An assessment of fisheries resources in the coastal water of the Mekong Delta, Vietnam

[1]Dinh D. Tran, [2]Hung V. Cao, [3]Quang M. Dinh, [1]Loi X. Tran

[1] Department Fisheries Management and Economics, College of Aquaculture and Fisheries, Can Tho University, Campus II, 3/2 Street, Can Tho City, Vietnam; [2] Research Institute for Marine Fisheries, Ministry of Agriculture and Rural Development, 224 Le Lai Street, Hai Phong, Vietnam; [3] Department of Biology, School of Education, Can Tho University, Campus II, 3/2 Street, Can Tho City, Vietnam. Corresponding author: Q. M. Dinh, dmquang@ctu.edu.vn

Abstract. Marine fisheries play an important role in Vietnam's economy, especially inshore fishing, accounting for most total catch and providing a livelihood for local fishers. However, coastal ecosystems have faced many anthropogenic and natural threats, causing degradation and altering habitats. Besides, inadequate fisheries statistics make fisheries management ineffective and uncontrolled. In the present study, we examined the fisheries resources' status in the Mekong Delta's estuarine region to instruct fisheries management. Six surveys were done by trawling in 25 sites along the coastline. Data on species, number of individuals, weight, fishing operation, and environmental parameters were collected. Data were arranged in different spatiotemporal aspects, including seasons (dry and rainy), estuary related (ER) sites and non-estuary related (NER) sites, and south of the Hau river sites and north of the Hau river sites as analysis. The relative species abundance, Simpson index, Jaccard coefficient, and the catch per unit area (CPUA) were employed to understand the study region's fisheries resources. T-test and one-way ANOVA were employed to examine the significant difference among these factors. Results show that 199 species belonging to 65 families were identified. There were significant differences in the species abundance, diversity, the CPUA, and environmental factors in different seasons and sites. Remarkably, the species abundance, diversity, and CPUA were different from previous surveys. The possible reasons for the differences and the significance of our findings in fisheries management were discussed.

Key Words: coastal ecosystem, fisheries resources, species diversity, the Mekong Delta.

Introduction. With a coastline of 3,260 km and approximately a million km^2 of the exclusive economic zone, the fisheries sector is one of the most important economic sectors in Vietnam, which contributed about 3% of Gross Domestic Product (GDP), 4.3% of household's income, 5.1% of the labor force and 40% of protein consumption (Pomeroy et al 2009). Marine fisheries catch has increased in recent years, from 1.66 million tons in 2000 to 1.98 million tons in 2005 and 2.41 million tons in 2010. Consequently, the export value also increased from 2.2 billion USD in 2003 to 2.65 billion USD in 2005 and 6.2 billion USD in 2012, making Vietnam the third largest seafood exporter worldwide (GSO 2001, 2006, 2011). Nevertheless, the marine fisheries catch has mainly come from near-shore fishing, accounting for 82% of the total catch. Approximately 72% of fishing boats have engines less than 45 HP and 84% with engines less than 90 HP, which legally operate in the coastal zone (Pomeroy et al 2009). In 2018, vietnam has total 109,762 fishing vessels, of which 76,589 vessels (69.8%) of less than 90 HP (Nguyet 2018). Therefore, Vietnam's marine fisheries are considered to be small-scale and are concentrated in coastal waters.

The coastal region of the Mekong Delta, one of the four main fish grounds of Vietnam, plays a vital role in the country's fisheries industry (Pomeroy et al 2009). As Chung et al (2001) estimated, fisheries resources in the Mekong Delta's coastal areas are most abundant, accounting for 50% of both pelagic and demersal fisheries resources of the four regions. The pelagic fisheries resources were estimated roughly to 524,000 tons of standing stock and a potential yield of 209,600 tons per year, while the demersal fisheries resource was about 1,051,117 tons of biomass with stock density being 4.73 tons km^{-2} (Thuoc 2001). In the coastal region, fisheries are the primary source of household income (9.1%) and provide about 9.8% of primary employment for this region's people (Pomeroy et al 2009).

Even though playing essential roles, fisheries resources in the Mekong Delta's coastal region have faced numerous threats. The rapid development of the coastal economy, i.e., large-scale reclamation of the coast and mangrove deforestation, has posed the coastal environment under degradation (Anthony et al 2015). Also, land-sourced pollution, including plastic waste, elevated concentration of heavy metals are accumulated in this region, which caused a decrease in the hatching and survival rates of the marine species leading to reductions in their population and abundance (Cui et al 2003; Jambeck et al 2015). Decreasing water quality from the Mekong River's upstream has negatively impacted coastal habitat by altering sedimentation, salinity, and water temperature (Dugan et al 2010). Moreover, large-scale shrimp aquaculture has directly impacted coastal habitats through disposing a high content of nutrients causing eutrophication (Tho et al 2014). More importantly, uncontrolled fishing and using destructive fishing methods have caused a decrease or loss of coastal fisheries resources (Pomeroy et al 2009). Combining these factors has put already over-exploited fisheries resources and the coastal ecosystem under colossal unfavourable pressure (Barlow et al 2008; Pomeroy et al 2009).

Urgent actions should be implemented to conserve the ecosystem and fisheries resources based on scientific advice from stock assessment results (Hilborn & Ovando 2014; Melnychuk et al 2017). However, the stock assessment and fisheries statistics in Vietnam have been under-estimated (less than 75% of it should be), and the frequency of fisheries monitoring is too sparse (Teh et al 2014). In that situation, this study was aimed to evaluate the composition, diversity, and abundance of fisheries resources of the coastal region of the Mekong Delta, which can be used to instruct local government in fisheries management.

Material and Method

Data collection. Twenty-five sites distributed along the Mekong Delta coast (less than fifteen nautical miles from the shore) were chosen and coded for later analysis (Figure 1 and Table 1). Six surveys were made from January 2018 to October 2019. The data were classified into two seasons, i.e., rainy and dry seasons, with January 2018, March 2018, and December 2018 being the dry season, and June 2019, September 2019, and October 2019 being the rainy season. Data were also divided into estuary related (ER) sites including sites 1, 3, 8, 12, 17, and 19 and non-estuary related (NER) sites including sites 2, 4, 5, 6, 7, 9, 10, 11, 13, 14, 15, 16, 18, 20, 21, 22, 23, 24, and 25 located aside from the river mouths. Besides, due to the coastal region being strongly affected by the water flow of Hau river, we also like to figure out whether any difference between fisheries resources in the north (sites 1 to 16) and south (site 17 to 25) of Hau river so that we also classified data into these two types. Trawling with 18 mm of mesh size in the codend was employed in the surveys. Each fishing operation was taken in 60 minutes with a speed of 2.0 to 3.0 nm h^{-1}, and fisheries resources were weighted, identified at the species level, counted all of specimens, taken photos, and then preserved in 90% ethanol. Identification has followed classification documents of FAO (1999) and Tran et al (2013). Information on environmental parameters (water temperature, pH, dissolved oxygen-DO and salinity) and fishing operation (operation time, speed) was recorded.

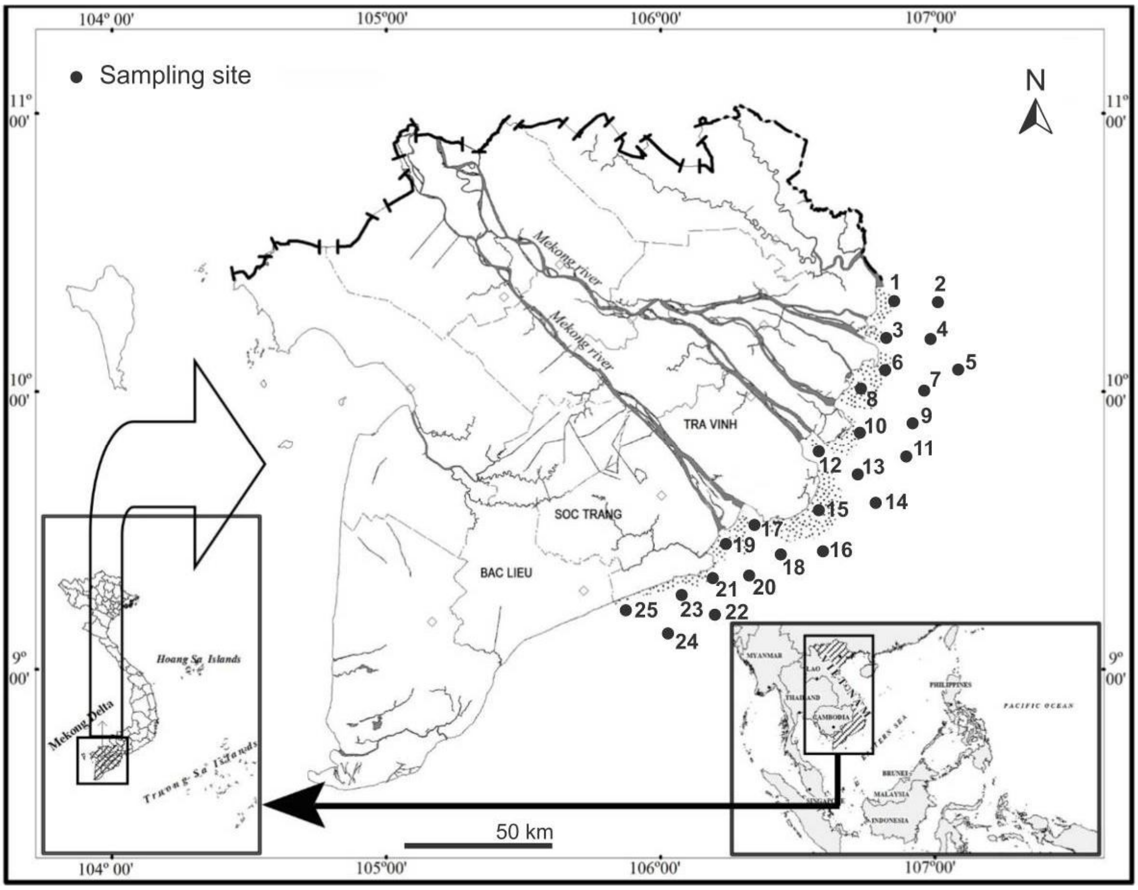

Figure 1. Map of the sampling site
[Modification with permission from Figure 1 produced by Dinh (2018)].

Table 1

Coordinates of the 25 study sites

Sites	*Latitude*	*Longitude*	*Site belonging to the province*
1	10°22'26.2"N	106°48'37.4"E	Tien Giang
2	10°17'14.8"N	106°55'48.8"E	Tien Giang
3	10°15'50.8"N	106°47'32.9"E	Tien Giang
4	10°15'53.9"N	106°53'07.6"E	Tien Giang
5	10°07'53.2"N	106°57'24.3"E	Tien Giang
6	10°05'40.1"N	106°49'35.3"E	Ben Tre
7	10°00'38.9"N	106°51'34.7"E	Ben Tre
8	9°57'58.9"N	106°41'08.4"E	Ben Tre
9	9°53'09.6"N	106°49'03.8"E	Ben Tre
10	9°49'44.1"N	106°41'41.3"E	Ben Tre
11	9°44'43.6"N	106°46'49.4"E	Ben Tre
12	9°46'39.8"N	106°35'18.3"E	Ben Tre
13	9°43'48.8"N	106°38'41.5"E	Ben Tre
14	9°37'35.1"N	106°40'48.1"E	Tra Vinh
15	9°34'50.0"N	106°34'28.8"E	Tra Vinh
16	9°26'20.8"N	106°32'17.3"E	Tra Vinh
17	9°31'40.1"N	106°19'51.5"E	Tra Vinh
18	9°26'06.4"N	106°22'29.9"E	Tra Vinh
19	9°26'54.4"N	106°14'05.9"E	Soc Trang
20	9°22'30.9"N	106°20'28.8"E	Soc Trang
21	9°21'19.3"N	106°12'58.5"E	Soc Trang
22	9°14'50.4"N	106°10'11.8"E	Soc Trang
23	9°16'26.0"N	106°02'52.8"E	Soc Trang
24	9°11'31.5"N	105°59'50.6"E	Soc Trang
25	9°13'45.9"N	105°53'12.7"E	Soc Trang

Data analysis. The species abundance, diversity, and similarity were calculated by plotting the species rank abundance (Whittaker 1965), Simpson index ($D=1/\Sigma p_i^2$), where p_i = the fractional abundance of the i^{th} species in each season, Simpson (1949)), and Jaccard coefficient ($CC_j=c/S$, where C is the number of species common to both seasons and S is the total number of species in the two seasons, Jaccard (1912)). We also examined changes in the catch per unit area by estimation of CPUA (catch per unit area, kg km^{-2}) and NPUA (individual per unit area, individual km^{-2}) (Pauly 1984). These parameters were compared among sites, seasons, and ER and NER sites by T-test, one-way ANOVA using Rstudio version 0.99.903 (Rstudio, Inc). A similar analysis was also applied to environmental factors. The visualization of CPUA and NPUA was done with the QGIS (version 3.12), a Free and Open Source Geographic Information System.

Results

Environmental parameters. Environmental factors are essential factors in any ecosystem, and their variations strongly influence the biotic composition. The most variation was found in salinity between two seasons, while other factors were also significantly different, but their variations were small. The significant differences in salinity, pH, and DO between the two seasons were presented in Table 2. Comparing between the ER and NER sites in different seasons, salinity in the ER sites were significantly lower than those in the NER sites, but there was no significant difference between seasons within the ER and NER sites. Although small variations in pH, there were significant differences among the ER and NER sites in two seasons. DO values were low in the rainy season for both the ER and NER sites but higher in the dry season (Table 2). The results show that the environmental factors dramatically fluctuate in the areas related to estuaries.

Species composition. One hundred ninety-nine species were belonging to 22 orders, 65 families, and 134 genera, which compose 138 species of Actinopterypgii (69.4%), 47 species of Malacostraca (23.6%), nine species of Cephalopoda (4.5%), and five species of Gastropoda (2.5%) (Table 3). Regarding the order, Perciformes was dominant with 74 species (37.2%), followed by Decapoda with 36 species (18.1%), Clupeiformes, and Pleuronectiformes with 15 species each (15.5%), Stomatopoda with nine species (4.5%), and others with one to five species. Concerning family, Sciaenidae and Gobiidae have the highest number of species (15 species each), followed closely by Penaeidae (14 species), Portunidae (12 species), Cynoglossidae (10 species), Engraulidae (9 species), Squillidae (8 species), and others families (6 to 1 species).

Species composition was significantly different between seasons, with the number of species in the rainy season higher than the dry season. Fifty-three species belonging to 34 families occurred in the rainy season compared to 31 species belonging to 22 families only found in the dry season, while 144 species belonging to 46 families found in both seasons. The distinctiveness between the two seasons is 39% (Jaccard coefficient being 0.61), which means species composition dramatically fluctuated. Species only found in rainy seasons are tolerant to freshwater, while species only found in dry seasons are marine originated.

Table 2

Environmental factors and the catch per unit area (CPUA and NPUA) (mean±SE) for the two seasons and the estuary related and non-estuary related sites at different seasons

Category	*Dry season*	*Rainy season*	*T-test*	*ER-R*	*ER-D*	*NER-R*	*NER-D*	*One-way ANOVA*
Salinity (‰)	22.1±0.9	22.2±0.72	t = -0.15, df = 24, p = 0.88	17.6±1.1[a]	19.1±2.3[b]	23.7±0.5[c]	23.0±0.9[d]	F = 6.9, df = 46, p < 0.001
pH	6.8±0.06	6.8±0.06	t = -0.2, df = 24, p = 0.84	6.9±0.1[a]	6.8±0.1[a]	6.8±0.1[a]	6.8±0.1[a]	F = 0.3, df = 46, p = 0.83
DO (mg L^{-1})	5.8±0.35	5.0±0.06	t = 2.5, df = 24, p = 0.02	5.0±0.1[a]	5.5±0.1[a]	5.0±0.1[a]	6.0±0.4[a]	F = 2.3, df = 46, p = 0.09
NPUA (ind km^{-2})	13,652±1,697	23,475±1,814	t = 3.9, df = 147.4, p < 0.001	25,019±2,880[a]	13,434±2,740[b]	22,049±2,269[c]	13,853±2,095[b]	F = 5.4, df = 146, p < 0.001
CPUA (kg km^{-2})	124.5±12	357.6±29	t = 7.4, df = 99.7, p < 0.001	365.8±48.7[a]	108.1±14.9[b]	350.1±33.4[a]	139.6±18.9[b]	F = 18.4, df = 146, p < 0.001

Note: T-test and one-way ANOVA were applied for the studied types. ER-R: estuary related sites in the rainy season; ER-D: estuary related sites in the dry season; NER-R: non-estuary related sites in the rainy season; NER-D: non-estuary related sites in the dry season. Different letters in the each row show the significant difference in catch per unit area.

Table 3

Species composition in the coastal areas of the Mekong Delta

Classes	*Orders*	*Family*		*Genus*		*Species*	
		Number	*%*	*Number*	*%*	*Number*	*%*
Elasmobranchii	Myliobatiformes	2	3.1	3	2.2	5	2.5
Actinopterygii	Anguilliformes	3	4.6	4	3.0	5	2.5
	Clupeiformes	3	4.6	9	6.7	15	7.5
	Siluriformes	2	3.1	4	3.0	7	3.5
	Aulopiformes	1	1.5	3	2.2	5	2.5
	Gadiformes	1	1.5	1	0.8	1	0.5
	Batrachoidiformes	1	1.5	1	0.8	1	0.5
	Pleuronectiformes	3	4.6	6	4.5	15	7.5
	Mugiliformes	1	1.5	3	2.2	3	1.5
	Tetraodontiformes	1	1.5	3	2.2	4	2.0
	Scorpaeniformes	2	3.1	3	2.2	3	1.5
	Perciformes	25	38.5	57	42.5	74	37.2
Cephalopoda	Myopsida	1	1.5	2	1.5	4	2.0
	Octopoda	1	1.5	1	0.8	1	0.5
	Sepiida	2	3.1	3	2.2	4	2.0
Malacostraca	Decapoda	8	12.3	17	12.7	36	18.1
	Stomatopoda	2	3.1	7	5.2	9	4.5
	Xiphosura	1	1.5	2	1.5	2	1.0
Gastropoda	Arcida	1	1.5	1	0.8	1	0.5
	Neogastropoda	1	1.5	1	0.8	1	0.5
	Littorinimorpha	2	3.1	2	1.5	2	1.0
	Ostreida	1	1.5	1	0.8	1	0.5
Total		65	100	134	100	199	100

Species abundance and diversity. Even though the number of species in the rainy season is higher than in the dry season, relative abundance results show that these indices in the dry season are more species-rich than in the rainy season. Specifically, the ER sites in the dry season (ER-D) have the highest species richness, while the least species-richness is in the NER sites in the rainy season (NER-R). Species-richness in the ER in the dry season (ER-D) and the NER sites in the rainy season (NER-R) are similar and in the middle of the four types (Figure 2). These results mean that ER-R species composition is most balanced, followed by NER-D, ER-R, and NER-R, which means that the ecosystem is more heathier in the ER-R and most vulnerable in the NER-R, which means the ecosystem is healthier in the ER-D and most vulnerable in the NER-R.

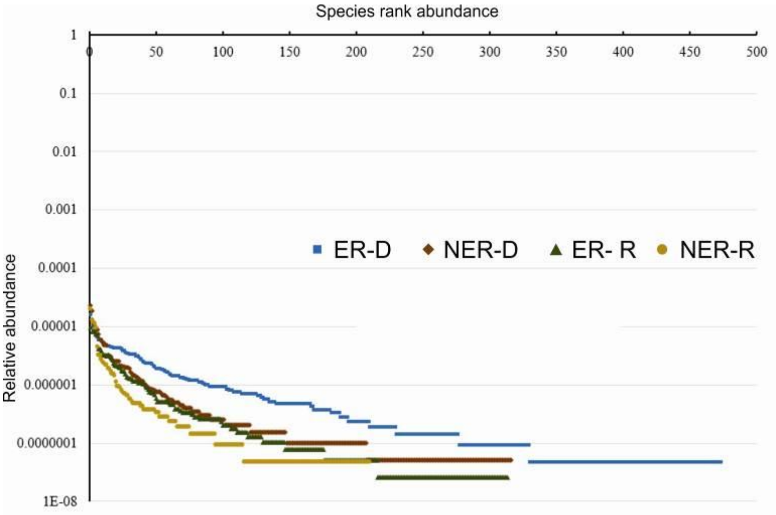

Figure 2. The dominance-diversity distribution for 25 sites. Symbols: ER-D estuary related sites in the dry season, ER-R estuary related sites in the rainy season, NER-D non-estuary related sites in the dry season, NER-R non-estuary related sites in the rainy season.

In terms of diversity evaluation, species diversity in the rainy season is much higher than the dry season, with the Simpson index being 123.6 and 47.9, respectively. It is also true when comparing the ER and NER sites between seasons, but NER sites are more diverse than ER sites. The diversity indices are highest in the NER-R (Simpson index being 91), followed by ER-R (42.4), NER-D (31.1), and ER-D (16.9).

CPUA variation. CPUA was higher in the rainy season than in the dry season, whereas a reversed case was found in NPUA. Similar results were found when comparing the ER and NER sites. We also found the CPUA and NPUA in the sites of the north of the Hau river (sites 1 to 16) were significantly higher than those in the south of the Hau river (sites 17 to 25) (Figure 3).

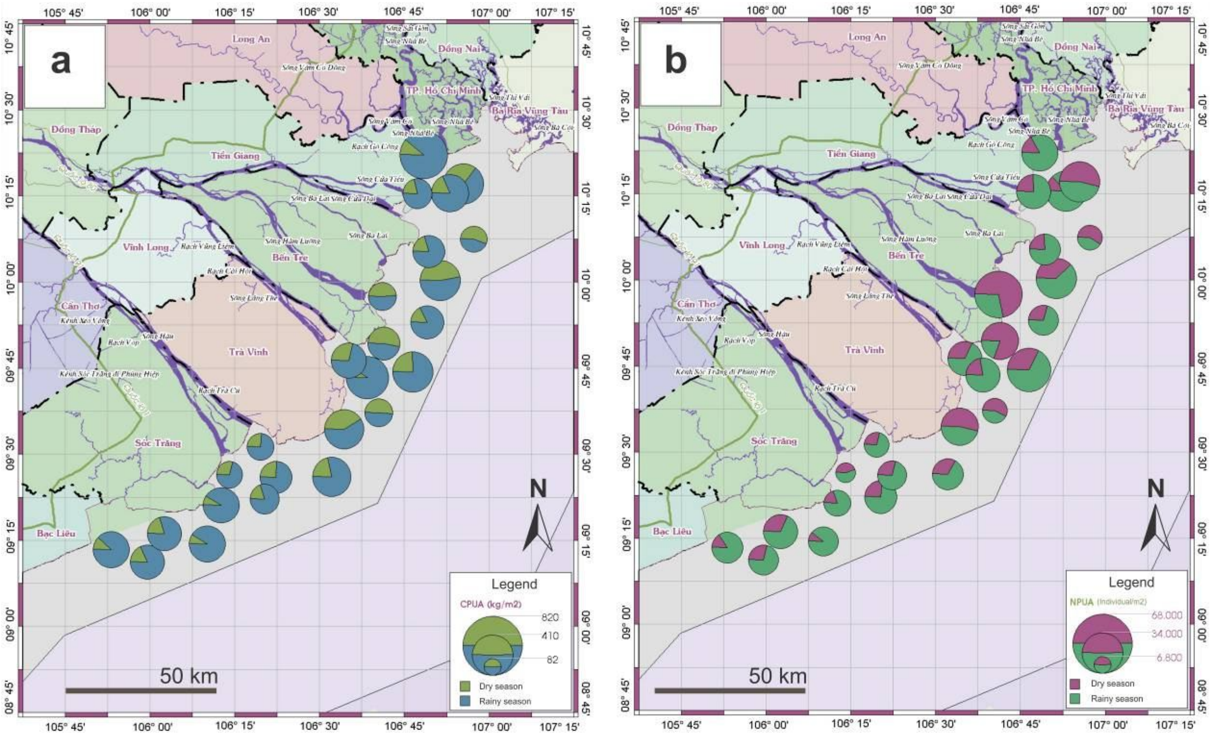

Figure 3. The catch per unit area, CPUA (a) and NPUA (b), of 25 sites in two seasons.

Discussion

***Characteristics of fisheries resources in the coastal region of the Mekong Delta*.** Results from a survey in 2012-2013 (Nghia 2013) show that the fisheries resources diversity in the southern sea part of Vietnam were highest compared to the other three (northern, middle, and southwestern sea parts) with 619 species belonging to 321 genera, and 148 families, which also includes an offshore region. Species abundance was higher in the dry season with 491 species than in the rainy season with 451 species. A similar trend is also found in the studies of Huong (1995), Chung et al (2001), and Dao & Pham (2003). They pointed out that coastal regions in the southern part of Vietnam have characteristics of the tropical climate, so fisheries resources concentrate near-shore areas during the dry season but disperse during the rainy season. However, the present study found that the fisheries resources in the rainy season were more abundant and diverse than those in the dry season (Figure 2 and Table 3). It could be because the surveyed area in the previous studies included a larger region, the sites were sparse, and the survey frequency was low. In contrast, our study focused on the estuarine areas of a narrow region (less than fifteen nautical miles from the shore) of the Mekong Delta with a high number of sites (25 sites) and a high frequency of surveys (six times). Besides, the environmental factors in the very near coastal areas could be strongly influenced by river flows. The Mekong River brings 475,000 million m^3 of water in the rainy season and sedimentation (59 to 160 million tons/year) to its river mouths (Sokheng et al 1999;

Walling 2008; Lu et al 2014). Therefore, the environmental factors fluctuated significantly between seasons and between the ER and NER sites (Table 2).

In terms of potential yield, Nghia (2013) found that potential yield in the dry season (1.4 million tons) was much higher than that in the rainy season (791 thousand tons), which means the CPUA of the dry season was higher than that of the rainy season. In contrast, our results with the CPUA and NPUA of the rainy season were much higher than those of the dry season (Table 2). The explanation for the difference could be the same as above.

The distinct characteristics of environmental factors along the Mekong Delta's coastline are also correlated to the spatiotemporal changes in juvenile fishes' density (Nghia 2013). The juvenile fish density was extremely abundant in the rainy season's estuaries. In contrast, in the dry season, juvenile fish density was much lower (Nghia 2013) since more sediment is drawn by the Mekong River in the rainy season, leading to high concentration of nutrients, an optimal condition for the growing number of juveniles (Hortle 2009). It indicates that the Mekong Delta's coastal area is a fundamental spawning ground, so fishing activities should consider this feature to ensure sustainable exploitation. Our findings agree with these results and truly reflect our previous study on species composition in the Mekong Delta's estuarine areas (Tran et al, unpublished data).

In practice, an increase of global warming and sea-level rise, the coastal area, especially in the Mekong Delta, is predicted to be strongly impacted (CCAFS-SEA 2016; Minderhoud et al 2019). Also, the Mekong River's flow has been altered by building numerous hydropower dams on the mainstream, which causes changes in environmental factors in the regions (Dugan et al 2010). The increasing anthropogenic effects from aquaculture, industrial development, deforestation, and plastic pollution have put these ecosystems under huge pressure (Jambeck et al 2015). Nevertheless, the fisheries resources statistics have been under-estimated up to 70%, which means the marine resources are more seriously threatened than we thought (Teh et al 2014). Therefore, urgent actions need to be done to protect the ecosystem. Due to the difference of our findings to previous studies and the very close coastal region's distinct characteristics, we recommend that fisheries management should be careful with data to instruct the management. More detailed surveys on spawning grounds with species life cycles should be done in order to support enough data to establish the marine protected area or fisheries refugia before too late.

Implications for fisheries management. The fisheries management's main purpose is to sustain the fisheries resources by balancing the exploitation and the recovery of the fisheries resources (Restrepo et al 1992). What fisheries managers have to do is to control the fishing capacity (input control) and limit the catch (output control), which must be based on scientific advice coming from stock assessment (Hilborn & Ovando 2014; Melnychuk et al 2017). However, the interaction between management implementations and fish population dynamics makes challenges for management. Therefore, monitoring should be done frequently to ensure unified management.

Fisheries management in Vietnam is described as "open access" fisheries (Pomeroy et al 2009) due to weak management, which also involves numerously fisheries statistics, implementation and assessment. The "input control" through managing fishing boats is unknowing reliably how many boats operating. Blaha (2017) estimated about 20,000 fishing vessels with roughly 65% being under 90 HP, whereas the Vietnam Association of Seafood Exporter and Producers (VACEP) said 110,000 fishing vessels with 70% under 90 HP. Besides, the "output control" through managing total catch has been underestimated. According to Teh et al (2014), the total catch of marine fisheries from 1950 to 2010 was underestimated, which should be 75% higher of annual catch reported by FAO. More importantly, the present study results pointed out the different results from previous studies, which means the local fisheries management have been applied to the coastal fishing could be not properly. For example, fish diversity and density are higher in the rainy season instead of the dry season. The CPUA and NPUA are different and distinguished between the south and north of the Hau river (Table 2).

Therefore, fisheries management should be implemented differently among provinces with more attention on estuarine areas of the Mekong Delta.

In general, to sustainable use the fisheries resources, particularly estuarine fishing, the local fisheries officers should re-evaluate the issues mentioned in order to get more accurate data advising the fisheries management.

Conclusions. The study identified 199 species belonging to 65 families, with species number in the rainy season being more abundant and diverse than that in the dry season. There were significant differences in the CPUA and NPUA between ER and NER sites and between seasons. These differences may be due to the distinct characteristics of the environmental factors influenced by the Mekong River. Our findings are different with the previous surveys, which can instruct the local fisheries officers in fisheries management, especially for estuarine areas of the Mekong Delta. The future monitoring activities should be focused on the coastal areas, vulnerable regions, both in the frequency of surveys and sites' density.

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Authors:
Dinh Dac Tran, Department of Fisheries Management and Economics, College of Aquaculture and Fisheries, Can Tho University, Ninh Kieu, Can Tho 900000, Vietnam, e-mail: tddinh@ctu.edu.vn
Hung Van Cao, Research Institute for Marine Fisheries, Ministry of Agriculture and Rural Development, 224 Le Lai Street, Hai Phong, Vietnam, e-mail: hungrimf@gmail.com
Quang Minh Dinh, Can Tho University, Department of Biology, School of Education, Department of Biology, Vietnam, Can Tho 900000, Can Tho city, 3/2 street, e-mail: dmquang@ctu.edu.vn
Loi Xuan Tran, Department of Fisheries Management and Economics, College of Aquaculture and Fisheries, Can Tho University, Ninh Kieu, Can Tho 900000, Vietnam, e-mail: txloi@ctu.edu.vn

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