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Original Article

# Seasonal variation, habitat complexity, and trophic structure of fish assemblages in the Irrawaddy Delta, Myanmar

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**Abstract**
The Irrawaddy mangrove ecosystem in Myanmar is a crucial habitat for aquatic biodiversity, yet its ecological dynamics remain understudied. This research explored the seasonal variation, spatial dynamics, and trophic structure of fish assemblages in Pyapon and Bogale townships, Myanmar. Seasonal and market surveys recorded 129 fish species from 64 families, with *Mystus gulio*, *Oryzias dancena*, *Coilia dussumieri*, and *Glossogobius giuris* dominating the community. Seasonal shifts significantly influenced species diversity. Winter exhibited the highest species richness and diversity, while summer displayed the lowest. Nevertheless, species evenness remained highly stable across all seasons, suggesting a consistently balanced community. Moving beyond basic water parameters, multivariate analyses demonstrated that habitat complexity and food web dynamics are likely key drivers of community structuring. Permutational multivariate analysis of variance revealed a highly significant spatial separation of fish assemblages between mangrove and agricultural land habitats. Furthermore, indicator species analysis identified specific taxa driving this divergence, while functional feeding guild analysis revealed a marked dominance of benthivores and detritivores in mangrove sites. This highlights the critical role of mangrove-derived organic matter in supporting the estuarine food web. The presence of four threatened species, including the Endangered *Eleutheronema tetradactylum* and *Johnius macrorhynus*, demonstrates that preserving the physical integrity and trophic inputs of mangroves is paramount for sustaining estuarine fish diversity and supporting sustainable local fisheries management.

**Keywords:** DNA barcoding; fish diversity; Irrawaddy mangrove; seasonal variation; species composition

## 1 | INTRODUCTION

The Irrawaddy mangrove ecosystem is a critical transitional habitat that supports diverse estuarine food webs and regional fisheries (Faunce and Serafy 2006; Chong 2007). Despite its immense ecological and economic importance, the spatial and temporal dynamics of its fish assemblages remain largely unexplored compared to other major river systems (Yang *et al*. 2016; Li *et al*. 2021).

Similar to adjacent coastal systems in Bangladesh, the Irrawaddy ecosystem experiences monsoonal shifts that profoundly influence estuarine fish diversity and assemblage structure (Ullah *et al*. 2023).

Therefore, understanding the ecological dynamics within the Irrawaddy Delta provides crucial comparative insights for regional fisheries management across these interconnected South and Southeast Asian aquatic networks. While the general significance of mangroves is recognized, the specific environmental determinants, including habitat complexity, trophic dynamics, and seasonal hydrological shifts, that structure the fish communities in the Irrawaddy Delta are poorly understood, although such factors are known to be critical in tropical estuarine ecology (Baran and Myschowoda 2009; Elliott and Whitfield 2011). This study seeks to address this knowledge gap by offering a comprehensive understanding of the ichthyofauna in the region.

The objectives of this study were to: document seasonal variation in fish diversity, utilizing a core dataset of 109 species from standardized plots; assess spatial variations and trophic structures; and identify the primary environmental drivers shaping these estuarine communities.

## 2 | METHODOLOGY

### 2.1 Study area

Bogale and Pyapon Townships, located in the Pyapon District of the Irrawaddy Delta, were selected as the study area, as shown in Figure 1. The area extends between north latitude 16°50′ and 17°02′ and east longitude 94°15′ and 96°05′. These townships were chosen based on their current forested area and their status as primary sources of fisheries in the Irrawaddy region. Ecologically, these areas are characterized by a dynamic estuarine salinity gradient and are dominated by complex mangrove vegetation.

### 2.2 Fish sampling and species identification

In 2022, three seasonal field surveys were carried out: summer or pre-monsoon (March–April), rainy or monsoon (July–August), and winter or post-monsoon (November–December). A total of 24 sampling sites were established across the habitats, with one spatial replicate was conducted at each site during every season. Several techniques, such as cast nets (mesh size: 1.5–2.5 cm), tiger mouth nets (mesh size: 0.2–5.0 cm), stake nets (mesh size: 1.5–3.0 cm), and beach surrounding gill nets (mesh size: 1.0–5.0 cm), were used to gather fish specimens. Market surveys were additionally carried out at major local fish markets (e.g. Bogale MyoMa market and Pyapon MyoMa market) to augment field sampling. These specific markets were selected because they serve as the primary landing sites for local commercial fishers, ensuring a comprehensive record of pelagic and deep-channel species that are typically challenging to capture directly with the employed netting techniques. Tissue samples were kept in 99% ethanol for genetic analysis, all collected specimens were photographed, and they were preserved in a 10% formaldehyde solution for morphological analysis. Counts and measurements followed by Hubbs *et al*. (2004). Point-to-point measurements were performed with callipers to the nearest 0.2 mm. The local information of the research areas was noted by using a Garmin eTrex-309 handheld device. The examined specimens in the present study were deposited in the Laboratory of Aquatic Biodiversity Research Group, SEABRI, CAS, which is based in the Forest Research Institute, Myanmar. Data from Vidthayanon *et al*. (2005), Psomadakis *et al*. (2019), Tun (2021), Eschmeyer's Catalog of Fishes (Fricke *et al*. 2024), FishBase (Froese and Pauly 2024), and GBIF (GBIF 2024) were used for species identification.

Relevant literature, including Hebert *et al*. (2003) and Bucklin *et al*. (2011) together with online databases including NCBI GenBank (NCBI 2025) and BOLD Systems (BOLD 2025), were used to identify the species. DNA barcoding targeting the cytochrome c oxidase subunit I (COI) mitochondrial gene marker was applied for species challenging to categorize morphologically, following best practices described by Gusmao *et al*. (2025). Specifically, tissue samples from 299 individuals were utilized for the molecular study. The COI gene was amplified using FishF1 and FishR1 primers. Genomic DNA was extracted using the DNA Isolation mini kit. PCR amplification conditions for the COI gene consisted of an initial pre-denaturation at 92°C for 3 min, followed by 35 cycles of 92°C for 45 s, 52°C for 45 s, and 72°C for 60 s, with a final extension at 72°C for 5 min, after which the amplified products were sequenced by Sangon Biotech (Shanghai) Co. Ltd. Following sequence analysis using SeqMan software, a sequence identity threshold of 95% or greater was applied against the NCBI (GenBank) database for accurate species-level identification.

### 2.3 Water quality assessment

During each sampling period, in situ physicochemical water parameters—specifically salinity (ppt), dissolved oxygen (DO, mg $L^{-1}$), water temperature (°C), pH, and electrical conductivity—were systematically measured at all sample plots. To ensure that these recorded variables accurately represented the environmental baseline during the primary period of fish activity and habitat utilization, all measurements were synchronized with the local tidal cycle and taken exactly at peak high tide, coinciding with the moment the nets were secured. Water temperature, dissolved oxygen, and pH were evaluated using a Sanxin portable water quality meter, while salinity and electrical conductivity were measured using a CT-3080 salinity meter. These precise in situ evaluations provided crucial data for assessing the physiological stress and overall health of the estuarine aquatic environments.

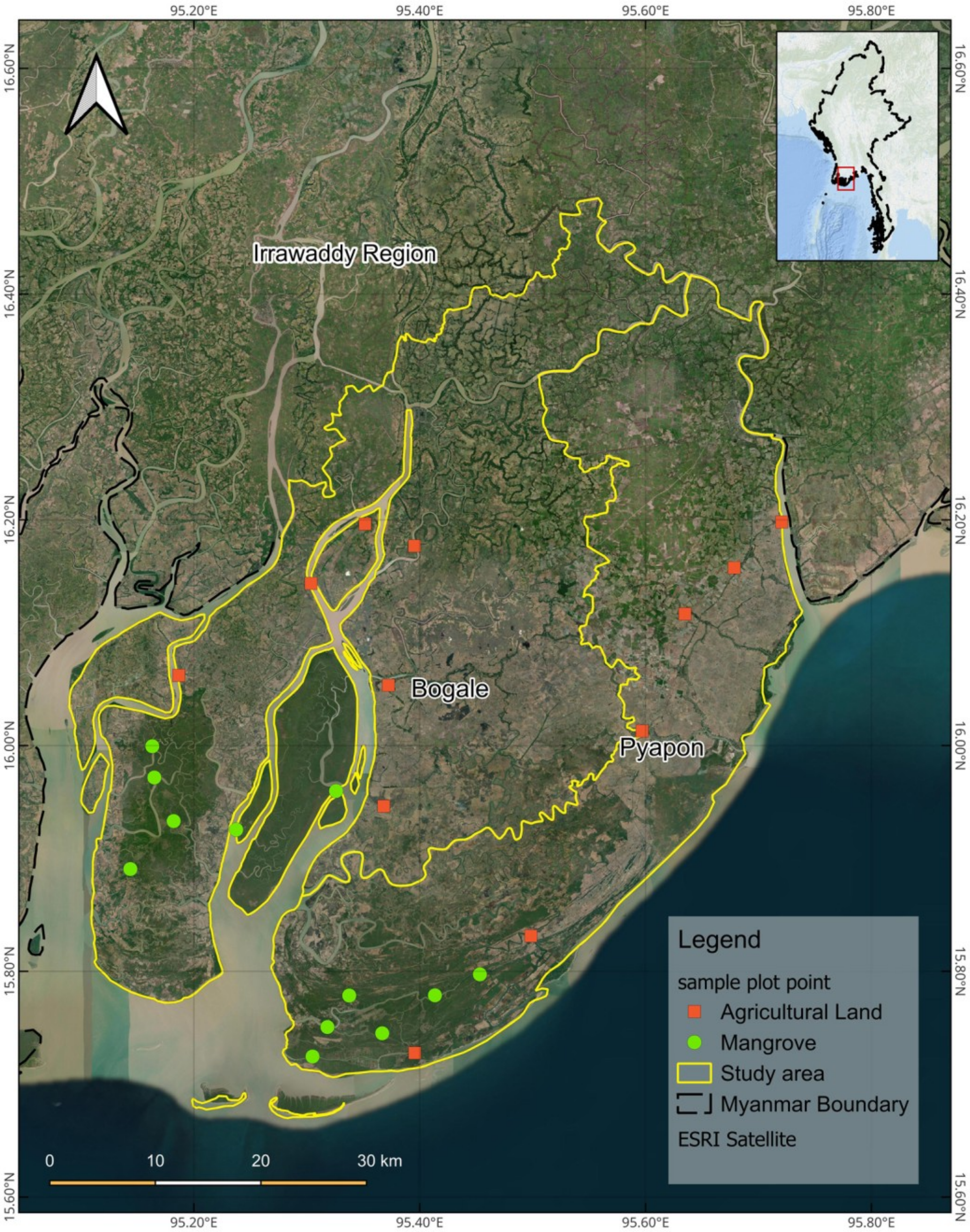


**FIGURE 1** Location of the study area – Irrawaddy Delta in Myanmar.

**2.4 Sample plot selection**

Sample plots for each type of land use (forested and agricultural land) were selected based on the Forest Resources Assessment (FRA) 2020 (Forest Department, 2020). To ensure standardized fishing effort (Catch Per Unit Effort, CPUE) across all sampling sites and seasons for the accurate calculation of biodiversity indices, a constant sampling protocol was strictly applied. Each sampling site lasted 12 hours to synchronize with the complete tidal cycle. The net-setting process began during the falling tide, when a series of bamboo stakes were driven firmly into the substrate along the riverbanks or across tidal creeks. The mouth of the 400 m stake net (Paik-ba-win) was then secured to these stakes, with the opening facing the current and the lead line resting on the riverbed. At high tide, the net was pulled up into position to begin catching fish. Following the 12-hour period, the harvest took place at the next lowest tide. All fishes were subsequently identified, counted, and recorded in field data sheets to determine the species composition and density for each specific habitat type.

**2.5 Data analysis**

While the overall biodiversity checklist comprises 129 species (including 20 species from market surveys), all subsequent quantitative ecological analyses (e.g., diversity indices, NMDS, PERMANOVA, and CCA) were strictly performed using the abundance data of 109 species directly collected from the sample plots. This ensures an accurate correlation with the specific in-situ water quality and habitat parameters.

The species abundance data derived from each seasonal survey was utilized to scrutinize the structure of the fish assemblage. The total count of distinct species discovered in each season was enumerated to compute species richness (S). Furthermore, the Shannon–Wiener diversity index (H'), Simpson's diversity index (D), and Pielou's evenness index (J') were calculated to gauge biodiversity. All diversity metrics were computed using the vegan package in R statistical software (R Core Team 2023). Prior to the analysis, the assumptions of normality and homogeneity of variances were confirmed using Shapiro–Wilk and Levene's tests, respectively. One-way ANOVA was used to test for significant differences in diversity indices among the three seasons. The Bray–Curtis similarity index was used to compare seasonal differences in fish species composition. A Pearson correlation analysis was conducted to determine the relationship between the five water parameters measured and species composition. Furthermore, a Welch's two-sample *t*-test was used to compare the means of water parameters and species composition between sampling sites with and without mangroves. All statistical analyses were conducted using Microsoft Excel (version 2021) and RStudio. Furthermore, a Canonical Correspondence Analysis (CCA) was conducted to assess the relationship between water parameters and fish assemblages across various habitats in the study area.

To analyze the community structure, species were categorized into three abundance groups based on their mean relative abundance across all seasonal samples. First, the average relative abundance for each species was calculated. Subsequently, each species was assigned to a category using predetermined thresholds: species with a mean relative abundance greater than 5% were classified as "Very Common"; those with a mean abundance between 1% and 5% were classified as "Common"; and species contributing less than 1% to the mean abundance were classified as "Uncommon." The total relative abundance for all species within each of these three categories was then summed for each season to facilitate seasonal comparisons of community composition. Fish assemblage habitat partitioning into freshwater, marine, and euryhaline categories can be effectively analyzed using the rfishbase package (Boettiger *et al*. 2012) in RStudio.

To assess the trophic structure and ecological function of the fish assemblage, recorded species were classified into distinct functional feeding guilds (e.g., benthivores, detritivores, piscivores, planktivores, and omnivores) based on their primary diet utilizing FishBase (Froese and Pauly 2024) and relevant literature (Okey *et al*. 1999).

To evaluate spatial and temporal differences in fish community structure between habitats (mangrove vs. agricultural land) and seasons, multivariate analyses were conducted using the vegan package (Oksanen *et al*. 2022) in R software. Prior to analysis, the fish abundance data were fourth-root transformed. This transformation was crucial to reduce the disproportionate influence of highly abundant species and to adequately represent fewer common species in the analysis.

A Bray–Curtis dissimilarity matrix was then generated from the transformed abundance data. To visualize the spatial patterns and distinctness of fish communities across different habitats, a non-metric multidimensional scaling (NMDS) ordination was performed. The NMDS was computed in three dimensions ($k = 3$) to achieve a highly acceptable stress value (Stress = 0.103), ensuring an accurate representation of the community data. Furthermore, a permutational multivariate analysis of variance (PERMANOVA) was executed with 999 permutations to statistically test the significance of habitat and seasonal effects on the overall fish assemblage structure.

## 3 | RESULTS

### 3.1 Species composition and diversity of fish assemblage

A total of 129 fish species, spanning 64 families and 19 orders, were identified across the three seasonal surveys. It accounts for 470 species diversities of Irrawaddy according to all the known records (Li *et al*. 2021). A detailed breakdown of these species and their seasonal distributions can be seen in Table S1. A seasonal relative abundance analysis revealed that *Mystus gulio* (Hamilton, 1822) was the predominant species in the study area, followed by *Oryzias dancena*, *Coilia dussumieri*, and *Glossogobius giuris* (Figure S1).

Perciformes, Siluriformes, and Clupeiformes are dominant orders in the study area. Sciaenidae, Engraulidae, and Gobiidae are the dominant families in the study area (Figure S2). Within the family Sciaenidae, 5 genera have been identified, encompassing a total of 10 species. Gobiidae, on the other hand, is represented by 6 genera and a total of 6 species. Engraulidae is also remarkable, featuring 5 genera and 6 species. These fish species play a vital role in the ecosystem, offering a unique set of characteristics and interactions within the aquatic ecosystem (Figure S2).

The analysis of seasonal abundance patterns revealed significant shifts in the community structure across the rainy, summer, and winter seasons. During the summer, the fish community was predominantly composed of "Very Common" species, which constituted the largest portion of the total relative abundance (~47%).

In contrast, the rainy season was characterized by a shift in dominance, with "Common" species becoming the most abundant group, contributing approximately 40% of the total abundance. The winter season exhibited a co-dominance between "Very Common" (~38%) and "Common" (~37%) species, which were present in nearly equal proportions. Notably, the "Uncommon" species group maintained a relatively stable contribution across all seasons, with its highest relative abundance observed during the winter (~26%) (Figure S2).

### 3.2 Habitat partitioning in mangrove fish assemblages

Based on the habitat analysis of mangrove fish species, the data reveal a diverse ecological community with distinct habitat preferences. Saltwater species dominate the assemblage (46.5%), reflecting the marine influence in mangrove ecosystems, followed by freshwater species (27.9%) that likely inhabit the upper estuarine regions. Euryhaline species, capable of tolerating both fresh and saltwater, comprise 14.0% of the community, demonstrating their adaptability to the fluctuating salinity conditions characteristic of mangrove environments. Brackish-water specialists, specifically adapted to intermediate salinity levels, account for 11.6% of the species in Figure S2.

This distribution highlights the mangrove ecosystem's role as an ecotone, supporting species across the salinity spectrum and underscoring its importance as a transitional habitat that connects marine and freshwater environments.

### 3.3 Seasonal variation in the fish assemblage

This study recorded a total of 129 fish species, predominantly belonging to the orders Perciformes and Siluriformes, revealing distinct seasonal assemblages within the study area. A substantial portion of the community, including economically significant species such as *Tenualosa ilisha* (Hamilton, 1822), *Lates calcarifer* (Bloch, 1790), *Eleutheronema tetradactylum* (Shaw, 1804), and *Tenualosa toli* (Valenciennes, 1847), were established as year-round residents, indicating a stable habitat for these key populations. Seasonal exclusivity was also evident, with species such as *Megalops cyprinoides* (Broussonet, 1782) and *Pangasius myanmar* Roberts and Vidthayanon, 1991 restricted to the winter months, whereas *Narcine timlei* (Bloch & Schneider, 1801) was recorded solely during the rainy season. Conversely, *Brevitrygon walga* (Müller and Henle, 1841) and marine-associated species like *Echeneis naucrates* Linnaeus, 1758 were unique to the summer period, likely driven by seasonal fluctuations in salinity and water temperature.

The species composition of the fish assemblage exhibited significant variation across seasons, peaking in the winter and diminishing to its lowest during the summer (Figure 2). This observation aligns with prior research indicating that fish diversity reaches its peaks in the winter (Win and Myint 2020). In the study area, there were notable seasonal variations in the composition of the fish assemblage. Winter exhibited the highest species richness (S = 95) and diversity (Shannon Index H'=3.54), followed by the rainy season (S = 86, H' = 3.43). Summer displayed the lowest species richness (S = 77) and diversity (H' = 3.40). However, the community balance remained highly stable across all seasons, with Pielou's evenness index ranging narrowly from 0.77 in the rainy season to 0.78 in both summer and winter (Figure 2).

### 3.4 Spatial distribution and species richness

This study revealed a marked disparity in ichthyofaunal diversity, with the mangrove forested area supporting significantly higher species richness (106 species) relative to the agricultural land (79 species). The forested habitat functions as a critical stronghold for threatened and economically valuable biodiversity. Additionally, the endangered *Johnius macrorhynus* (Mohan, 1976) was recorded in the study area, underscoring the conservation value of these habitats. Notably, *E. tetradactylum* was nearly four times more abundant in the forested plots (n = 363) compared to agricultural sites (n = 99). Similarly, *T. ilisha* exhibited a strong preference for the mangrove environment, being seven times more prevalent there. Exclusive occurrences in the forested zone included species such as *M. cyprinoides* and *Epinephelus coioides* (Hamilton, 1822), which were entirely absent from agricultural waters.

Conversely, while the agricultural land displayed reduced overall diversity, it supported distinct assemblages and higher densities of specific taxa. The Near Threatened *Osteobrama belangeri* (Valenciennes, 1844) was notably more common in agricultural plots ($n$ = 81) than in the forest ($n$ = 36), and the commercially important *L. calcarifer* showed a slight prevalence in this modified landscape. Uniquely, the regional endemic *P. myanmar* was recorded exclusively within the agricultural sampling sites, contrasting with its congener *Pangasius pangasius* (Hamilton, 1822), which was dominant in the forested area.

### 3.5 Bray–Curtis Similarity Index within seasons

Cluster analysis based on the Bray–Curtis similarity index revealed that summer and winter fish assemblages shared the highest similarity, whereas the rainy season exhibited a distinctly different community structure (Figure S4). The pronounced separation of the rainy season indicates a substantial shift in the fish assemblage, likely brought on by significant seasonal hydrological changes.

### 3.6 Seasonal fish diversity and water quality parameters

Significant positive relationships were confirmed between species composition and salinity, pH, DO, and conductivity, while water temperature exhibited a significant negative correlation (Figure 3). Welch’s t-test further confirmed that mangrove sites had significantly lower temperatures but higher salinity, DO, pH, and conductivity compared to non-mangrove sites (Table S2).

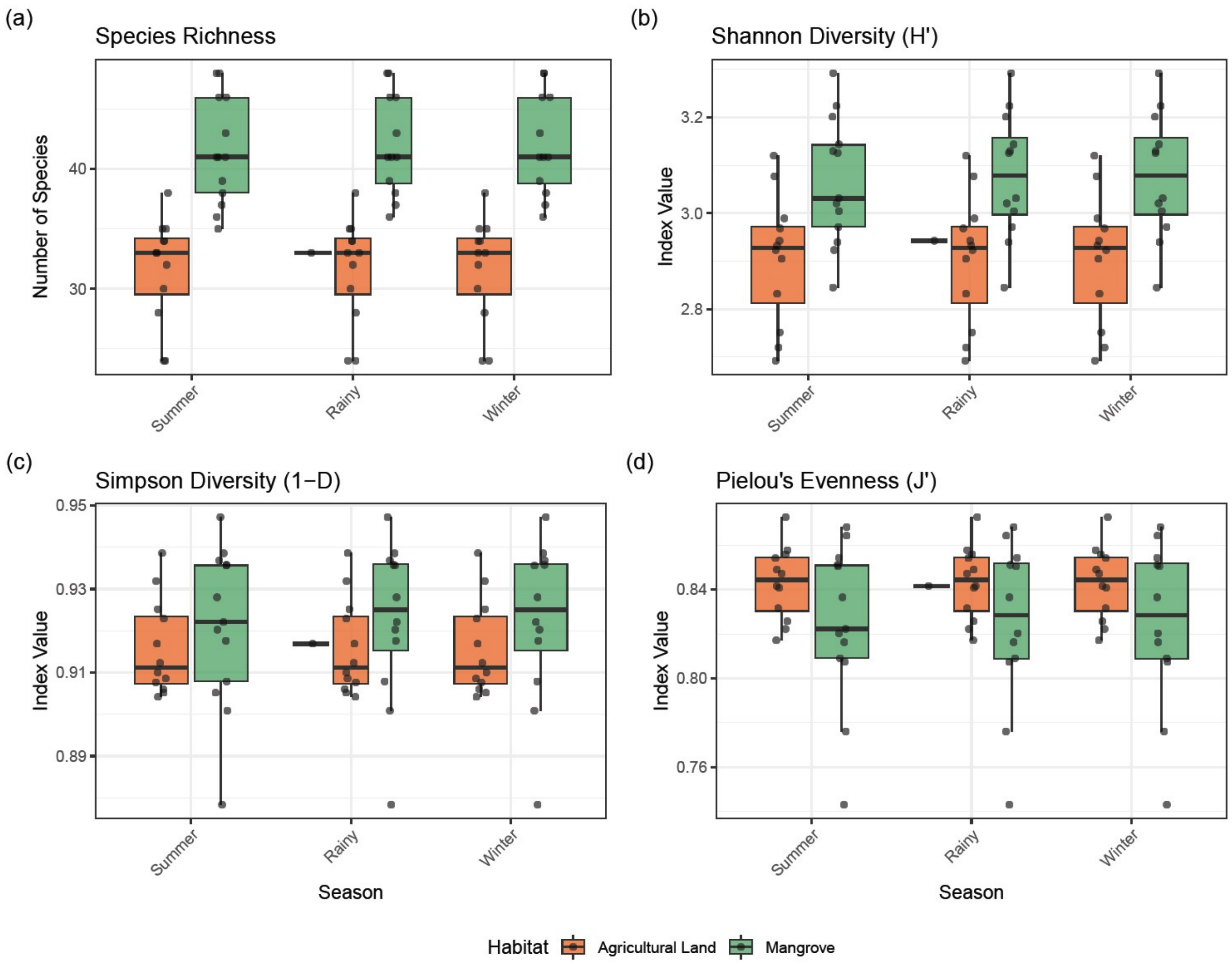


**FIGURE 2** Biodiversity indices of fish communities in the study area – Irrawaddy Delta in Myanmar.

### 3.7 Influence of land use and water quality on fish communities

A canonical correspondence analysis was used to find the influence of land use and water quality on fish communities (Figure 4). The results revealed that the key environmental factors structuring fish assemblages differed markedly between the two study locations. In Pyapon Township, the fish community structure was mostly shaped by water temperature ($R^2$ = 0.716, $p$ = 0.005) and pH ($R^2$ = 0.850, $p$ = 0.001), which together created the primary environmental gradient separating the non-mangrove and mangrove habitats. On the other hand, in Bogale Township, the most influential factors were dissolved oxygen (DO; $r$ = 0.945, $p$ = 0.001), conductivity ($r$ = 0.702, $p$ = 0.008), and salinity ($r$ = 0.643, $p$ = 0.020).

### 3.8 Fish community and trophic structure

Non-metric multidimensional scaling (NMDS) ordination based on fourth-root transformed abundance data revealed a clear spatial separation of fish assemblages between the mangrove and agricultural land habitats (Figure 5). The three-dimensional NMDS model provided an accurate representation of the community data with a highly acceptable stress value of 0.103. The visual clustering indicated that mangrove sites harbor a distinct fish community composition compared to the agricultural sites. This spatial divergence was statistically validated by the PERMANOVA test, which confirmed that habitat type and seasonal changes significantly influenced the overall fish community structure ($F$ = 4.19, $R^2$ = 0.15, $p$ = 0.001).

To determine which distinct taxa were driving the observed spatial divergence, an indicator species analysis (ISA) was performed. The analysis successfully identified highly significant indicator species for both ecosystems. Mangrove habitats were significantly characterized by taxa such as *Gagata melanopterus* Roberts and Ferraris, 1998 ($p$ = 0.001) and *C. dussumieri* ($p$ = 0.001), along with the Endangered *E. tetradactylum* ($p$ = 0.016) (IUCN 2024). Conversely, agricultural lands were defined by a completely distinct set of indicators, predominantly *Parapocryptes serperaster* (Richardson, 1846) ($p$ = 0.002) and *Puntius sophore* (Hamilton, 1822) ($p$ = 0.007) (Figure 6).

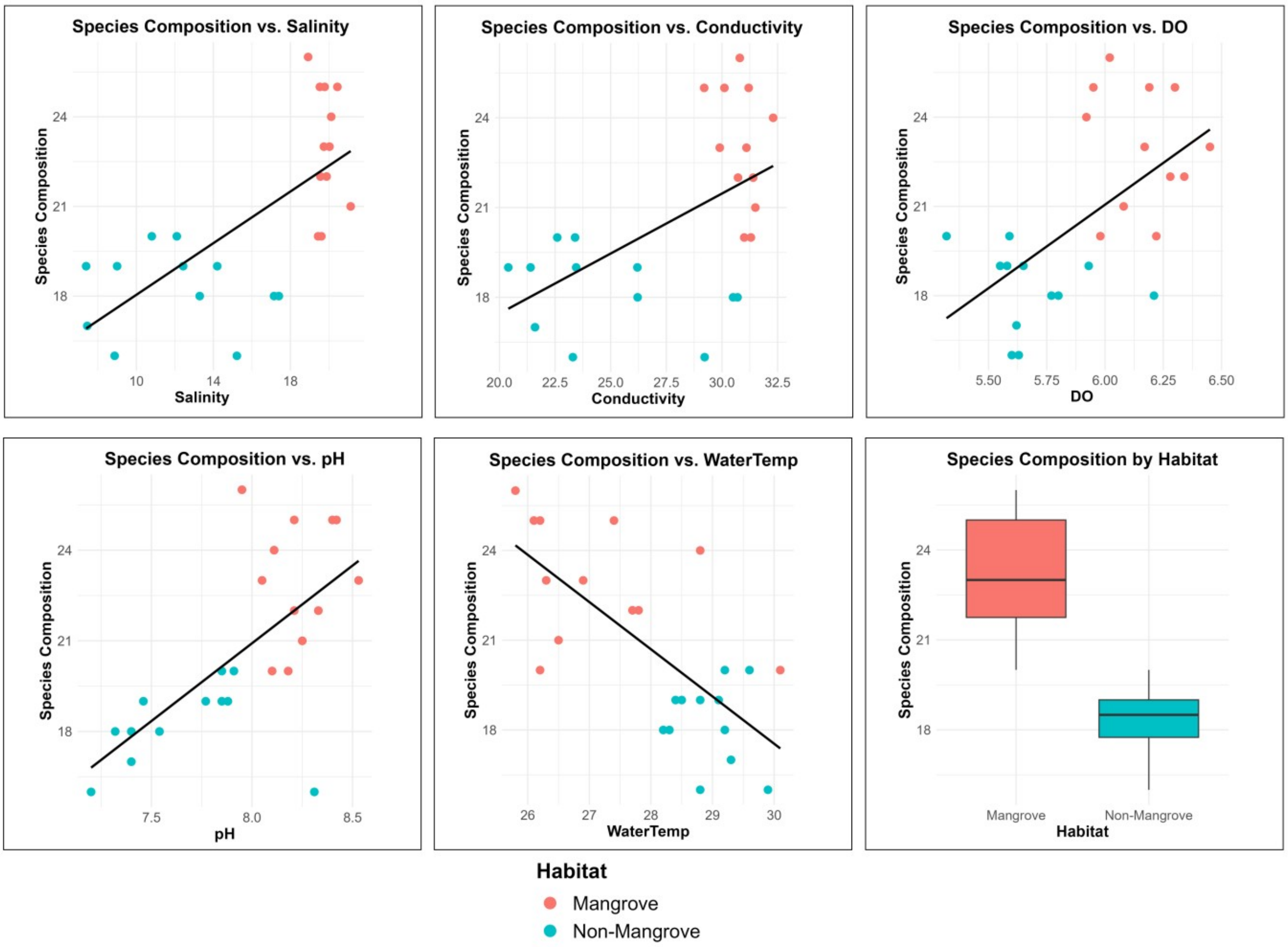


**FIGURE 3** The relationship between water parameters and species composition in mangrove and non-mangrove habitats in the Irrawaddy Delta, Myanmar.

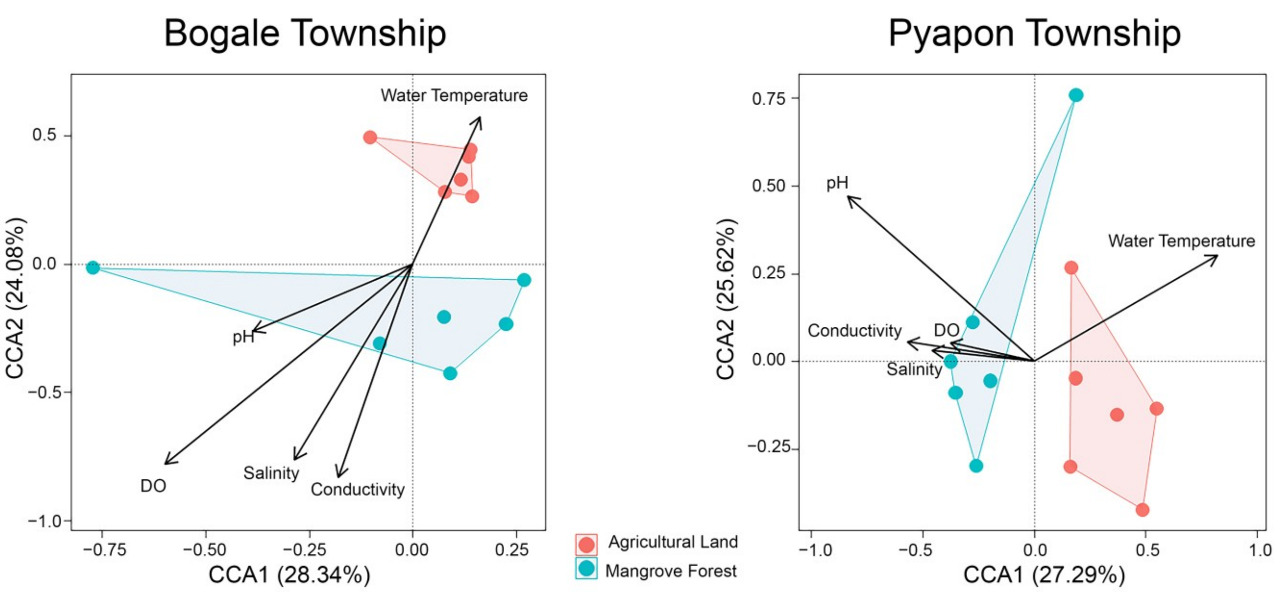


**FIGURE 4** Correlation of fish assemblages with land use and water parameters in mangrove and non-mangrove habitats in the Irrawaddy Delta, Myanmar.

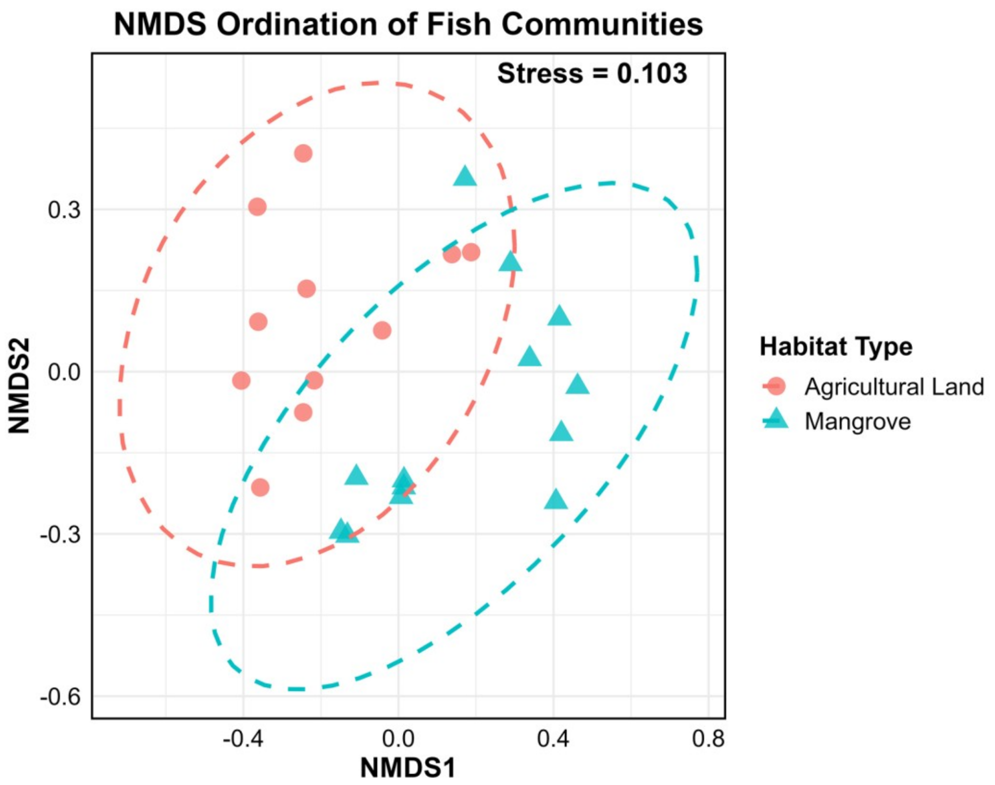


**FIGURE 5** Non-metric multidimensional scaling (NMDS) ordination of fish assemblages between mangrove and agricultural land habitats in the Irrawaddy Delta, Myanmar.

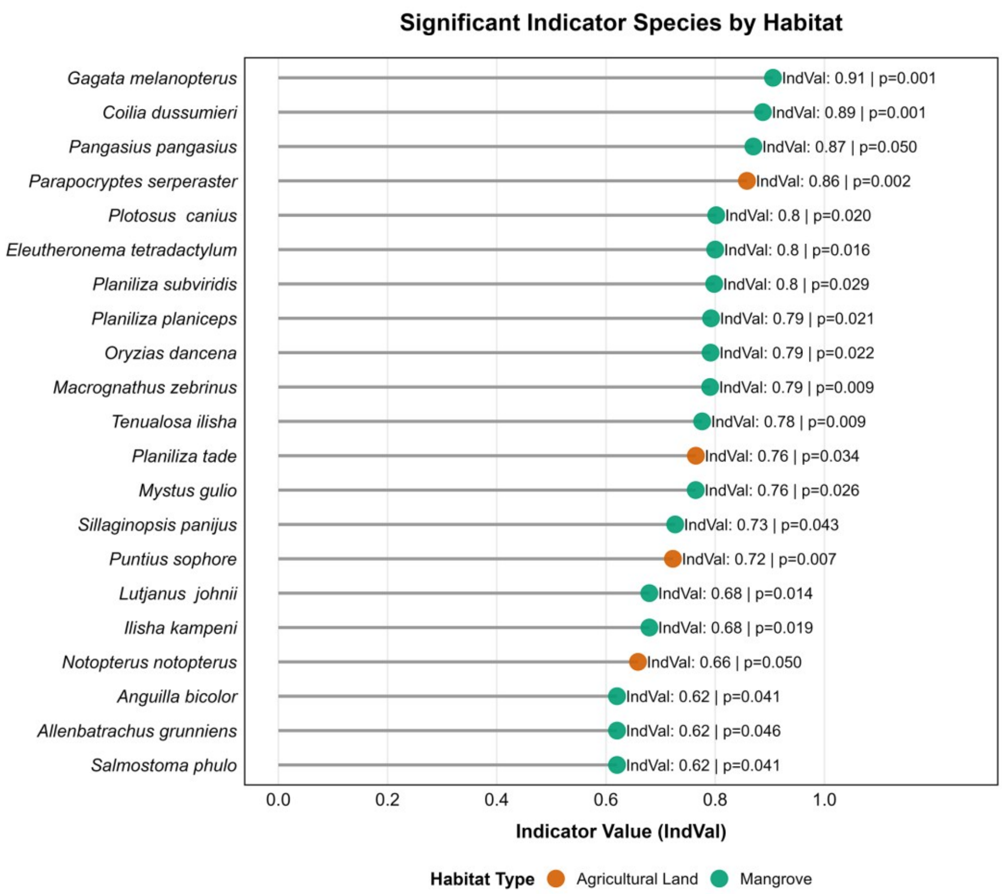


**FIGURE 6** Significant indicator species by habitat in the Irrawaddy Delta, Myanmar.

Furthermore, the functional feeding guild analysis highlighted substantial differences in the trophic structure between the two ecosystems (Figure 7). The mangrove habitats were characterized by a prominent dominance of benthivores and detritivores, indicating a high reliance on bottom-dwelling organisms and decaying organic matter. Conversely, the agricultural land habitats displayed a distinctly different proportion of feeding guilds, reflecting a shift in available basal food resources. The pronounced abundance of detritus- and benthic-feeding groups in the mangrove zones underscores the structural complexity and rich organic input of the Irrawaddy mangrove ecosystem in supporting the local estuarine food web.

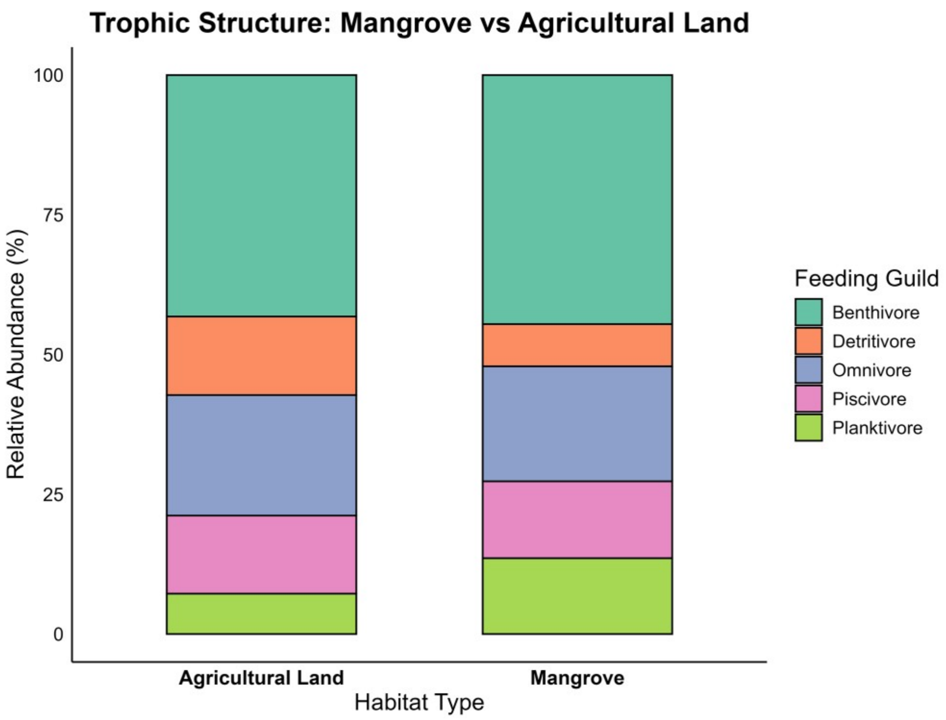


**FIGURE 7** Relative abundance of functional feeding guilds comparing mangrove and agricultural land ecosystems.

## 4 | DISCUSSION

### 4.1 Seasonal hydrological dynamics and fish diversity

This study recorded 129 fish species, exhibiting distinct seasonal variations in assemblage structure primarily driven by the monsoonal hydrological cycle. Winter supported the highest species richness and diversity, likely due to stabilized water conditions and reduced river discharge, a seasonal peak remarkably consistent with ecologically critical wetlands in neighboring Bangladesh (Hendy *et al*. 2020; Aziz *et al*. 2021). Despite these fluctuations in richness, species evenness remained highly stable across all seasons. This mirrors the ecological resilience documented in Bangladeshi coastal rivers and other dynamic tropical systems, where fish communities adapt robustly to intense short-term environmental variability (Casatti 2005; Silva *et al*. 2021; Ullah *et al*. 2023).

Furthermore, Bray–Curtis similarity analysis revealed that the summer and winter dry seasons shared the highest assemblage similarity (0.438), indicating a relatively stable community structure outside the monsoon period. In contrast, the rainy season exhibited the lowest similarity to both summer (0.281) and winter (0.194), signaling a marked structural shift in the community. This monsoonal restructuring, driven by increased flooding, turbidity, and altered salinity, is a well-documented phenomenon in tropical ecosystems like the Amazon and Paraná floodplains, where rainy-season assemblages diverge significantly from dry-season groups (Neiff *et al.* 2009; Chea *et al*. 2020; Silva *et al*. 2021). Ultimately, these seasonal shifts highlight the critical role of the monsoonal hydrological cycle in driving fish community dynamics within the Irrawaddy mangrove ecosystem.

### 4.2 Correlation of water parameters with species composition

Our findings indicate that mangrove habitats, characterized by more stable and nutrient-rich aquatic conditions, supported significantly higher biodiversity compared to non-mangrove sites. These results corroborate the view that mangroves support more diverse and abundant fish fauna due to their nutrient-rich waters (Faunce and Serafy 2006; Chong 2007), whereas non-mangrove sites characterized by warmer temperatures are often correlated with low species richness (Nagelkerken *et al*. 2000). However, while basic water quality indicators exert some influence, they are likely secondary proxies to the broader structural and trophic dynamics within the estuarine ecosystem.

**4.3 Influence of habitat complexity and trophic dynamics**

While seasonal variations in basic water parameters exert some influence on the estuarine fish assemblage, our findings highlight that habitat complexity and trophic dynamics are the primary drivers of community structuring. The highly significant separation of fish assemblages between mangrove and agricultural land habitats, as demonstrated by the NMDS and PERMANOVA results, strongly aligns with the concept that structurally complex environments offer diverse ecological niches. Mangrove roots and complex pneumatophore systems not only act as physical refuges for juvenile fishes and small species from predators but also support a highly specialized food web.

This ecological distinctness is strongly supported by the indicator species analysis, a pattern widely documented in global mangrove ecosystems where structural complexity serves as critical nursery grounds (Faunce and Serafy 2006; Nagelkerken *et al*. 2000). Mangrove indicators like *G. melanopterus* and *C. dussumieri* are tightly linked to the complex physical structures and rich estuarine conditions. Importantly, the significant association of the endangered *E. tetradactylum* with the mangrove ecosystem confirms its role as an indispensable nursery and feeding ground. In contrast, agricultural land indicators such as *P. serperaster* reflect a community adapted to structurally simplified, mudflat-like environments devoid of dense canopy cover.

This is corroborated by our functional feeding guild analysis, which demonstrated a marked dominance of benthivores and detritivores within the mangrove sites. The abundant leaf litter and decomposing organic matter characteristic of intact mangrove ecosystems serve as the foundational energy source for these detritus-based food webs. Conversely, the agricultural land habitats, which lack such structural complexity and distinct organic inputs, exhibited a significantly different trophic composition. Therefore, these findings strongly suggest that the physical integrity and energy inputs of the Irrawaddy mangroves are paramount for sustaining the local estuarine food web and its associated high fish diversity, extending beyond the simple influence of water quality parameters.

**4.4 Relationship of land use and water quality on fish communities**

The CCA results demonstrated a strong spatial dependency, indicating that environmental parameters act hierarchically on species' occurrence (Frissell *et al*. 1986). Pyapon Township was primarily influenced by temperature and pH, favoring thermotolerant species in less-canopied non-mangrove areas (Pusey and Arthington 2003; Allan 2004). In contrast, marine-influenced parameters like salinity, conductivity, and dissolved oxygen primarily structured the fish assemblages in Bogale, a common pattern in coastal ecosystems where salinity is considered the master environmental gradient (Elliott and Whitfield 2011). This highlights how distinct local hydrology and environmental gradients strictly dictate spatial community structures.

**4.5 Limitations and future perspectives**

Despite the comprehensive sampling design and robust statistical analyses, certain limitations in this study should be acknowledged. First, inherent fishing gear selectivity may influence the species composition recorded. Although a combination of cast nets, tiger mouth nets, stake nets, and beach surrounding gill nets (mesh sizes ranging from 1.0 to 5.5 cm) supplemented by market surveys were employed, highly mobile pelagic species or small cryptobenthic taxa that hide deep within the complex mangrove root systems might still be underrepresented.

Second, while the functional feeding guild analysis provided critical insights into the estuarine food web, trophic classifications were based on FishBase and established literature rather than in-situ gut content or stable isotope analyses. This approach provides a broad ecological overview but may not capture localized dietary shifts or opportunistic feeding behaviors specific to the Irrawaddy Delta. Finally, the environmental parameters measured were limited to fundamental physicochemical properties (e.g., temperature, salinity, DO, pH). Future studies should incorporate extensive water chemistry data (e.g., nutrient loads, heavy metals) and long-term inter-annual sampling to further elucidate the complex drivers of fish assemblage dynamics in this vital ecosystem.

## 5 | CONCLUSIONS

This study provides a comprehensive documentation of 129 fish species in the Irrawaddy mangrove ecosystem, highlighting its critical role as a biodiversity hotspot and estuarine nursery. Our analysis reveals that while the fish assemblage experiences seasonal fluctuations, peaking in richness and diversity during winter, the overall community balance remains remarkably stable throughout the year. Beyond the basic influence of water parameters, advanced multivariate (PERMANOVA and NMDS) and trophic guild analyses conclusively demonstrate that habitat complexity and food web dynamics are the primary drivers of fish community structure, with indicator species analysis (ISA) confirming that distinctly different taxa uniquely characterize the mangrove and agricultural ecosystems. The pronounced dominance of benthivores and detritivores in the mangrove areas underscores the heavy reliance of the estuarine food web on mangrove-derived organic matter. Ultimately, these findings emphasize that conserving the physical integrity and natural energy inputs of the Irrawaddy Delta's mangroves is essential for sustaining regional fisheries and protecting endangered species, extending far beyond the mere management of water quality. Therefore, future fisheries management strategies in the Irrawaddy Delta should prioritize the strict protection of core mangrove habitats and restrict destructive fishing practices in these critical nursery zones. Integrating such habitat-based conservation efforts with local fishery policies will be essential to ensure the long-term sustainability of the regional estuarine ecosystem.

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**ETHICAL APPROVAL**
All applicable international, national and/or institutional guidelines for the care and use of animals were followed in this study.

**CONFLICT OF INTEREST**
The author declares no conflict of interest.

**AUTHORS' CONTRIBUTION**
Ko Ko Tun Thwin: Data collection (lead); Data curation (lead); formal analysis (lead); investigation (equal); writing original draft (lead). Jiang Bai: Data curation (equal); formal analysis (equal). Htet Naing Nay: Investigation (equal). Htet Zaw Phyo: Data curation (equal). Thaung Naing Oo: provided assistance in the conduct of fieldwork and collection of specimens (lead). Xiao Yong Chen: Conceptualization (lead); Funding acquisition (lead); methodology (lead); writing - review and editing (lead); supervision (lead); visualization (lead); investigation (equal).

**DATA AVAILABILITY STATEMENT**
The data that support the findings of this study are available on request from the corresponding author.

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