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Mangrove ecosystems as fundamental habitats for fish from the Mexican Caribbean: An evaluation between a conserved and restoration zone

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A R T I C L E I N F O

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A B S T R A C T

Mangrove ecosystems can function as a habitat for many juvenile marine fish species, with provisions of food and refuge. Seemingly, these ecosystems have been extensively reduced due to anthropogenic activity, as is widespread land use and road construction along the coastline. Nonetheless, much needed restoration efforts have increased tremendously over time. This study analyzes fish community, and the manner in which habitats in the mangrove ecosystem are used, comparing two mangrove zones, a conserved zone (healthier state) and one undergoing restoration. Hydrologically, no significant differences were registered (KW $p>0.05$). Of the 24 species registered, marine species were dominant in the conserved zone and estuarine species dominant in the restoration zone. Juvenile fishes were more abundant in the conserved mangrove zone, with a higher proportion of adults found in the restoration zone. According to Hutcheson's t test, fish diversity showed significant statistical differences between sites combined with distinct climatic seasons. The Canonical Correspondence Analysis (CCA) indicated a relationship between secondary freshwater species *Floridichthys polyommus* and *Cyprinodon artifrons* and greater salinity and temperature, whereas marine species had a higher relationship with well oxygenated sites. A high number of marine fish species in juvenile stage in the conserved area may relate to mangroves functioning as nurseries. This can serve as a useful indicator by managers taking an integral approach to evaluate and monitor present and future mangrove restoration programs and pathways.

1. Introduction

Due to their spatial geographic location, mangroves are considered coastal ecotones that function in storing carbon, and as energy transferring sites with adjacent systems. They provide several services to society, for example: maintaining coastlines, buffer zones against hurricanes, and a habitat with significant numbers of terrestrial and aquatic fauna (Nagelkerken et al., 2008; Arceo-Carranza et al., 2021). These ecosystems are considered as nurseries for many fish and vertebrate species, which can be categorized as: 1) residents, 2) migratory, and 3) seasonal and occasional visitors. These species take advantage of its environmental heterogeneity and use different habitats for refuge, feeding, or reproduction zones. Primarily, marine fish species use the mangrove as a nursery zone, and, whereupon reaching adult lengths, migrate back to coral reefs, or to deeper marine zones. The structure and composition of this habitat is crucial in considering mangroves as

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fundamental habitats for juvenile fishes (Pereira et al., 2022). Despite the ecological importance of mangroves, clear-cutting, or increased removal due to industrial activities (*e.g.* agriculture, cattle ranching, aquaculture and tourism) operating in close proximity has resulted in ecosystem degradation. Worldwide, the total loss of mangroves is estimated between 20 % and 35 % (Goldberg et al., 2020).

In recuperating ecological functions, and health of a mangrove ecosystem, hydrology is a prioritized component, since it directly affects the fish community. The salinity, temperature, flood level and dissolved oxygen, are also within those determining parameters that influence the presence and distribution of fish species in estuarine ecosystems. The change in salinity, spatially and seasonally is primarily due to variations in the water supply, either through subterranean discharge from the most inner sites, runoff, or by the rainy seasons (Herrera-Silveira et al., 2014) that lower the salinity, nonetheless, remains isolated in the dry season, a season associated with a high evaporation rate, which increases the salt concentration. (Wolanski and Ridd, 1986; Zaldívar Jiménez et al., 2004).

As a means of mitigating damages and recuperating, and/or conserving the ecosystem function of the mangroves, various restoration programs have been implemented, that are primarily based on the restoration of hydrologic flow. One such program was done in the Mexican Caribbean, in the Sian Ka'an ecological reserve. This area presents a decrease or total loss of vegetation cover in the mangrove ecosystem towards on the south end of the road. A zone where the plant community dominated by red mangrove (*Rhizophora mangle*) has been severely impacted for approximately 40 years due to road construction (now allowing access to the Felipe Carrillo-Puerto municipality). The hydrologic flow and connectivity of the site was altered by such construction, resulting in two microbasins. Consequently, it impedes the flow of water from north to south, gradually affecting the zone's hydrology, making the site hypersaline, and consequently altering its diversity (CONANP, 2014). In 2009, various measures were taken to recuperate the zone through techniques that considered hydrologic patterns and flow related to microtopography. This involved the construction of culverts at established points to allow connection of the conserved area with dead mangrove zones that should lead to restoring the hydrology of the zone (Herrera-Silveira et al., 2015), additionally, the use of *R. mangle* for reforestation purposes. Consequently, the general objective of this study was to compare the structure of fish communities between mangrove restoration sites and those conserved (healthier state), using ecological parameters of the ichthyofauna to determine if the ecosystem maintains its ecological function as a nursery. This can serve as a useful indicator by managers taking an integral approach to evaluating and monitoring present and future mangrove restoration programs and pathways.

2. Materials and methods

2.1. Study area

The Sian Ka'an Biosphere Reserve (SBR) is located east of Quintana

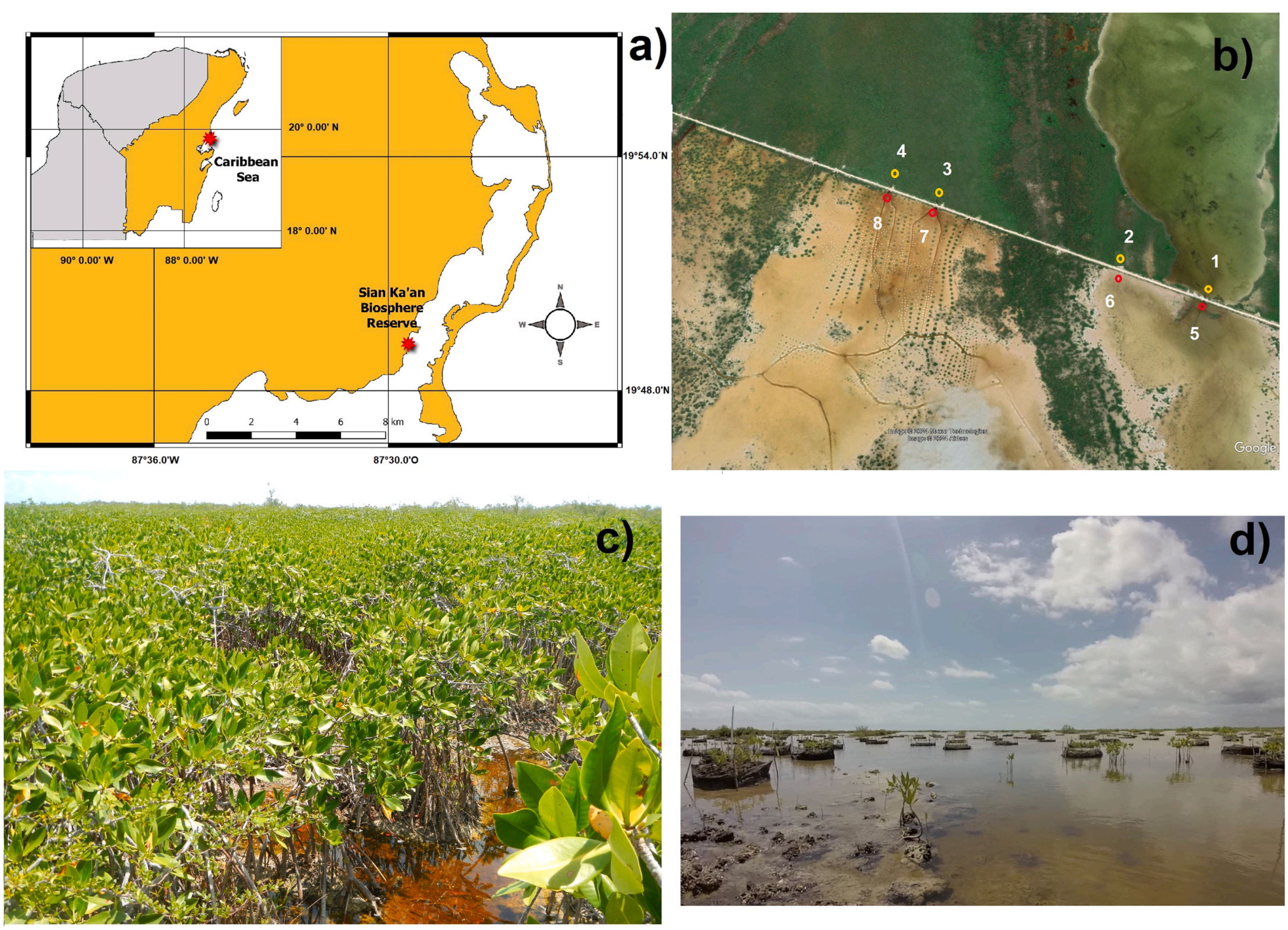

Fig. 1. a) Study area located in Sian Kaan Biosphere Reserve, b) Sampling sites in conserved and restoration mangrove zones c) Conserved mangrove, and d) Restoration mangrove.

Roo State, in the western portion of the Yucatan Peninsula, Mexico (Fig. 1). It comprises a total area of 652000 ha, of which 116000 pertains to the zone known as "El Playón", The sampling points are located on a transect between the coordinates 19°49'15.06"N; 87°29'37.33"W and 19°49'24.13"N; 87°30'1.44"W, and located at the coastal strip adjacent with the Xamach lagoon (connects to the Caribbean Sea). The study area is characterized by having a conserved mangrove site and other under ecological restoration. In the conserved site, one hundred percent of coverage of *Rhizophora mangle* dwarf is observed, the water in the site has few dissolved solids and the presence of epiphytes in the roots of the mangroves are observed, it has a high number of invertebrate due to habitats structured.

In the restoration zone, there are few seedlings of *Avicennia germinans* and *R. mangle*, high turbidity due to a greater number of suspended solids, higher temperature due to the absence of vegetation and therefore fewer prey species (zoobenthos) (Hernández.Mendoza 2020). This zone also presents some culverts that connect the hydrology between the conserved and restoration zones, since they are divided by a road that interrupts the natural hydrological flow.

Temporally the site is influenced by three distinctive seasons characteristic to this region: a dry season (March to May), rainy season (June to October) and the "nortes" season (November to February). The nortes is a season defined by the influence of cold fronts along with strong winds.

2.2. Sample collection

Six bimonthly fish collections were done for one year (August 2017 to May 2018) in the "El Playon" zone in the Sian Ka'an Biosphere Reserve. The sampling design consisted of four sites each for the conserved and restoration mangrove zones respectively. Sites four and five are in the inner and sites one and eight are located near to the coastal lagoon (Fig. 1). All samples were obtained from the culvert end within the restoration zone using the end within the conserved zone as a reference point (always considering the direction of the salinity gradient). Registered at each site were the salinity variables, temperature (°C), dissolved oxygen (mg/l), pH and total dissolved solids (TDS) using a Multiparametric Yellow Spring Instrument (YSI) model 556 MPS, additionally, water depth was measured using a meter ruler. Fish were collected using a cast net (70 cm radius; with a 3 mm mesh size); with two throws per site. This fishing gear is selective to some fish species (Chiappa-Carrara et al., 2024), however, due the site only has water near the culverts, was the most appropriate collection method, because of this, it is likely that some fish species in both zones (conserved and restoration) will not be captured.

The fishes collected were fixed in 4 % formaldehyde and transported to the UMDI – UNAM, Ecology laboratory, in Sisal Yucatan. Fish were identified to species level using specialized guides (Castro Aguirre et al., 1999; FAO, 2002; Miller, 2009); standard length (cm) and individual weight (g) was registered for each fish. The data on first maturity and habitat use were obtained through the criteria established by Froese and Pauly (2023).

2.3. Statistical analysis

The database for the physicochemical variables were tested with a Shapiro-Wilk normality test using an R studio program and a *stats* version 3.4.3 package. A non-parametric Kruskal-Wallis statistical test was applied to identify the differences between the conserved and restoration zones.

For the fish analysis, the relative abundance was quantified, and the Shannon-Weiner diversity indices (H) and equity (j) was evaluated. Hutcheson's t test (Magurran, 1988) was used to confirm the existence of significant differences in Shannon diversity between climatic seasons.

For the fish composition analysis between the conserved and restoration zones an Analysis of Similarities (ANOSIM) was applied through the PRIMER-e 7 program (Clarke and Gorley, 2015) using the abundance data, with the juvenile/adult stage as a factor.

2.4. Species relationship-hydrological variables

To establish the relationship between the distribution of fish species and the hydrological variables in the sample sites, an Analysis of Canonical Correspondence (ACC) was done, applying the Monte Carlo test with the CANOCO and CANOCO DRAW version 4.5 for Windows software (Leps and Smilauer, 2003). Environmental variables considered were mean salinity, water temperature, dissolved oxygen concentration, pH, total dissolved solids concentration, and depth.

3. Results

3.1. Physico-chemical analyses

The hydrological variables did not show significant differences between the conserved and restoration mangrove zones (KW $p>0.05$), however, between climatic seasons (rains, "nortes" and dry), for both zones, variations occurred in salinity, temperature, TDS and pH (KW $p<0.05$). There were no seasonal differences observed for dissolved oxygen and depth.

The highest salinity values were observed during the dry season, being significantly different to the values obtained during the "nortes" and dry season. Likewise, differences in the salinity gradient were observed between the sampling sites for both zones, with minimum values (1.92) at the most inner point (sites four and five), up to values higher in salinity (37.34) at points one and eight, that are closer to the lagoon.

The temperature ranged between 24°C and 34°C with an average of 28°C in the conserved and restoration zones, with the lowest values being registered during the "nortes".

As per pH, significant differences were registered between seasons, "nortes"-rainy and dry-rainy. During the rainy season the pH decreased to four, whereas for the dry and "nortes" pH values of seven and eight were registered, respectively.

3.2. Analysis of the ichthyological assemblage

A total of 24 species belonging to 13 families were registered, with the Gerreidae family being well represented with six species, followed by Poecilidae and Cyprinodontidae with three, and Lutjanidae and Sphyraenidae families registered two species each. For the remaining, one species was registered for each family (Fig. 2 and Table 1).

In relation to abundance, a total of 775 fishes were captured in the conserved zone, and 1088 in the restoration zone. The conserved zone showed a higher number of species and diversity (H') than the restoration zone. Also, a higher number of unique species were observed in the conserved zone, species not shared with the restoration zone. The ANOSIM analysis gave similarity values of 41.3 % between zones (Table 2).

Hutcheson's t test indicated significant statistical differences as per the fish assemblage diversity in almost all the combined sites during distinct climatic seasons, except between the conserved-nortes and conserved-rainy, as well as the restoration-dry and restoration-rainy (Table 3).

3.3. Ecological categories and life stage

The 24 registered species were grouped in the following ecological categories: Primary freshwater, secondary freshwater, marine and peripheral/diadromous. The marine category was well represented with 15 species, secondary freshwater fishes category had a seven fish species, primary freshwater and peripheral fishes categories had one species each one (Fig. 3a). Species registered were grouped in each category for

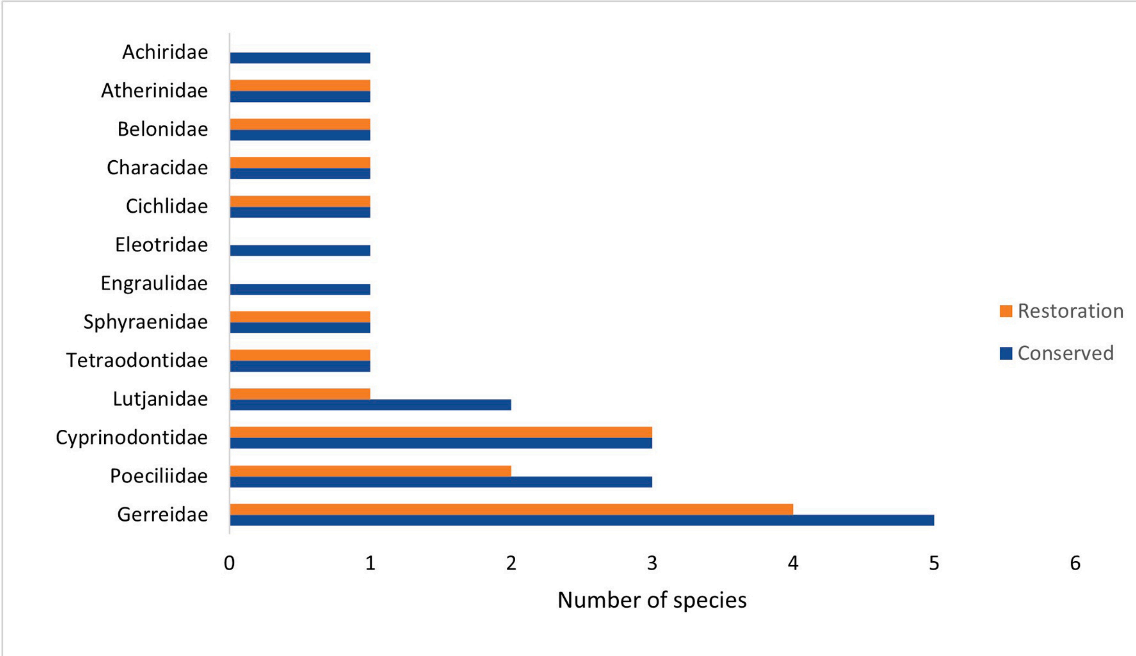

Fig. 2. Families and number of the dominant species by mangrove zones in the conserved and restoration sites in the Sian Ka'an Biosphere Reserve, Yucatan Peninsula, Mexico.

Table 1
List of fish species in mangrove conserved and restoration zones (showed Abundance, size range (min-max), ecological category, and juvenile life stage).

Species	Abundance		Size range (cm) Standard length (SL)		Ecological category	Lenght (SL) at first maturity (cm)	Juvenile Life stage	
	C	R	C	R			C	R
Achirus lineatus	2	0	3.3–5.0	-	P	14	2	-
Anchoa lyolepis	6	0	5.0–6.1	-	M	8.2	6	-
Astyanax altior	109	0	3.0–6.0	-	Pf	4	44	-
Atherinomorus stipes	255	20	1.9–4.3	2.1–3.9	M	6.4	255	20
Belonesox belizanus	12	0	4.9–7.0	-	S	13	12	-
Cyprinodon artifrons	1	102	2.9	1.3–3.7	S	4	1	102
Diapterus rhombeus	6	0	3.6–13.6	-	M	15	6	-
Dormitator maculatus	1	0	6.3	-	M	11	1	-
Eucinostomus gula	34	27	2.4–6.1	2.7–7.4	M	11	34	27
Eucinostomus harengulus	2	7	3.0–4.1	2.8–8.4	M	10	2	7
Eucinostomus melanopterus	0	6	-	1.6–3.5	M	18	-	6
Eugerres plumieri	3	0	2.5–3.6	-	M	23.5	3	-
Floridichthys polyommus	18	258	1.6–5.4	3.1–19.4	S	4.2	8	6
Gambusia yucatana	207	397	1.1–11.6	1.0–3.4	S	-	-	-
Jordanella pulchra	2	6	2.6–4.2	1.4–2.4	S	-	-	-
Gerres cinereus	32	113	1.8–11.6	2.1–12.5	M	16.5	32	113
Lutjanus apodus	2	0	11.0–12.0	-	M	25	2	-
Lutjanus griseus	7	7	2.5–10.3	6.8–10.1	M	18	7	7
Mayaheros urophthalmus	6	21	5.7–8.5	3.2–12.3	S	10.2	6	18
Poecilia mexicana	55	94	1.5–4.3	1.4–3.1	S	3	20	91
Sphoeroides testudineus	7	28	1.0–11.6	9.1–14.0	M	10.8	6	2
Sphyraena barracuda	0	1	-	27.5	M	46	1	-
Sphyraena borealis	2	0	10.5–11.0	-	M	26.9	2	-
Strongylura notata	6	1	12.6–23.0	15.9	M	22	5	1
Total	775	1088					453	400

C. Conserved; R: Restoration; Pf: Primary freshwater; Sf: Secondary freshwater; P: Peripheral/Diadromous; M: Marine

Table 2
Comparative results of the ecological parameters for ichthyological assemblages in conserved and restoration zones in the Sian Ka'an Biosphere Reserve, Yucatan Peninsula, Mexico.

Mangrove Zone	Richness (S)	Abundance (N)	Unshare species	Evenness Pielou J′	Diversity H′ (bits/ind)	Bray-Curtis Similarity
Conserved	23	775	9	0.6321	1.954	41.331
Restoration	15	1088	2	0.6826	1.849	
Total	24	1863				

Table 3
Differences in assemblage fish diversity according to Hutcheson's t test.

	C-rn	C-n	C-d	R-rn	R-n	R-d
C-rn						
C-n	0.47854					
C-d	0*	0*				
R-rn	0.0147*	0.0120*	0			
R-n	0*	0*	0.0014*	0.0001*		
R-d	0.0002*	0.0001*	0	0.0524	0.0013*	

α:0.05;C: Conserved; R: Restoration; rn: rainy; n: nortes; d: dry season; *bold: significant differences

both conserved and restoration zones. The relative abundance was different between zones. Marine fish were the major components of the restoration and conserved zone representing 60 % of the total number of fish species, whereas secondary freshwater fish species showed the 40 % in the restoration zone and 31.8 % in the conserved zone.

To life stages, from a total of 775 fish obtained in the conserved zone community, 453 individuals were registered as juveniles, whereas for the restoration zone, 400 from a total of 1088 were juvenile fish, representing a total of 58 % and 36 % of the fish community, respectively (Fig. 3b).

All fishes from the marine category were observed in early life stages (i.e. prior to the first sexual maturity), except *Sphoeroides testudineus*, a species that presented juvenile and adult sizes in both conserved and restoration zones. Notably, majority of the secondary freshwater fish were registered as adults.

3.4. Seasonal variation of the community

The Analysis of Similarities results (ANOSIM) did not show significant differences in the structure of the fish community between the conserved and restoration mangrove zones, as well as between climatic seasons ($p>5$ %). However, for the conserved zone, the rainy and "nortes" seasons showed higher numbers of fish species (S=15), whereas for the dry season only 10 species were registered. In the conserved mangrove zone, *Atherinomorous stipes* was the most abundant species found during the dry season. *Achirus lineatus, Anchoa lyolepis, Cyprinodon artifrons* and *Eugerres plumieri*, were only present during the "nortes" season, whereas *Strongylura notata*, *Diapterus rhombeus, Lutjanus apodus*, *L. griseus* and *Sphyraena borealis* were collected only during the rainy season. *Jordanella pulchra* and *Dormitator maculatus* were present during the dry season (Fig. 4).

In the restoration zone, the "nortes" season had a higher richness (S=13) followed by the dry season (S=12), and the rainy season showed the lowest richness, with only seven species. *Gambusia yucatana* was the most abundant species, primarily in the "nortes" season. *Atherinomorus stipes* was registered only for the rainy season. *Eucinostomus melanopterus* and *S. barracuda* were registered during the "nortes" season having a relative abundance less than 2 %, whereas *S. notata* was registered only during the dry season with an abundance less than 1 % (Fig. 4).

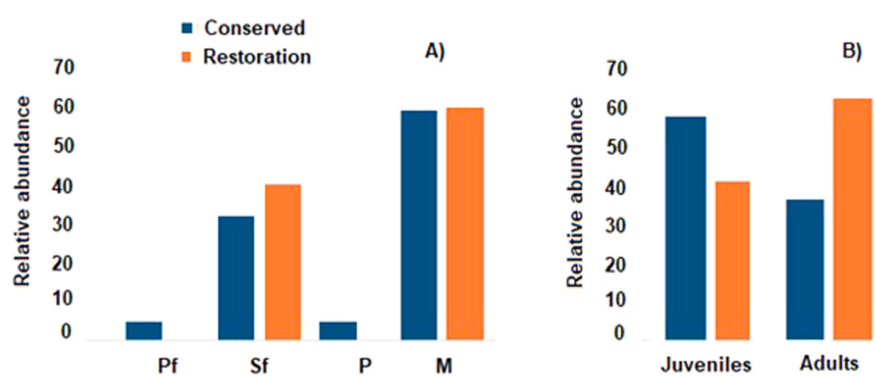

Fig. 3. A) Relative fish abundance for each ecological category: pf=primary freshwater fishes; Sf=Secondary freshwater fishes; P=Peripheral fishes; M=Marine fishes, and **B)** Relative abundance of juvenile and adult fishes in the conserved and restoration zones.

Fig. 4. Relative abundance of fish species in conserved and restored mangroves, showing climatic season and habitat use.

3.5. Relationship of physico-chemical variables and ichthyological assemblage

According to the CCA results (Fig. 5), the first two axes, account for 68.8 % of the accumulated variance in the species-environmental variables bi-plot (axis 1, 41.1 %; and axis 2, 27.7 %). The results obtained, showed the distribution of fish species throughout salinity and total dissolved solids gradients, while temperature was the most important gradient on axis 2. In this analysis, percentage of variance can be explained by biotic variables that were not measured (i.e. the availability of prey or the reproductive biology of the fish species), which could structure the fish assemblages spatial or temporally.

Species categorized as marine (*L. apodus*, *D. rhombeus*, *S. borealis)* were distributed towards zones higher in salinity (i.e. sites 1 and 2), found closer to the coastal lagoon, whereas in sites three and four, in the conserved zone (i.e. the innermost sites with lower salinity), freshwater species like *Astyanax altior* and *Belonesox belizanus* were present.

Secondary freshwater species *Floridichthys polyommus* and *C. artifrons* were associated with high salinities and higher temperatures, this species were recorded on restoration zone that are characterized by the absence of vegetation, where high evaporation and high salinity occur as a consequence of higher temperatures.

4. Discussion

A saline gradient was identified extending from the lagoon to the mangroves, occurring because of underground runoff originating from inland.

These saline gradients, strongly marked for wetland zones within the Sian Ka'an reserve have been previously reported by López-Portillo et al. (1989). The difference in the minimum and maximum salinity values reached between the conserved and restoration zones may be attributed to the road that divides them. This type of infrastructure has been identified as a factor of change in the patterns of hydrologic flow,

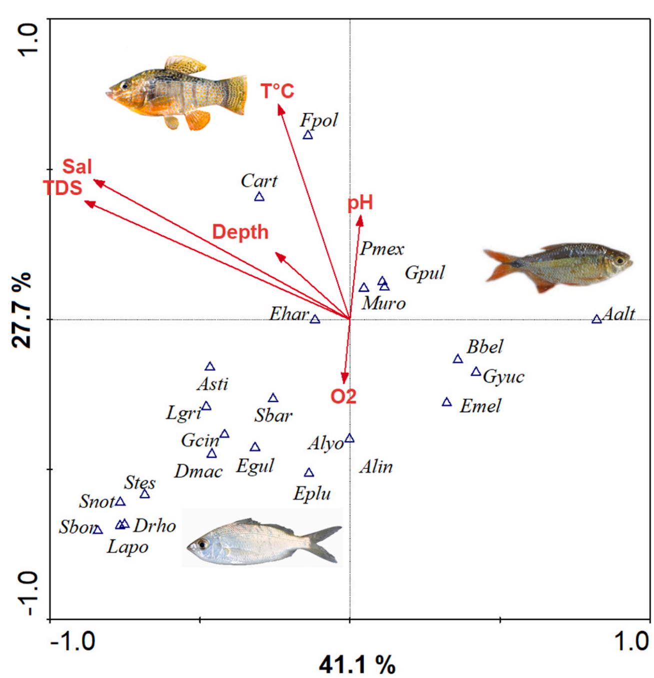

Fig. 5. Canonical correspondence analysis. Vectors represent environmental variables and triangles represent species in both zones; name of each species are in key format, with the first letter (uppercase) correspond to genus and the remaining three (lowercase), the species. Arrows indicate environmental gradients for salinity (sal), depth, temperature (T°C), pH, dissolved oxygen (O_2) and total dissolved solids (TDS).

overall, affecting all entries of freshwater to the system, despite after the implementation of hydrologic restoration projects (Teutli-Hernández, Herrera Silveira, 2018). As a result, the restoration zone showed an increase in its salinity.

Also, the differences in the total dissolved solids are attributed to the effects of deforestation in the restoration zone, since, in the conserved zone the water is more transparent due to existing mangrove vegetation that lowers the water current speed, trapping sediments and assisting in suspended solids being precipitated.

Because of these gradients, many fish species recorded were marine juveniles. Marine fish species such as snappers and barracudas migrate from coral reefs to mangrove roots, carrying energy, food and nutrients between them, that could eventually be used as a food source for other species and favorable to the local trophic web diversity.

Studies from Nagelkerken et al. (2008) and Enchelmaier et al. (2020) state that fauna associated with mangroves are an important component for the ecosystem to function and could be a useful indicator of ecological function, i.e. the role of mangroves as a fish habitat. Either as nursery zones (Beck et al., 2001), or as feeding zones visited by marine species (Laegdsgaar and Johnson, 2001; Nagelkerken et al., 2008; Vaslet et al., 2012). Mangroves connect not only with adjacent aquatic systems as are coastal lagoons and coral reefs, (Nagelkerken et al., 2000, 2002; Mumby et al., 2004), but also with terrestrial ecosystems, serving as a feeding ground for large vertebrates like birds (Trexler and Goss, 2008; De Dios Arcos et al., 2019; Arceo-Carranza et al., 2021).

The Gerreidae family had a higher species richness recorded in both the conserved and restoration zones. It is the most abundant family in coastal lagoons, estuaries and mangroves from the Gulf of Mexico and the Mexican Caribbean, mainly in zones that are strongly influenced by salinity gradients (Enchelmaier et al., 2020, Flores-Hernández et al., 2021).

In relation to abundance, the Poeciliidae family was higher in the restoration zone. *Gambusia yucatana* and *Poecilia mexicana* represented more than 40 % in total abundance; these secondary freshwater fish species are highly tolerant to environmental changes, thus, are abundant in altered systems (Avilés-Torres et al., 2001, Arceo-Carranza et al., 2016).

For the conserved zone *A. stipes* represented 32 % of the abundance, this marine species uses the mangroves during the juvenile stage to feed and grow (Hammerschlag et al., 2010; Nash et al., 2017) particularly in the dry season, where large schools were registered associated to the mangrove roots at the conserved zone. Likewise, other marine species, like *Gerres cinereus* or *E. melanopterus* enter the mangrove zones in juvenile stages, migrating thereafter, to coral reefs zones in their adult stages (Vidy, 2000; Jones et al., 2010).

The marine species, these were well represented in both the conserved and restoration zones, with a total of 13 and 9 species registered, respectively. The richness can be attributed to the zones' connectivity to Xamach (a coastal lagoon) and the Caribbean Sea. Although for the restoration zone this fish category had more species, the relative abundance is merely at 16 %, these can be attributed to the food and habitat conditions are not the best conditions for it to fulfill its functions (Arceo-Carranza et al., 2016; Hernández-Mendoza et al., 2022). The results to the marine species at the conserved zone are quite contrasting, the total abundance of the fish community was represented at 59 %, secondary freshwater fishes were 31.82 %, while primary freshwater and transient/diadromous fishes each recorded 4 % of total abundance. Conversely, marine fish (except for *S. testudineus*), were found in life stages previous to their first maturity, indicating that their life cycle is not completed in the mangrove habitat. This determines that mangroves do offer a specific function (as a nursery) in earlier life stages. This affirmation was strengthened by Nagelkerken and collaborators (2000) for diverse species such as *Eucinostomus spp*, *Gerres cinereus, L. griseus*, *L. apodus* and *S. barracuda*. Other authors like Laegdsgaar and Johnson (2001) have proposed two hypotheses to explain the relationship between juvenile fish and mangrove ecosystems: 1. The structural complexity of mangrove ecosystems serve to protect against large predators, and 2. The high productivity offers food to juveniles, reducing their risk of predation; in accordance with the hypothesis, it can be inferred that the restoration zone offers this nursery function to some marine species. Nonetheless, the low abundance of this category in comparison to the conserved area may indicate that plant structural complexity and its productivity, as well as the abundance of prey, is still, not yet at its optimum level (Hernández Mendoza et al., 2022).

Seasonally no significant difference was observed in the structure of the ichthyological assemblage between climatic seasons. However, species richness did change in both study zones, primarily during rainy season where many freshwater species were registered (*B. belizanus*, *Mayaheros urophthalmus*, *P. mexicana* and *A. altior*) in the conserved zone. This must be due to the freshwater water supply to the system. Contrarily, the restoration zone only presented freshwater species in this season (i.e. *M. urophthalmus)*; a species that is eminently freshwater, and tolerant to brackish environments (Smoak and Schmid, 2021). Changes in the fish community structure during climatic seasons have been reported in various parts of the world (Vega Cendejas and Hernández de Santillana, 2004; Rodríguez-Romero et al., 2012; Franco-López, 2017). According to Lara-Domínguez and Yáñez-Arancibia (1999), habitat use, as per seasonal changes, is common in fish, depending on the species, where some show different life strategies and habitat use. This behavior optimizes recruitment, making it more efficient to use several habitats throughout the day, with differing motives, such as, protection, searching for food, refuge and rest (Verweij et al., 2006; Nagelkerken et al., 2015).

In the Sian Ka'an mangroves, a saline gradient is present, which seems to have a direct effect on the distribution of freshwater species such as *A. altior* (registered in the conserve zone), in the inner-most sites, and in seasons where the water was less saline; given that this species is stenohaline and is distributed only in water bodies with salinities less than six (Schmitter-Soto, 2016). Another freshwater species registered was *B. belizanus*, a species that has a wide tolerance range to salinity, also registered in marine and brackish environments, with salinities as high as 40 (Miller, 2009; Vega Cendejas and Hernández de Santillana, 2004). Notwithstanding, its distribution in this study was restricted to the conserved zone, which may be due to this species preferring water bodies with abundant vegetation (Vega Cendejas and Hernández de Santillana, 2004).

The difference in the ichthyological assemblage between zones is characterized by the absence of freshwater species as *A. altior* and *B. belizanus* (seen in the restoration zone). This may indicate that ecological functions of the system are still not serving as the habitat for food and protection which these species need for their development, a factor influencing the composition of the ichthyological assemblage (Shinnaka et al., 2007).

5. Conclusions

The biological indicators between conserved and restoration zones showing the best evidence in the restoration process, was the difference in juvenile fish composition and presence of marine species associated with the mangrove roots. This is evidence of mangrove protection. Mangroves are attractive and safe sites for marine fish species, especially in environments with high habitat quality (i.e. more vegetation and its relating to increase in food availability). Generalist and secondary freshwater fish species showed a tendency to be more tolerant to environmental changes and had the ability to dominate impacted sites with little vegetation.

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CRediT authorship contribution statement

D. Arceo-Carranza: Conceptualization, Methodology, Investigation, Writing – original draft, Funding acquisition. **L.C. Hernández Mendoza:** Conceptualization, Methodology, Investigation, Formal analysis, Writing – original draft. **C. Teutli-Hernández:** Conceptualization, Methodology, Writing – review & editing. **J.A. Herrera-Silveira:** Conceptualization, Methodology, Writing – review & editing. **J.A. Caballero Vázquez:** Methodology, Investigation, Writing – review & editing. **X. Chiappa-Carrara:** Conceptualization, Methodology, Investigation, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data will be made available on request.

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