Egyptian Journal of Aquatic Biology & Fisheries
Zoology Department, Faculty of Science,
Ain Shams University, Cairo, Egypt.
ISSN 1110 – 6131
Vol. 29(3): 929 – 945 (2025)
www.ejabf.journals.ekb.eg

Diversity of Fishes in the Estuarine Areas of the Mekong River

Dinh Dac Tran[1], Vang Thi Nguyen[1], Hoang Thi My To[1], Atsushi Ishimatsu[1], Toan Thanh Vo[1], and Quang Minh Dinh[2*]

[1]College of Aquaculture and Fisheries, Can Tho University, Can Tho 900000, Vietnam
[2]School of Education, Can Tho University, Can Tho 900000, Vietnam

[*]**Corresponding Author:** dmquang@ctu.edu.vn

ARTICLE INFO

Article History:
Received: Nov. 3, 2023
Accepted: April 30, 2025
Online: May 21, 2025

Keywords:
Estuarine ecosystem,
Fish diversity,
The Mekong River

ABSTRACT

Estuarine areas are ecologically and sustainablty important for fisheries development. However, they have faced numerous threats causing habitat degradation. Urgent actions to conserve the estuarine ecosystem are needed. In the present study, the Simpson index, Jarccard coefficient, and Bray-Curtis were employed to evaluate fish composition in four estuaries (i.e., Dinh An, Tran De, Cua Lon and Bay Hap) of the Mekong River. Data on environmental parameters, including surface and bottom salinity, transparency, pH, and temperature, were gathered. A total of 162 species were identified, with a number of species varying from 84 to 94 among the four estuaries. Relative abundances were similar among the estuaries and seasons, whereas diversity indices went considerably. The high Simpson indices were found in Tran De (9.2), Cua Lon (8.0), and Dinh An (6.8) in the dry season, whereas the lowest values were in Dinh An (3.2), Cua Lon (3.6), and Bai Hap (4.3) in the rainy season. The distinctiveness and cluster analyses showed that fish composition was classified into two groups, i.e., the estuaries in the east (Dinh An, Tran De) and the west (Cua Lon, Bay Hap) of the Mekong Delta. Fish composition in the east coast estuaries was further classified into rainy and dry seasons. Environmental factors could explain the spatiotemporal variations in fish composition. The ecological role of the estuaries was also discussed. Findings from the study could be helpful for fisheries management of the Mekong River.

INTRODUCTION

An estuary is a complex habitat where the freshwater of rivers interacts with seawater **(Cameron & Pritchard, 1963)**. It comprises intertidal flats, salt marshes, mangroves, creek systems, and river mouths, which serve as substantial feeding and breeding grounds for many species. Consequently, the biodiversity in estuaries is vibrant **(Savenije, 2005)**. To humans, they are essential in both providing food and transport lines between land and sea. The estuarine ecosystem nurtures and enriches the economies of coastal communities and the human spirit **(NOAA, 2002)**. However, the estuarine ecosystem integrity depends largely on salinity patterns, tide cycles, and flows **(Davis *et al.*, 2005; Brownscombe & Fox, 2012)**, hence they are vulnerable to climate change, such as changes in rainfall, drought, sea level rise, and temperature.

The Mekong River originated from the Tibet plateau, 3000m above sea level, flowing long distances to the sea. In Phnom Penh, the river splits into three main tributaries, and two of these form a vast delta in Vietnam. Before flowing to the sea, the Mekong River forms nine estuaries **(MRC, 2003)**. The Mekong Delta's estuarine ecosystem plays economically and ecologically essential roles. According to **GSO (1999)**, the number of households working on inland fishing, including estuary, is 87,645, with roughly 448,564 fishermen **(Sverdrup-Jensen, 2002)**. The estuarine ecosystem also provides important protein sources and creates seasonal jobs for locals **(Vu & Ngwenya, 2008)**. In addition, this region is also known as a biodiversity hotspot with numerous endemic species **(Hortle, 2009a)**.

Nevertheless, the estuarine ecosystem in the Mekong Delta has faced many threats from both natural and anthropogenic impacts. High pressure from overfishing **(Barlow *et al.*, 2008)**, pollution, especially from plastic waste, and hydropower dam construction on the mainstream **(Dugan *et al.*, 2010)** primarily harm the estuaries. In addition, climate change, with an increasingly severe impact from sea level rise and salinization **(CGIAR, 2016)**, has also altered this ecosystem. Therefore, urgent actions need to be implemented to conserve the ecosystem.

There have been some studies about fish composition in the estuarine regions of the Mekong Delta. However, they focused on small areas (a single estuary) or small groups of fish. For instance, fish composition was investigated in Dinh An estuary **(Huan *et al.*, 2016)**, Cu Lao Dung Island **(Tran *et al.*, 2021)**, and Co Chien River **(Nguyen *et al.*, 2022)**. **Tran *et al.* (2013)** investigated the fish composition of 13 provinces of the Mekong Delta but mainly focused on inland fishes. Recent studies have explored fish diversity in specific estuarine systems of the Mekong Delta. For example, **Nguyen *et al*. (2022)** comprehensively assessed fish species composition, diversity, and ecological value in the Co Chien River, contributing valuable insights into spatial variation and management needs. In contrast, **Ut *et al.* (2020)** focused on the fish diversity of a Mekong River (Hau River) branch. There is no study on fish composition in the estuaries of the whole region, which could be helpful for fisheries management. Therefore, the present study aimed to understand fish assemblage characteristics in the Mekong River's estuaries by examining fish composition, evaluating fish diversity, and comparing similarities and distinctiveness among sites and seasons. Data from the current study could advise further fisheries management in the study region. This research also contributes to the achievement of the United Nations Sustainable Development Goals (SDGs), particularly SDG 14 (Life Below Water), SDG 13 (Climate Action), and SDG 2 (Zero Hunger), by providing data that support sustainable fisheries management, biodiversity conservation, and resilience of estuarine ecosystems under environmental stressors.

MATERIALS AND METHODS

Study area

There are two types of estuaries in the Mekong Delta; the Mekong River's flow directly influences one type, and the other does not (Fig. 1). Estuaries of the former are located on the delta's east coast and receive a considerable freshwater plume annually. Consequently, nutrients, plankton, and fish larvae biomass are high during flooding **(Lagler, 1976)**. In the low-flow season, the saline water extends roughly 60km from the river mouth **(MRC, 2003)**. Therefore, the environment of these estuaries varies dramatically. The estuaries of the latter are located on the west coast and are little influenced by the Mekong River's flow. The marine environment mainly affects these estuaries and consequently increases salinity. In the present study, we chose Dinh An and Tran De estuaries on the east coast and Cua Lon and Bay Hap estuaries on the west coast.

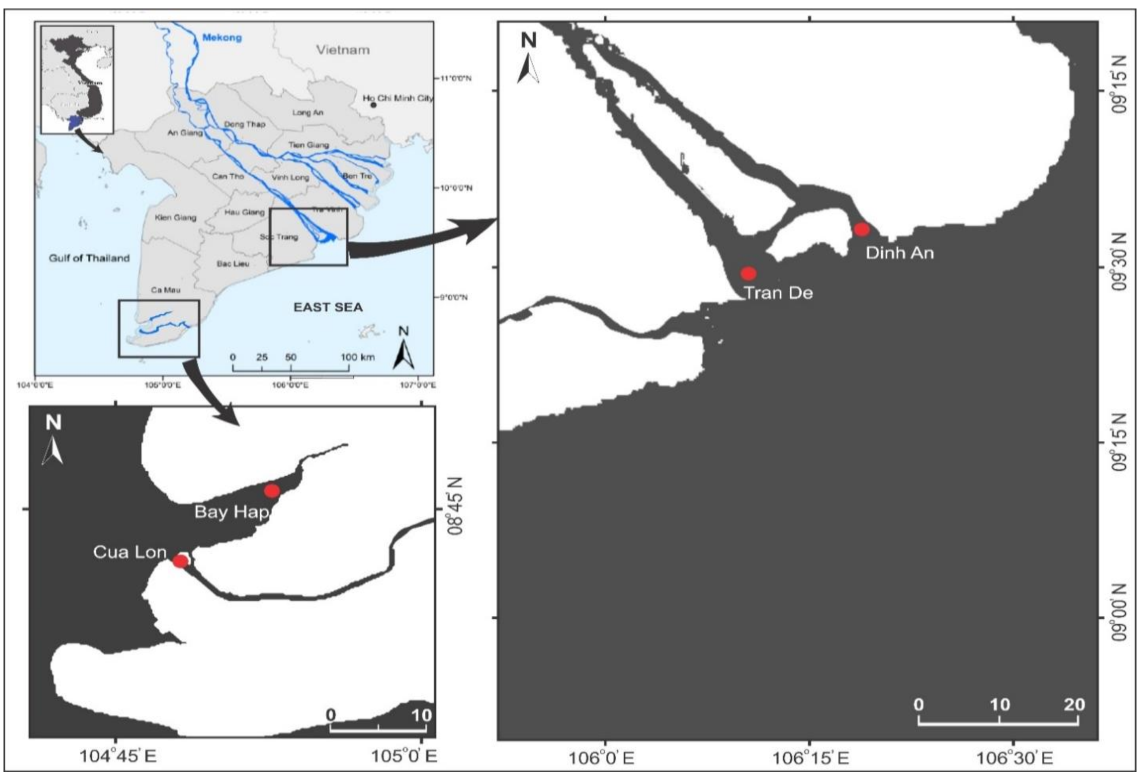

Fig. 1. Location of the Mekong Delta (the upper left) and the sampling sites on the east side (Dinh An and Tran De) (the upper right) and the west side (Cua Lon and Bay Hap) (the bottom left). The filled red circles are the sampling sites. Source: revised from **Kuenzer *et al.* (2013)** and Google maps

Data collection

Three locations at each estuary (two near the banks and one in the middle of the river mouth) were chosen for sampling. Trawling nets, i.e., 7.0×1.5m (length×width) of the mouth frame and 20mm of the mesh size at the cod end, were employed to collect samples. The average operating speed was roughly $0.73 \pm 0.17 m \cdot s^{-1}$ over a distance of 1,962±581m. Specimens were preserved in crushed ice and were analyzed later on the sampling day. Fish were identified at the species level based on the guidance of **Rainboth (1996)**, **FAO (1999)**, **Kottelat (2001)** and **Tran *et al.* (2013)**. Information on the number of individuals, size, and wet weight of each species was also gathered. Samples were photographed and preserved for later retrieval.

Environmental parameters were collected at each sampling site, including water depth (Portable Depth Sounder, Model: HONDEX PS7), temperature, pH (pH Meter, Model: HI 98107), salinity at the surface and bottom (Refractometer, Model: ATC), and water transparency (Secchi disc, 20cm diameter).

Twelve sampling trips were implemented from July 2017 to May 2019 (every two months). Note that there are two seasons in the Mekong Delta; therefore, we classified data into two groups, i.e., rainy (May to November) and dry (December to April). The fish composition, diversity, and environmental factors were compared between estuaries and seasons.

Data analysis

To examine the variations of fish assemblages among estuaries in different seasons, data were classified into eight groups, including rainy season in Dinh An (DA-Rainy), Tran De (TD-Rainy), Cua Lon (CL-Rainy), Bay Hap (BH-Rainy), and dry season in Dinh An (DA-Dry), Tran De (TD-Dry), Cua Lon (CL-Dry), and Bay Hap (BH-Dry). Different aspects of fish assemblages were examined in detail to gain insight into relative abundance, diversity, evenness, similarity, and clustering. The relative abundance was expressed by plotting the species rank abundance against the relative abundance **(Whittaker, 1965)**. The Simpson index examined the fish composition, diversity, and season similarity **(Simpson, 1949)**. The community similarity was also calculated using the Jaccard coefficient to compare each pair of treatments separately **(Jaccard, 1912)**. The similarity of each site was calculated using the Bray-Curtis similarity index **(Bray & Curtis, 1957)**.

Preliminary tests of normality and homogeneity were applied for the environmental parameters before the performance of suitable analysis of one-way ANOVA and post hoc Tukey tests, one-way ANOVA and post hoc Welch tests, or Kruskal-Wallis ANOVA, or Wilcoxon-Mann-Whitney post hoc test. The software IBM SPSS version 24.0 (IBM Corp) was used for the analyses.

RESULTS

Environmental parameters

Among the environmental factors, salinity differed between the east and west estuaries. The surface salinity was significantly lower in the east coast estuaries for both seasons compared to the west coast estuaries (Table 1). Similarly, the bottom salinity follows the same trend, but the values were slightly higher than the surface salinity. For the comparison of salinity between seasons, generally, salinity in the dry season was higher than in the rainy season for each estuary. Regarding transparency, the values were higher in the east coast estuaries than the west coast estuaries, but not significantly different. The only significant difference was found in the openness of Dinh An and Cua Lon in the dry season (Table 1). The pH was significantly higher in the west coast estuaries, whereas there was no significant difference in the temperature between seasons and estuaries (Table 1).

Table 1. The environmental parameters (mean±SD, n = 6 for each)

Place-season	Surface salinity (ppt)	Bottom salinity (ppt)	Transparency (cm)	pH	Temperature (°C)
Dinh An-rainy	0.5 ± 0.9^{a}	6.2 ± 3.5^{ab}	23.6 ± 6.3^{ab}	7.4 ± 0.3^{ab}	29.6 ± 0.9^{a}
Dinh An-dry	3.8 ± 2.0^{ab}	15.2 ± 2.4^{cd}	39.3 ± 6.8^{b}	7.9 ± 0.6^{ab}	29.2 ± 1.6^{a}
Tran De-rainy	2.2 ± 3.2^{a}	3.8 ± 4.2^{a}	26.7 ± 11.5^{ab}	7.1 ± 0.5^{a}	29.4 ± 0.8^{a}
Tran De-dry	9.3 ± 3.2^{b}	13.0 ± 4.7^{bc}	31.8 ± 9.5^{ab}	8.1 ± 0.4^{b}	29.0 ± 1.9^{a}
Cua Lon-rainy	24.7 ± 5.0^{c}	24.9 ± 4.9^{e}	23.5 ± 11.8^{ab}	7.9 ± 0.5^{ab}	29.2 ± 1.9^{a}
Cua Lon-dry	26.2 ± 2.0^{c}	26.9 ± 1.3^{e}	18.3 ± 11.8^{a}	8.1 ± 0.4^{b}	30.2 ± 2.3^{a}
Bay Hap-rainy	20.7 ± 5.3^{c}	20.9 ± 4.8^{de}	21.0 ± 8.6^{ab}	8.1 ± 0.4^{b}	29.8 ± 2.2^{a}
Bay Hap-dry	27.2 ± 2.5^{c}	27.3 ± 1.5^{e}	29.1 ± 9.9^{ab}	7.9 ± 0.5^{ab}	28.6 ± 1.6^{a}
One-way ANOVA or Kruskal-Wallis	$\chi^2 = 39.7$ $P \leq 0.001$	$\chi^2 = 31.0$ $P\leq0.001$	$\chi^2 = 2.4$ $P\leq0.04$	F = 3.1 $P\leq0.01$	F = 0.43 $P\leq0.87$

Note: One-way ANOVA and Wilcoxon-Mann-Whitney were performed for pH and temperature. Kruskal-Wallis and Wilcoxon-Mann-Whitney tests were performed for the remaining factors. The data with different letters in the same columns are significantly different ($P\leq0.05$)

Fish composition among the estuaries

During the study period, 100,903 individuals of 162 species were collected. Among the four estuaries, Tran De has the highest number of species (94 species belonging to 16 families), followed by Cua Lon, Bay Hay, and Dinh An with 89, 85, and 84 species, respectively. Regarding species composition, estuaries on the east coast share similarities, and those on the west coast also have standard features. For instance, Gobiidae was the largest group of species, accounting for 23.6 and 21.2% of the number of species in Cua Lon and Bay Hap, respectively, whereas the sharing of this family was 13.1% (Dinh An) and 12.8% (Tran De) on the east coast. Other families also follow the same trend. For example, families of Scorpaenidae (accounting for 10.7% and 10.6% of the total species in Dinh An and Tran De, respectively), Pangasidae (7.1% and 7.4%), Ariidae (8.3% and 7.4%), Cyprinidae (7.1% and 6.4%), Cynoglossidae (6.0% and 7.4%), and Engraulidae (6.0 % and 7.4 %) were dominant families on the east coast. In contrast, families of Engraulidae (accounting for 7.9% and 9.4% of the total species in Cua Lon and Bay Hap, respectively) and Scorpaenidae (11.2% and 7.1%) showed a high number of species on the west coast.

Regarding evenness, some families were only found on the east coast. For instance, Cyprinidae, Pangasidae, Soleidae, and Ariidae (having only two species in Bay Hap) were only found in Dinh An and Tran De. They are typical species migrating along the Mekong River to the estuaries. Atherinidae, Belonidae, Dasyatidae, Lutjanidae, Sphyraenidae, Synbrachidae, and Tetraodonidae only occurred in the Cua Lon and Bay Hap. They are species inhabiting the estuaries that are highly influenced by the marine environment. In addition, there were some typical families found on both sides, such as Clupeidae, Cynoglossidae, Eleotridae, Engraulidae, Gobidae, Polynemidae, and Sciaenidae, which are euryhaline. The number of species in each family in the four estuaries is shown in Table (2).

Table 2. Number of species in the family among the estuaries

No	Family	Dinh An	Tran De	Cua Lon	Bay Hap	No	Family	Dinh An	Tran De	Cua Lon	Bay Hap
1	Akysidae	2	2	-	-	26	Mugilidae	-	1	4	4
2	Ambassidae	2	2	-	1	27	Mullidae	-	-	1	1
3	Ariidae	7	7	-	2	28	Muraenesocidae	-	1	1	1
4	Atherinidae	-	-	1	1	29	Muraenidae	-	-	-	1
5	Bagridae	1	1	-	-	30	Ophichthidae	1	2	3	3
6	Batrachoididae	2	2	1		31	Pangasidae	6	7		
7	Belonidae	-	-	1	1	32	Phallostethidae	-	-	2	-
8	Callionymidae	2	2	1	1	33	Platycephalidae	-	-	-	2
9	Carangidae	-	-	1	3	34	Plotosidae	1	1	1	
10	Clupeidae	4	3	4	4	35	Polynemidae	2	2	2	2
11	Cobitidae	1	1	-	-	36	Pristigasteridae	-	-	2	1
12	Cynoglossidae	5	7	5	2	37	Scatophagidae	1	1	1	1
13	Cyprinidae	6	6	-	-	38	Sciaenidae	9	10	10	6
14	Dasyatidae	-	-	1	1	39	Scorpaenidae	-	1	-	-
15	Drepaneidae	-	-	1		40	Seranidae	-	-	-	3
16	Eleotridae	3	3	2	2	41	Siganidae	1	1	2	-
17	Engraulidae	5	7	7	8	42	Sillaginidae	2	1	1	1
18	Gerreidae	-	-	1	2	43	Siluridae	-	2	-	-
19	Gobiidae	11	12	21	18	44	Soleidae	3	3	-	-
20	Haemulidae	1	-	-	-	45	Sphyraenidae	-	-	1	1
21	Hemiramphidae	1	1	3	3	46	Synanceiidae	1	-	-	-
22	Leiognathidae	-	1	2	3	47	Synbrachidae	-	-	1	1
23	Lobotidae	1	1	-	-	48	Synodontidae	1	1	-	-

No Family	Dinh An	Tran De	Cua Lon	Bay Hap	No Family	Dinh An	Tran De	Cua Lon	Bay Hap
24 Loricariidae	-	1	-	-	49 Tetraodontidae	1	-	2	2
25 Lutjanidae	-	-	2	2	50 Trichiuridae	1	1	1	1
					Total	**84**	**94**	**89**	**85**

In terms of abundance, some species were common and dominant. For instance, *Polynemus melanochir* was most abundant in Tran De in the rainy season, with 8,628 individuals (accounting for 38 % of total individuals caught), and in Dinh An with 7,778 individuals (51%) in the rainy season and 1,107 individuals (28%) in the dry season. *Coilia rebentischii* was dominant in Tran De in the dry season (23%), while *Ambassiss vechellii* was abundant in Cua Lon in the rainy season (44%). *Stolephorus dubiosus* was common in Cua Lon in the dry season (19.3%) and in Bay Hap in the rainy (49%) and dry (36%) seasons.

Relative abundance of fishes

Logarithm transformation of species abundance has been employed to reveal the commonness and rarity of species in a specific habitat. Plotted relative abundance data show that the dominance-diversity curves are similar among the estuaries and seasons. This means these habitats are species-rich, and the species composition is balanced. The relative abundances were variable between seasons (Fig. 2). For instance, the dominance-diversity curves were steeper in the rainy season than in the dry season, meaning some species were dominant in these estuaries in the rainy season. In the rainy season, *Polynemus melanochir* was dominant in Dinh An and Tran De, with species relative abundance being 0.51 and 0.39, respectively. In contrast, *Ambassis vechellii* and *Stolephorus dubiosus* were common in Cua Lon (0.44) and Bay Hap (0.49), respectively.

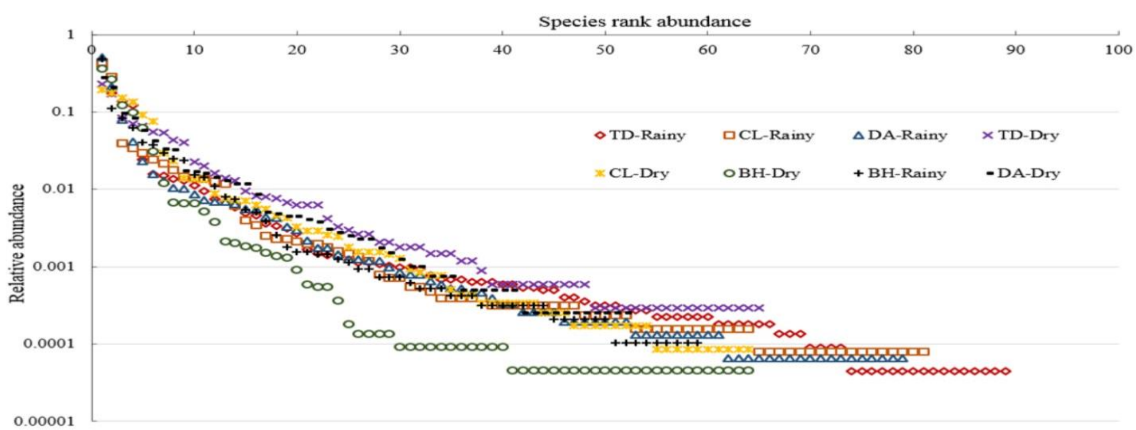

Fig. 2. The dominance-diversity distribution for four estuaries in two seasons. TD-Rainy: Tran De in rainy season, TD-Dry: Tran De in dry season, DA-Rainy: Dinh An in rainy season, DA-Dry: Dinh An in dry season, CL-Rainy: Cua Lon in rainy season, CL-Dry: Cua Lon in dry season, BH-Rainy: Bay Hap in rainy season, and BH-Dry: Bay Hap in dry season

Community density of fishes

Simpson reciprocal index shows that the values in the dry season were much higher than those of the rainy season (6.8 for DA-Dry, 9.2 for TD-Dry, 8.0 for CL-Dry, and 4.3 for BH-Dry compared to 3.2 for DA-Rainy, 4.6 for TD-Rainy, 3.6 for CL-Rainy, and 3.7 for BH-Rainy). The highest diversity was found in Tran De during the dry season, whereas the lowest was in Dinh An during the rainy season.

Community distinctiveness

Results from the Jaccard coefficient show that the fish composition was distinctive between estuaries on the east and west coasts. The lowest similarities were found in some pairs of DA-Dry and BH-Rainy, DA-Rainy and BH-Dry, TD-Rainy and BH-Dry, DA-Rainy and BH-Rainy, TD-Rainy and BH-Rainy, and TD-Dry and BH-Dry with Jaccard coefficient of 0.11, .012, 0.13, 0.14, 0.14, and 0.14, respectively. The highest similarity was found in the estuaries in the east, with DA-Rainy sharing 71% similarity to TD-Rainy, followed by DA-Rainy and TD-Dry with 47%, and DA-Rainy and DA-Dry with 46%. The other pairs had the Jaccard coefficient varying from 0.16 to 0.39 (Table 3).

Table 3. Pearson correlation coefficients between the estuaries in the two seasons

Jarcard matrix	DA-Rainy	DA-Dry	TD-Rainy	TD-Dry	CL-Rainy	CL-Dry	BH-Rainy	BH-Dry
DA-Rainy		0.46	0.71	0.47	0.20	0.18	0.14	0.12
DA-Dry			0.28	0.39	0.17	0.16	0.11	0.08
TD-Rainy				0.32	0.17	0.18	0.14	0.13
TD-Dry					0.22	0.20	0.18	0.14
CL-Rainy						0.34	0.38	0.31
CL-Dry							0.32	0.31
BH-Rainy								0.29
BH-Dry								

Cluster analysis

The multivariate analysis of fish assemblage was examined, taking both distinctiveness and similarity with Bray-Curtis dissimilarity. The results clearly show two groups of fish assemblages, the east and west sides (group 1 and group 2, respectively). The similarity between these two was only 14.8%. Specifically, group 1 can be subdivided into two sub-groups (group 1a and 1b), representing the dissimilarity between rainy and dry seasons in the two estuaries, with similarity being 35.9%. In contrast, there was no apparent difference in fish assemblage between the two seasons in the estuaries in the west (Fig. 3).

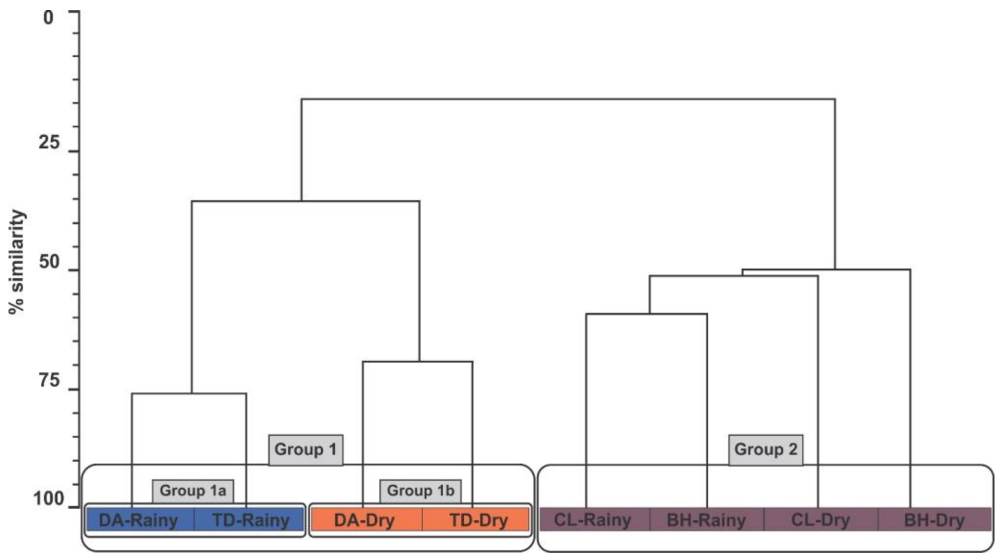

Fig. 3. Dendrogram produced using the Bray-Curtis similarity measure among estuaries in two seasons

The dendrogram separates the fish assemblages into two major groups, corresponding to the east and west coast estuaries. Within the eastern group, further subdivisions were observed between the rainy and dry seasons, indicating higher seasonal variation compared to the western estuaries, where such variation was minimal.

DISCUSSION

Environmental parameters

The environmental factors, including salinity, temperature, turbidity, and pH, play essential roles in species abundance and diversity because the changes in these factors influence primary production **(González-Sansón *et al*., 2022; Nuon *et al*., 2025)**, which has been proven in many studies. For instance, temperature and salinity are two main factors determining fish assemblages in temperate estuaries such as the Elbe estuary **(Thiel *et al.*, 1995)** and the Rio de la Plata estuary **(Jaureguizar *et al.*, 2004)**. This could be because the temperature in these estuaries changes dramatically according to the seasons. Salinity is the primary factor affecting fish communities in tropical estuaries, while temperature does not fluctuate much **(Blaber, 2000)**. The estuaries in the Mekong Delta reflect the characteristics of the tropical estuary, with the main driving factors being salinity, transparency, and pH (Table 1). The Mekong River's flow highly influenced these environmental parameters. The salinity of the estuaries in the east is driven by the Mekong River's flow, which brings about 475,000 million m^3 of water in the rainy season **(Sokheng *et al.*, 1999)**. However, in the dry season, seawater intrusion causes the salinity to rise significantly **(MRC, 2003)**. In contrast, the two estuaries in the west are located in the Ca Mau peninsula, which is influenced by the sea, causing high salinity all year round. The distinctive characteristics of the environmental factors could explain the spatiotemporal differences in fish assemblage in the Mekong Delta (Fig. 3).

Species composition and diversity

The species abundance found in the Mekong Delta estuaries is composed of many species, with the relative abundance not much different among the estuaries. The number of taxa in the present study (162 species) is much higher than in the previous survey by the Mekong River Commission for all of the Mekong basin and Yunnan, with 113 fresh-brackish marine species **(Hortle, 2009b)**. This may be because the present study spent much time and effort on sampling. The species in the present study is also higher than other tropical estuaries in the Western Pacific (mostly under 53 species, only in the Subarnarekha estuary having 140 species) (Table 4). The difference in the number of species could be due to the differences in the sampling gear, sampling period, and habitat characteristics. Regarding seasonal fluctuations of species, three studies in nearby regions show similar trends and agree with our findings. Fish diversity was high in the dry season with the contribution of marine visiting species **(Hossain *et al.*, 2012; Jalal *et al.*, 2012; Ya *et al.*, 2015)**.

The species composition and diversity in the present study are correlated with both spatial and seasonal factors (Table 2 & Fig. 3). The reason for this may lie in the environmental factors discussed above. Some studies on the same issue noted that fish composition largely depends on salinity and temperature instead of spatiotemporal distribution. A survey by **Ghosh *et al.* (2011)** in the Subarnarekha estuary showed that the fish assemblage was strongly dependent on salinity, which is also true in the study of **Kannappan and Karthikeyan (2013)** in the Manakudy estuary. **Rashed-Un-Nabi *et al.* (2011)** also found that environmental changes drove the fish composition in total abundance, diversity, and structure.

The present study found numerous juvenile fishes with high abundance occurring in the estuaries. In the east coast's estuaries, *Arius maculatus*, *Osteogeneiosus militaris*, *Polynemus melanochir* at small size (2.8-6.6cm, TL) were abundant in the rainy season. In addition, although catching at a low amount (due to using unsuitable fish gear), juveniles of *Pangasius krempfi*, *P. macronema* were the main target species of local fishermen (**Tran *et al***., Personal observation). These freshwater-originated species spend one or more stages of their lifecycle in the estuary **(Froese & Pauly, 2023)**. On the west coast's estuaries, juveniles of *Stolephorus dubiosus* were numerous in the rainy season, while in the dry season, *Nuchequula gereoides*, *Ilisha melastoma*, and *Stolephorus dubiosus* were dominant, except *Anodontostoma chacunda*, which occurred in large amounts in both seasons (Table 5). These species are marine-originated species, spending some stages of their lifecycle in the estuary **(Froese & Pauly, 2023)**.

Table 4. Fish diversity in the tropical estuaries in other regions

Study area	Fishing gear – analytical methods	Number of species	Comparison between two seasons or implementation	Source
The Sepang Besar estuary, Malaysia	Bag net and trawling - fish composition	29 species, 23 families	Provide information on fish composition	**Ya *et al.* (2015)**
The Manakudy estuary, India	Descriptive analysis	30 species, 13 families	Fish are more diverse during monsoon.	**Kannappan and Karthikeyan (2013)**
The Meghna River Estuary, Bangladesh	Bag net and trawling - species richness, Shannon-Wiener, similarity	53 species	The dry season is more diverse than the rainy season (Shannon-index being 3.14 and 2.78, respectively)	**Hossain *et al.* (2012)**
The Estuary Pahang, Malaysia	Gill net and trap – fish composition	24 species, 14 families	The dry season is more diverse than the rainy season.	**Jalal *et al.* (2012)**
The Bakkhali Estuary, Bangladesh	Barrier net – fish composition, diversity index	35 species	Fish are more diverse during monsoon.	**Rashed-Un-Nabi *et al.* (2011)**
The Subarnarekha estuary, India	Barrier net, cast net, gill net, bag net, and seine net - fish composition	140 species, 55 families	Fish diversity is dependent on salinity	**Ghosh *et al.* (2011)**

Table 5. Some main juvenile fishes at high abundance in the Mekong Delta's estuaries (only count species with higher than 120 individuals)

Estuary	Rainy season			Dry season		
	Scientific name	Size range (cm)	Number of individuals	Scientific name	Size range (cm)	Number of individuals
Dinh An	*Arius maculatus*	3.0 - 6.5	1176	*Johnius plagiostoma*	2.3 - 5.8	257
				Polynemus melanochir	3.9 - 6.1	254
Tran De	*Arius maculatus*	3.0 - 6.0	1768	*Johnius plagiostoma*	3.2 - 5.5	207
	Osteogeneiosus milataris	3.5 - 5.3	2113	*Johnius trachycephalus*	3.0 - 5.6	120
	Polynemus melanochir	2.8 - 5.4	1768	*Osteogeneiosus militaris*	3.7 - 6.1	153
				Polynemus melanochir	3.2 - 6.5	366
Cua Lon	*Anodontostoma chacunda*	1.8 - 4.9	734	*Anodontostoma chacunda*	2.3 - 5.5	386
	Chelon subviridis	1.9 - 6.5	373	*Chelon subviridis*	1.5 - 6.5	209
	Eleutheronema tetradactylum	1.8 - 4.8	299	*Coilia rebentischii*	3.7 - 5.5	482
	Gerres limbatus	1.2 - 3.0	178	*Escualosa thoracata*	1.6 - 3.5	152
	Nucheguula gerroides	0.9 - 3.0	225	*Ilisha melastoma*	1.8 - 4.9	499
				Johnius sp.	2.7 - 4.1	184

Estuary	Rainy season			Dry season		
	Scientific name	Size range (cm)	Number of individuals	Scientific name	Size range (cm)	Number of individuals
				Nuchequula gereoides	1.2 - 3.3	1724
				Secutor hanedai	1.3 - 2.9	125
				Stolephorus dubiosus	1.2 - 2.8	290
Bay Hap	*Anodontostoma chacunda*	2.3 - 5.0	1513	*Ambassis vachellii*	1.6 - 2.5	373
	Chelon subviridis	3.2 - 6.5	369	*Anodontostoma chacunda*	1.8 - 4.9	1807
	Eleutheronema tetradactylum	1.8 - 6.5	393	*Chelon subviridis*	2.5 - 6.5	309
	Escualosa thoracata	1.8 - 4.2	219	*Escualosa thoracata*	1.8 - 4.2	641
	Johnius sp.	1.2 - 2.6	211	*Ilisha melastoma*	1.9 - 3.8	2784
	Stolephorus dubiosus	2.0 - 3.5	994	*Nuchequula gereoides*	1.5 - 2.7	406
				Secutor hanedai	1.2 - 3.8	202
				Stolephorus dubiosus	1.8 - 3.2	1534

Ecological role of estuary

The general role of the estuary is to provide spawning, nursing grounds, migration routes, and refuge for some species. A study in New Zealand estuaries showed the vital role of estuaries as migration pathways for many freshwater species, but for only some marine species. An author proved that even though they play a temporary role in the life cycles of fishes, the estuaries are essential for their life cycles. Therefore, this ecosystem should be protected from pollution and modification **(McDowall, 1976)**. The estuaries in the Mekong Delta also share these roles, especially providing migrant routes for endemic species of the Mekong River, such as *Pangasius krempfi*, *P. macronema*, *P. elongatus,* and *P. conchophilus*. There may be two populations of *P. krempfi*, one upstream of the Mekong River and the other from midstream. The latter is hypothesized to spawn in Cambodia, and larvae drift downstream to the estuaries of the Mekong Delta. Fish grow in the estuaries and migrate back to the midstream for maturation **(Hogan *et al.*, 2007)**. This species was listed as vulnerable in the IUCN Red List **(Baird, 2011)** but has recently been heavily caught and cultured in the coastal zones of the Mekong Delta **(Tran *et al.*, unpublished data)**. *Pangasius macronema* and *P. conchophilus*, another migrant species in the Mekong River, are the critical target species of fishermen living in Laos and Cambodia. It distributes from Laos to the Mekong Delta, Vietnam. However, due to the construction of hydropower plants along the mainstream, the population in Laos and Cambodia is significantly impacted **(Baird *et al.*, 2001)**. Therefore, the Mekong Delta population could be considered a “source” that can disperse to a “sink” in Cambodia and Laos. *Pangasius elongatus* is another critical economic species. Their lifecycle is unknown, but this species is a long migrant **(Poulsen *et al.*, 2004)**. In the current study, numerous adults of this species were found, and we believe they are at least spending some stages of their lifecycle in the estuary. More studies on these species must be done to provide biological information supporting conservation.

The other important role of the Mekong Delta's estuaries is breeding and nursing grounds for a few species. At least 17 juvenile fishes were abundant in the study area (Table 5). Freshwater-originated species were found in the east coast's estuaries, while marine-originated species occurred in the west. In addition, 15 gobiid species are found in the Co Chien River, Ben Tre Province **(Nguyen *et al.*, 2022)**. Most are amphidromous, using estuaries as nursing grounds and migrant routes in their lifecycles. Biological information on these species is limited, but many are commercially and increasingly exploited. For example, *Periophthalmus chrysospilos*, widely distributed in the Mekong Delta's estuarine and inland water systems, is essential to local fisheries and is often caught for food **(Dinh *et al.*, 2022)**. More studies on their biology should be conducted to support conservation and management.

Even though it plays a significant ecological role, the Mekong Delta estuaries have faced many anthropogenic and climate change risks. More urgently, juvenile fishing has risen recently, depleting targeted species and killing other young species, such as bycatch. Therefore, actions to protect these ecosystems are needed. Recent studies have emphasized that identifying and classifying estuary types based on hydrological and ecological characteristics is essential for designing effective conservation and restoration strategies, particularly under increasing anthropogenic pressures and climate change **(Chevalier *et al*., 2023; Kennish, 2023)**. They recommended that conservation actions should be specific for each type of ecosystem. In the present study, due to the distinct difference between the two groups of estuaries, fishery management and conservation should be treated differently. For instance, due to many fish using the east coast's estuaries for breeding and nursing in the rainy season while employing the west estuaries in the dry season, we recommend that fishermen should avoid fishing in the regions at these times; instead, they can fish further from the river mouth.

CONCLUSION

This study successfully examined the fish composition in four estuarine areas of the Mekong Delta, identifying 162 species with significant spatial and seasonal variation. The study evaluated fish diversity using indices such as the Simpson index and revealed higher diversity in the dry season, particularly in the east coast estuaries. Moreover, comparative analysis of similarities and distinctiveness among sites and seasons using Jaccard and Bray-Curtis indices demonstrated an apparent clustering between east and west estuaries and seasonal differentiation in the east. These findings highlight the importance of estuarine ecosystems as habitats for juvenile and migratory species and provide critical insights for developing tailored and seasonally adjusted fisheries management strategies.

ACKNOWLEDGEMENTS

We would like to thank the colleagues of Department of Fisheries Management and Economics (College of Aquaculture and Fisheries, Can Tho University) for support during the study; Fishermen from Cu Lao Dung Island (Soc Trang province, Vietnam) and Cua Lon (Ca Mau province, Vietnam) for helping with sampling.

FUNDING

This study was supported by the Technical Cooperation Project VN14-16 (F3): "Building Capacity for Can Tho University to be excellent institution of Education, scientific research, and technology transfer".

REFERENCES

Baird, I.; Hogan, Z.; Phylaivanh, B. and Moyle, P. (2001). A Communal Fishery for the Migratory CatfishPangasius macronemain the Mekong River. Asian Fisheries Science, 14: 25-41.

Barlow, C.; Baran, E.; Halls, A. S. and Kshatriya, M. (2008). How much of the Mekong fish catch is at risk from mainstream dam development? Catch and Culture, 14: 16-21.

Blaber, S. J. M. (2000). Tropical estuarine fishes: ecology, exploitation and conservation. Oxford, United Kingdom: Blackwell Science, 372pp.

Bray, J. R. and Curtis, J. T. (1957). An ordination of the upland forest communities of southern Wisconsin. Ecological Monographs, 27(4): 326-349.

Brownscombe, J. W. and Fox, M. G. (2012). Range expansion dynamics of the invasive round goby (*Neogobius melanostomus*) in a river system. Aquatic Ecology, 46(2): 175-189.

Cameron, W. M. and Pritchard, D. W. (1963). Estuaries. In: The Sea (ed. M.N. Hill)John Wiley and Sons, New York, 306-324.

Chevalier, M.; Ngor, P. B.; Pin, K.; Touch, B.; Lek, S.; Grenouillet, G. and Hogan, Z. (2023). Long-term data show alarming decline of majority of fish species in a Lower Mekong basin fishery. Science of the Total Environment, 891: 164624.

CGIAR, R. P. o. C. C., Agriculture and Food Security-Southeast Asia (CCAFS-SEA) (2016). Assessment Report: The Drought and Salinity Intrusion in the Mekong River Delta of Vietnam. CCAFS-SEA, Hanoi, Vietnam: 51pp.

Davis, S. M.; Childers, D. L.; Lorenz, J. J.; Wanless, H. R. and Hopkins, T. E. (2005). A conceptual model of ecological interactions in the mangrove estuaries of the Florida Everglades. Wetlands, 25(4): 832-842.

Dinh, Q. M.; Nguyen, T. H. D.; Nguyen, T. T. K.; Lam, T. T. H.; Truong, N. T. and Tran, D. D. (2022). Population biological traits of *Periophthalmus chrysospilos* Bleeker, 1853 in the Vietnamese Mekong Delta. PeerJ, 10: e13289.

Dugan, P. J.; Barlow, C.; Agostinho, A. A.; Baran, E.; Cada, G. F.; Chen, D.; Cowx, I. G.; Ferguson, J. W.; Jutagate, T. and Mallen-Cooper, M. (2010). Fish migration, dams, and loss of ecosystem services in the Mekong basin. Ambio, 39(4): 344-348.

FAO, F. a. A. O. o. t. U. N. (1999). FAO Species Identification Guide for Fishery Purposes: The Living Marine Resources of the Western Central Pacific (Vol 3, 4, 5). FAO, Rome: 1397-3380.

Froese, R. and Pauly, D. (2023). FishBase. World Wide Web electronic publication, 10/2023. https://www.fishbase.se/search.php

Ghosh, A.; Bhaumik, U. and Satpathy, B. (2011). Fish diversity of Subarnarekha Estuary in relation to salinity. Journal of Inland Fisheries Society of India, 43(1): 51-61.

González-Sansón, G.; Rodríguez, F. N.; Aguilar-Betancourt, C. M. and Páez, Y. C. (2022). Estuarine fish diversity as indicator of natural environmental gradients. Marine Biodiversity, 52(3): 32.

GSO, G. S. O. (1999). Statistical data of agriculture, forestry and fisheries. GSO Vietnam. https://www.gso.gov.vn. Cited 15 Jan 2020.

Hogan, Z.; Baird, I. G.; Radtke, R. and Vander Zanden, M. J. (2007). Long distance migration and marine habitation in the tropical Asian catfish, Pangasius krempfi. Journal of Fish Biology, 71(3): 818-832.

Hortle, K. G. (2009a). Fishes of the Mekong—How many species are there. Catch and Culture, 15(2): 4-12.

Hortle, K. G. (2009b). Fisheries of the Mekong River Basin. In: Campbell, I. C. (Ed.). The Mekong. San Diego, United States: Academic Press, 197-249.

Hossain, M. S.; Das, N. G.; Sarker, S. and Rahaman, M. Z. (2012). Fish diversity and habitat relationship with environmental variables at Meghna river estuary, Bangladesh. The Egyptian Journal of Aquatic Research, 38(3): 213-226.

Huan, N. X.; Duyen, N. T. and Nam, N. T. (2016). Fish species composition variability in Cu Lao Dung, Soc Trang, Vietnam. VNU Journal of Science: Natural Science and Technology, 32(1S): 69-76.

Jaccard, P. (1912). The distribution of the flora in the alpine zone. 1. New phytologist, 11(2): 37-50.

Jalal, K.; Azfar, M. A.; John, B. A.; Kamaruzzaman, Y. and Shahbudin, S. (2012). Diversity and community composition of fishes in tropical estuary Pahang Malaysia. Pakistan Journal of Zoology, 44(1): 181-187.

Jaureguizar, A. J.; Menni, R.; Guerrero, R. and Lasta, C. (2004). Environmental factors structuring fish communities of the Rıo de la Plata estuary. Fisheries Research, 66(2-3): 195-211.

Kannappan, T. and Karthikeyan, M. (2013). Diversity of fishes in relation to physio-chemical properties of Manakudy estuary, Southwest coast of India. International Journal of Biodiversity and Conservation, 5(7): 396-407.

Kennish, M. J. (2023). Estuaries: Origin, Historical Development, and Classifications. In *Climate Change and Estuaries* (pp. 43-54). CRC Press.

Kottelat, M. (2001). Fishes of Laos WHT Publications Ltd. Colombo.

Kuenzer, C.; Guo, H.; Huth, J.; Leinenkugel, P.; Li, X. and Dech, S. (2013). Flood mapping and flood dynamics of the Mekong Delta: ENVISAT-ASAR-WSM based time series analyses. Remote Sensing, 5(2): 687-715.

Lagler, K. F. (1976). Fisheries and Integrated Mekong River Basin Development. The University of Michigan, School of Natural Resources, Michigan, USA: 39pp.

McDowall, R. M. (1976). The role of estuaries in the life cycles of fishes in New Zealand. Proceedings (New Zealand Ecological Society). JSTOR, 27-32.

MRC, M. R. C. M. (2003). State of the Basin Report 2003. Mekong River Commission, Vientiane, Lao PDR: 300pp.

Nguyen, X.-D.; Quang, N. X.; Pham, T. L. and Veettil, B. K. (2022). A Comprehensive Study on Fish Species Composition, Diversity, Migration, Threatened Status, Economic Value and Endemism in the Co Chien River, Ben Tre Province (Mekong Delta), Vietnam. Ocean Science Journal, 57(1): 69-90.

NOAA, N. O. a. A. A. (2002). A National Strategy to Restore Coastal and Estuarine Habitat. NOAA Fisheries Restoration Center, Washington DC, USA: 157pp.

Nuon, V., Chea, R., Hugueny, B., & Grenouillet, G. (2025). Environmental pressures on Mekong fish: Insights from temporal functional diversity dynamics. Journal of Environmental Management, 380: 125138.

Poulsen, A. F.; Hortle, K. G.; Valbo-Jorgensen, J.; Chan, S.; Chhuon, C. K.; Viravong, S.; Bouakhamvongsa, K.; Suntornratana, U.; Yoorong, N. and Nguyen, T. T. (2004). Distribution and ecology of some important riverine fish species of the Mekong River Basin. MRC technical paper. 116pp.

Rainboth, W. J. (1996). Fishes of the Cambodian Mekong. Roma: FAO, 265pp.

Rashed-Un-Nabi, M.; Al-Mamun, M. A.; Ullah, M. H. and Mustafa, M. G. (2011). Temporal and spatial distribution of fish and shrimp assemblage in the Bakkhali river estuary of Bangladesh in relation to some water quality parameters. Marine Biology Research, 7(5): 436-452.

Savenije, H. H. (2005). Salinity and tides in alluvial estuariesGulf Professional Publishing, 194pp.

Simpson, E. H. (1949). Measurement of diversity. Nature, 163(4148): 688-688.

Sokheng, C.; Chhea, C. K.; Viravong, S.; Bouakhamvongsa, K.; Suntornratana, U.; Yoorong, N.; Tung, N. T.; Bao, T. Q.; Poulsen, A. F. and Jorgensen, J. V. (1999). Fish migrations and spawning habitats in the Mekong mainstream: A survey using local knowledge. Cambodia Mekong River Commission, 57pp.

Sverdrup-Jensen, S. (2002). Fisheries in the lower Mekong basin: status and perspectives. Phnom Penh, Cambodia MRC Fisheries Programme, 103pp.

Thiel, R.; Sepulveda, A.; Kafemann, R. and Nellen, W. (1995). Environmental factors as forces structuring the fish community of the Elbe Estuary. Journal of Fish Biology, 46(1): 47-69.

Tran, D. D.; Shibukawa, K.; Nguyen, T. P.; Ha, P. H.; Tran, X. L.; Mai, V. H. and Utsugi, K. (2013). Fishes of Mekong Delta, Vietnam. Can Tho: Can Tho University Publisher, 174pp.

Tran, D. D.; Nguyen, V. T.; To, H. T. M.; Nguyen, T. T. and Dinh, Q. M. (2020). Species composition and biodiversity index of gobiid assemblage in estuarine areas of the Mekong Delta, Vietnam. Egyptian Journal of Aquatic Biology and Fisheries, 24(7): 931-941. 10.21608/ejabf.2020.131385.

Tran, D. D.; Le, B. P.; Dinh, Q. M.; Duong, N. V. and Nguyen, T. T. (2021). Fish species composition variability in Cu Lao Dung, Soc Trang, Vietnam. AACL Bioflux, 14(4): 1865-1876.

Ut, V. N.; Van Hoa, A. and Vinh, H. P. (2020). Status of fish biodiversity and fishing on Hau River, Mekong Delta, Vietnam. Annales de Limnologie-International Journal of Limnology. EDP Sciences, 14pp.

Vu, V. A. and Ngwenya, E. (2008). Impacts of Agriculture on the Inland Capture Fisheries in the Mekong Delta. International Institute of Fisheries Economics and Trade, 14th IIFET Conference July 2008.

Whittaker, R. H. (1965). Dominance and Diversity in Land Plant Communities: Numerical relations of species express the importance of competition in community function and evolution. Science, 147(3655): 250-260.

Ya, N.; Singh, H. R.; Ramli, N. H.; Makhtar, N.; Mohd Rashid, H.; Dzakaria, N. and Samat, A. (2015). Fish Diversity in Sepang Besar Estuary—A Preliminary Analysis. Int. J. Adv. Agric. Environ. Eng, 1: 229-233.