed the variability of finfish catches in continental coastal environments of the Pacific, particularly using gillnets, cast nets, or handlines, or have evaluated the intrinsic selectivity of these gears in relation to size structure [34]-[36]. This lack of information limits the understanding of how artisanal fishing practices influence population structure and exploitation patterns of these groups in lagoonal systems.

Seasonality strongly influenced catch patterns in BZ. More than 60% of total catches for finfish groups (snappers, snooks, mojarras, mulletts) and by-catch were obtained during the dry season, whereas shrimp catches using stow nets were re-

stricted to the rainy season. In contrast, shrimp were also captured with cast nets during the dry season, suggesting that organism availability and local abundance vary throughout the year in response to changing environmental conditions within coastal lagoon systems [37]. Similar seasonal trends have been reported for other artisanal fisheries of the Mexican Pacific. Ramírez-Rodríguez *et al.* [38] documented higher catches of crustaceans (Penaeid shrimps and Portunid crabs) from September to December, and increased landings of finfish groups, such as mullets and snappers, from November to June, despite year-round fishing activity. These authors emphasized the importance of identifying seasonal peaks in catches to support appropriate fisheries regulations. Together, these findings highlight the role of seasonal environmental forcing and gear-specific interactions in shaping catch dynamics in coastal lagoon fisheries, underscoring the need to incorporate temporal variability into management and assessment frameworks.

4.2. Composition

The taxonomic composition of the catch highlights the diversity of target species exploited by artisanal fishers in BZ, with 18 species identified across five key groups. The predominance of *P. vannamei* among shrimp species reflects both its natural abundance in estuarine lagoon environments and its economic relevance in regional markets [39]. The presence of multiple species within each target fish group—particularly snappers (Lutjanidae) and snooks (Centropomidae)—suggests a multispecific fishery structure, which is common in tropical estuarine systems where fishers target a broad suite of resources across trophic levels and habitats [40].

The number of commercially exploited fish species recorded in this study (18 spp.) falls within the wide range reported for other coastal artisanal fisheries of the Eastern Pacific, reflecting differences in environmental settings, fishing strategies, and data resolution. Comparable values have been reported for Bahía La Paz in the Gulf of California (18 spp.) [41], whereas substantially higher richness has been documented in Barra de Navidad, central Mexican Pacific (130 spp.) [42], and lower values in systems such as Bahía de Tumaco, Colombia (10 spp.) [36]. In Chiapas, Velázquez-Velázquez *et al.* [8] reported 29 commercially exploited fish species in the nearby La Palma fishery; however, those authors recognized that only about 15 species accounted for most of the landings, and that cooperative records frequently included as few as eight categories. This discrepancy was attributed to the use of common names and the aggregation of multiple species under single commercial labels—a limitation that was also observed in BZ and likely leads to an underestimation of true taxonomic richness in landing statistics. However, this pattern may also reflect spatial ecological structuring of fish assemblages within the lagoon, influenced by the distance between fishing grounds and the inlet, the zone of greatest interaction with marine-derived species entering the system [43] [44].

In addition to these methodological and spatial considerations, historical changes in species composition have been documented for fisheries within La Encrucijada Biosphere Reserve. Rodríguez-Perafán *et al.* [43] reported that several fish groups

commonly captured between the 1970s and 1990s—such as groupers, mackerels, grunts, and sharks—have either ceased to be reported or appear only intermittently in cooperative landing records. Other groups, including mullets and catfishes, have shown marked declines in reported catch volumes over time. These long-term changes suggest that the current species composition of artisanal catches reflects not only recording practices, but also structural shifts in fish assemblages and exploitation patterns, likely driven by cumulative fishing pressure and environmental degradation in lagoonal systems.

Beyond the target species, the composition of the by-catch is notable for its taxonomic breadth, including 20 fish taxa, four invertebrate taxa, five herpetofaunal species, and one bird species. This diversity reflects both the ecological richness of the lagoon system and the selectivity level of certain fishing gears, particularly low in the stow net. Although up to 40% of retained by-catch is utilized by fishers for sale or self-consumption, a substantial fraction is discarded, raising concerns about wastage and ecological impact.

In addition to its taxonomic diversity, the by-catch documented in this study also included species of conservation concern, such as chelonians and crocodylians, which are listed under Mexican environmental regulations (NOM-059) and international conservation frameworks. Although these events were relatively infrequent, their occurrence highlights the ecological sensitivity of estuarine lagoon systems where artisanal fisheries operate. Most of these organisms are released immediately when captured; however, their incidental capture underscores the importance of promoting mitigation measures adapted to local fishing practices. Strategies such as improving gear selectivity, strengthening monitoring of by-catch composition, and increasing fishers' awareness of protected species may help reduce incidental impacts while maintaining the socio-economic viability of artisanal fisheries within protected coastal ecosystems.

Studies explicitly addressing by-catch or discard associated with shrimp fisheries in coastal lagoons are scarce, and even fewer provide comparative evaluations among fishing gears. For instance, Amezcua *et al.* [45], in a coastal lagoon of the Gulf of California, reported 173 discarded fish species associated with three shrimp fishing gears, highlighting the particularly high impact of trawl nets and gillnets on the ichthyofauna. While trawling is not practiced in coastal lagoons of Chiapas, the use of stationary gears such as stow nets and fyke nets has been shown to generate substantial by-catch. In the Mar Muerto lagoon system (northern coast of Chiapas), Hernández-Roque *et al.* [30] documented 73 fish species, whereas López-Vila *et al.* [31] reported 71 species in the Chantuto-Panzacola system.

In BZ, the number of fish species associated with stow net by-catch was comparatively lower (15 spp.). This reduced richness may be related to the limited fishing effort evaluated during this characterization and to the specific areas where this unregulated gear is typically deployed by the cooperative, rather than to an intrinsically lower impact of the gear itself. These results suggest that both the composition and magnitude of by-catch are strongly context-dependent, being influ-

enced by fishing effort intensity, spatial deployment of the gear, and the characteristics of local habitats and ecotonal zones where the gear is operated within the estuarine system [46] [47].

Of particular concern is the incidental capture of species listed under environmental protection frameworks. The vulnerability of these taxa—some of which are classified as threatened under Mexican NOM-059 and the IUCN Red List—underscores the need for management strategies aimed at reducing by-catch, especially in fishing gears with limited selectivity and broad taxonomic interactions.

Together, these findings highlight the dual challenge of maintaining the productivity of artisanal shrimp fisheries while minimizing their ecological footprint [48]. Conservation and management efforts should therefore consider not only the efficiency of fishing gears, but also their by-catch profiles, promoting improved monitoring, gear-specific mitigation measures, and spatial or temporal regulations that reduce discard without undermining fishers' livelihoods.

4.3. Socio-Economic and Gender Profile

The demographic, educational, and gender profile of fishers in BZ provides important insights into the social structure, adaptive capacity, and potential resilience of the local artisanal fisheries. The predominance of older age groups—particularly fishers aged 55 years and above, who together represent just over 50% of respondents—suggests a potential generational gap in the recruitment of younger fishers. Although a notable proportion of respondents (28.26%) is under 35 years of age, the relatively low representation of middle-aged fishers (35 - 54 years) may reflect shifts in occupational preferences, economic migration, or reduced attractiveness of artisanal fishing as a primary livelihood, patterns previously documented for coastal fisheries in southern Mexico [49].

These demographic characteristics are broadly consistent with those reported for fishing cooperatives in the La Joya-Buenavista (northern coast of Chiapas), where de la Cruz-González *et al.* [50] documented a mean fisher age of 45.7 ± 15 years, with long-term residence in fishing communities (37.1 ± 16 years) and extensive experience in the activity (26 ± 14 years). In both systems, fishing represents a deeply rooted territorial practice, supported by strong local attachment and accumulated ecological knowledge.

In BZ, this rootedness is evident in the fact that nearly all fishers (97.62%) originate from local coastal communities and that a majority (61.0%) report more than 20 years of fishing experience. Such characteristics constitute an important asset for community-based management and conservation initiatives. However, educational attainment remains limited: nearly 40% of fishers have completed only primary education, and just 7.14% report higher education. Comparable patterns were reported in La Joya-Buenavista, where average schooling was 4.4 ± 3 years and 16% of fishers lacked formal education altogether [50]. This restricted access to education may constrain opportunities for livelihood diversification, limit engagement with regulatory or administrative processes, and hinder the adoption of new tech-

nologies or management practices.

Gender-based differences further illustrate the social organization and evolving dynamics of the fishery. Although women represented a smaller proportion of interviewed fishers in BZ (7 women vs. 35 men), their participation in fishing activities was evident. All interviewed fisherwomen reported using cast nets, while smaller proportions also used gillnets (29%) and handlines (14%). In contrast, men exhibited greater diversification in gear use, with 85% reporting cast net use, 41% gillnets, 38% handlines, and 14% stow nets. These patterns suggest that women's fishing practices are currently more selective and concentrated on specific gears, whereas men tend to engage in a broader range of fishing strategies.

Despite their more limited direct participation in capture fisheries, women play a significant role in complementary stages of the fishing value chain. In BZ, women are actively involved in post-harvest activities such as shrimp cooking and salting for sale, contributing to household income and local commercialization. Similar roles have been widely documented in Mexican artisanal fisheries, where women often have a prominent presence in pre-production and post-production activities rather than in capture itself [51]. Nationally, women typically represent less than 10% of formal cooperative membership, reflecting persistent structural and institutional barriers to full inclusion [51].

Differences in fishing effort and catch outcomes between men and women have also been linked to operational factors rather than ecological knowledge or fishing capacity. Purcell *et al.* [52] reported that fisherwomen's contributions to CPUE are often lower on average, largely due to factors such as limited access to boats, preference for specific gears, and shorter fishing periods associated with concurrent household responsibilities. Importantly, these authors also emphasize that women's participation in fisheries is gradually increasing and diversifying, a trend that appears to be emerging in BZ as well.

Together, these findings indicate that artisanal fisheries in coastal lagoons of Chiapas share common social features, including aging fishing populations, strong local attachment, limited formal education, and gender-differentiated participation across fishing and post-harvest activities. While these characteristics confer resilience through experience, adaptability, and local ecological knowledge, they also reveal vulnerabilities related to generational renewal, educational access, and gender equity. Addressing these challenges will require integrated management approaches that combine ecological conservation with social policies aimed at youth engagement, capacity building, and the recognition of women's contributions across the entire fishery value chain, thereby enhancing the long-term sustainability of artisanal fisheries in coastal lagoon systems.

4.4. Fishers' Perceptions

Importantly, local perceptions aligned closely with empirical findings indicating a decline in fishery productivity. In BZ, 60% of interviewed fishers recognized a gradual downward trend in catches, attributing this decline to tangible environ-

mental degradation processes such as mangrove deforestation, pollution, and lagoon sedimentation. In addition, fishers perceived that they currently capture fewer target groups than those exploited by their parents or grandparents, a concern that was identified as the most prioritized environmental problem (33%). Similar perceptions have been reported among other fishing communities along the Mexican Pacific [53].

Perceptions of catch trends are known to vary even among geographically proximate fishing communities, depending on factors such as individual experience, age, educational level, governance context, and proximity to protected areas or urban centers [52] [54]. In BZ, the second most prioritized concern was mangrove loss (28%), reflecting a broad recognition of the role of mangroves as nursery habitats for fish and shrimp. However, despite this general awareness, the nursery function of mangroves is not always explicitly identified in perception studies, likely due to its intangible nature and the difficulty of directly quantifying its benefits [5] [55].

At the same time, contrasting viewpoints toward conservation persist. Mangroves are still perceived by some fishers as a readily available raw material—for example, for the construction of borders or rustic shrimp enclosures locally known as “tapos”—and illegal extraction remains widespread along the coast of Chiapas [56]. In this context, Carranza-Ortiz *et al.* [57] reported that although a substantial sector of local inhabitants within La Encrucijada Biosphere Reserve has participated in conservation actions promoted by federal authorities—resulting in increased environmental awareness and the ability to identify key problems affecting fishing activities, such as mangrove loss and lagoon sedimentation—local communities have not yet developed sufficient capacities to effectively cope with their vulnerability to projected environmental changes. In BZ, fishers additionally perceived that reserve authorities have not widely socialized the guidelines established in the management plan, which has not been revised or updated since 1999, and that many of the problems identified in its original diagnostic assessment are currently perceived as aggravated. Among these, the loss of fishing areas, reflected in reductions in lagoon surface area and depth due to sedimentation, represents a complex problem intensified by anthropogenic modifications of river channels draining into the reserve, poorly planned dredging activities, dyke construction, deforestation, and changes in rainfall regimes over recent decades [12] [15], processes that have also contributed to social conflicts among fishing cooperatives. Together, these perceptions underscore the importance of integrating fishers’ ecological knowledge into management frameworks to design adaptive strategies that effectively link conservation objectives with local fisheries realities.

5. Conclusion

This study provides a comprehensive characterization of a multigear artisanal fishery operated by a cooperative society within the core zone of La Encrucijada Biosphere Reserve, highlighting the interactions between fishing gear selectivity and the social context of fishing activities in the region. Catch composition and CPUE

revealed a multispecific fishery strongly structured by fishing gear and hydrological seasonality, with finfish catches concentrated during the dry season and higher shrimp biomass exploitation linked to periods of increased freshwater discharge during the rainy season. Cast nets emerged as the most widely used and comparatively balanced gear, combining operational versatility with relatively low by-catch levels, whereas stow nets showed greater efficiency for shrimp harvesting but generated substantially higher by-catch, including species of conservation concern. The fishery is sustained by an experienced and locally rooted community with diversified livelihoods; however, the predominance of older fishers, limited formal education, and the underrepresentation of women in capture activities pose challenges for long-term sustainability. Fishers' perceptions of declining catches and environmental degradation—particularly mangrove loss, sedimentation, pollution, and the reduction of fishing areas—were consistent with empirical patterns and historical evidence, underscoring the value of local ecological knowledge as both a complementary source of information and an early warning system. Taken together, these findings emphasize the need for integrated and participatory management strategies that incorporate seasonal variability, promote selective fishing practices and by-catch mitigation, strengthen local capacities, and ensure that conservation objectives within protected areas are effectively aligned with the livelihoods and realities of artisanal fishing communities.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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