Research Article

The Effects of Flood Pulse on the Spatial and Temporal Dynamics of Fish Diversity in the Raphiphat Canal, Thailand

Weerawich Wongroj[1], Arin Ngamniyom[2], and Ruthairat Siriwattanarat[3]*

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ABSTRACT

This paper analyzes the effects of flood pulse on the spatial and temporal dynamics of fish diversity in the Raphiphat canal, Thailand, resulting from a study carried out in the period from May to December 2021. The fish samples were collected every month, covering the pre-flooded season (May to August) and the flooded season (September to December) on the rainy seasons at eight sampling stations. Fish were caught using cast nets with a mesh size of 1.5 cm and 2.5 cm, and gill nets with a mesh size of ¾ inch, 1.5 inches, and 2 inches. All data were analyzed to find out the fish diversity indices. A multivariate method of cluster analysis was used for data analysis. The result indicated that there was a total of 4,998 individual fish representing 33 species belonging to 25 genera and 14 families. The four most dominant fish varieties in the Raphiphat canal in terms of amount were *Puntioplites proctozystron, Barbonymus gonionotus, Cyclocheilichthys enoplos,* and *Oreochromis niloticus* which were distributed at all research stations. For temporal dynamics of fish diversity, the average species richness was 15.74±7.18. The highest species richness was found in August, and the lowest species richness was found in June. The H′ index 2.46±0.47 was found in December to May. The relative evenness index (J′) was 0.91±0.03 and varied between December and May. The cluster analysis each month in the Raphiphat canal can divide the fish community into 5 clusters.

Keywords: Flood, species diversity, spatial, temporal, species richness, Raphiphat canal

[1]Srinakharinwirot University Prasarnmit Demonstration School (Elementary), Bangkok, Thailand
[2]Major in Environment, Faculty of Environmental Culture and Eco-tourism, Srinakharinwirot University, Bangkok, Thailand
[3]Faculty of Science and Technology, Suan Sunandha Rajabhat University, Bangkok, Thailand
*Corresponding author, email: ruthairat.si@ssru.ac.th

Introduction

Flooding is a common natural phenomenon in the Chao Phraya River, Thailand, and typically occurs between August and December with a total of 13 severe floods observed in 1917, 1942, 1959, 1964, 1972, 1980, 1983, 1995, 1996, 2002, 2006, and 2011 [1]. Recently, Thailand suffered its largest floods since those caused by Tropical Storm Dianmu's high rainfall on September 23, 2021. As a result, the water level rises above the flood protection line, the excess water floods the low-lying land along the eastern Chao Phraya River when drainage from the Pa Sak Jolasid Dam into the Chao Phraya River and spilling the Rama VI dam into the lowlands at the dam's terminus impacted four central provinces: Lop Buri, Saraburi, Ayutthaya, and Pathum Thani.

Floodplains are rich in biodiversity and contribute significantly to the aquatic ecosystem's productivity [2]. During floodplain inundation, many fish migrate from the main channel to the flooded areas. Many species use the flood plain for breeding and nursery grounds, as evidenced by the vast quantity of fish there. The physical diversity of floodplain river systems has been reduced as a result of channelization and dykes, with much of the surrounding flood plain removed from the main river channel and associated flood episodes [3]. River hydrological regimes in Thailand, like everywhere in the tropics, vary dramatically from season to season. The dry season lasts from January to April, with the rainy season beginning in May to June [4] and the highest water level until flooding occurs from September to December [1]. Because of the vast water volume, the wet season can expect a great quantity and diversity of fish species. As a result, the accessible habitats have been extended to accommodate both resident and migratory fish [3]. However, flood control measures have been implemented in the Chao Phraya River Basin following the devastation caused by the 2011 Thailand flood. It is critical to understand the impact of floodplain areas and flood events on fish in the basin to ensure that flood management methods are tailored to minimize detrimental effects on the river-floodplain ecosystem [2]. Floods can improve the amount and diversity of fish assemblages in intermittent prairie streams by temporarily linking isolated pools and permitting previously obstructed movement. As a result, during floods, headwater reaches may provide refuge for fish, whereas significant flooding downstream should result in a larger risk of displacing algae, invertebrates, and fish [5]. The effects of floods, as expect, will vary depending on their severity and season. There is most likely a flood intensity threshold at which fish assemblages will shift. We hypothesized that floods should have a positive influence on fish numbers and species richness in headwater areas. We also looked at the impacts of flood and season on fish species diversity and richness in intermittent stretches between these research locations.

Materials and Methods

Study area

The study was conducted in the floodplains of the lower Chao Phraya river basin and the Pa Sak river basin from the Rama VI dam drainage gate to Rangsit Plain. Work was conducted in the Raphiphat canal, (length of 32 km), which is one of the canals that play an important role in drainage and irrigation projects in Phra Nakhon Si Ayutthaya, Saraburi, and nearby areas. That located between

100°40–100°90 E and 14°10–14°35 N, by drawing a grid to cover the geographic system from the digital map in Google Earth (version 6.0.3). The grid is 5 arcminutes per square; the study area was separated into eight stations: 1) Phra Narai Water Gate (ST1) (14°33'23.5"N 100°45'42.6"E); 2) Phramahin Water Gate (ST2) (14°30'20.9"N 100°44'05.5"E); 3) Eka Dhosarot Water Gate (ST3) (14°23'46.9"N 100°47'37.7"E); 4) Hemaraj Industrial Estate (ST4) (14°21'10.6"N 100°50'17.3"E); 5) Phra Sri Silp Water Gate (ST5) (14°19'52.8"N 100°52'22.4"E); 6) Nong Mu Water Gate (ST7) (14°16'35.9"N 100°53'29.7"E); 7) Chula Chindaram Temple Raphiphat Yaek Tok (ST8) (14°13'57.4"N 100°48'01.6"E); 8) Thanyaburi Raphiphat Yaek Tok (ST6) (14°12'22.2"N 100°44'43.2"E) to cover both upstream, midstream and downstream where water bodies are main and branch canals (Figure 1).

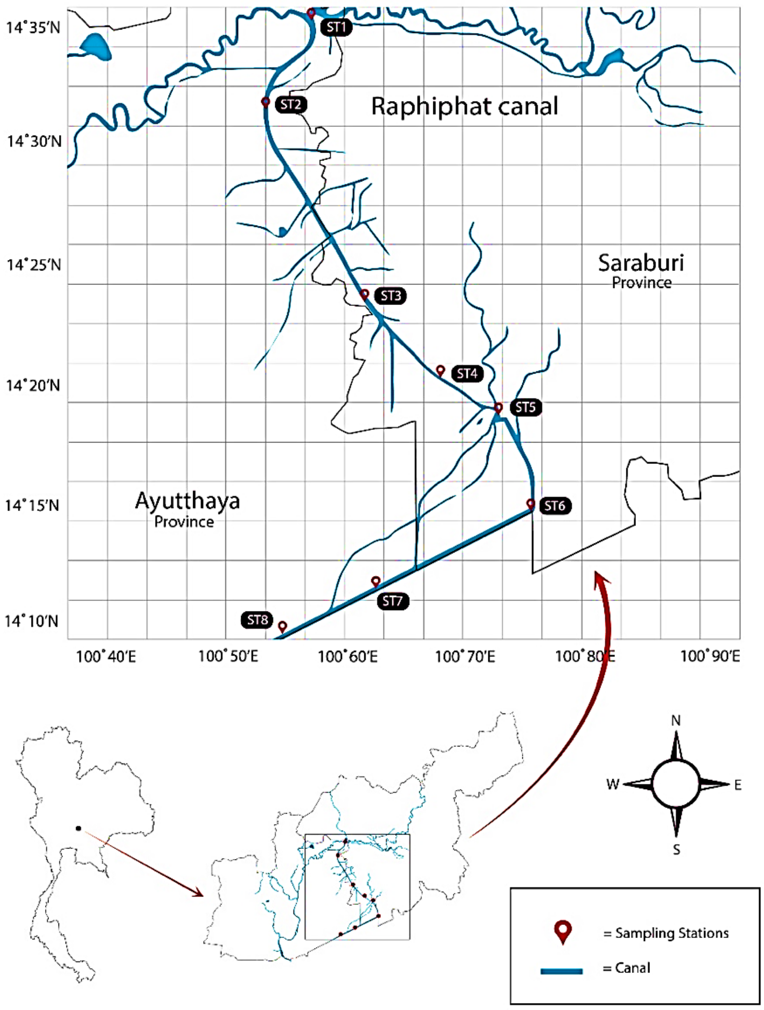


Figure 1 Location and sampling stations of the Raphiphat canal, Thailand.

Sample collection

The fish specimens were collected every month of the rainy season in the period from May to December 2021, covering the pre-flooded season (May to August), and the flooded season (September to December), at eight sampling stations in the Raphiphat canal (ST1-ST8), using cast nets with a mesh size of 1.5 cm and 2.5 cm, gill nets with a mesh size of ¾ inch, 1.5 inches and 2 inches. Fish samples were preserved in 10 percent formalin-freshwater solution, and deposited at the Faculty of Science and Technology, Suan Sunandha Rajabhat University, Bangkok. The species identification was conducted by following : Smith (1945), Rainboth (1996), Vidthayanon, *et al*. (1997), Kottelat (2001), and Nelson (2001) [6-10].

In the pre-flooded season, from May (the start of the rainy season) to August 2021, the water bank-level was below 100 millimeters. However, during the flooded season from September to December 2021, the water bank-level rises from 100 to over 600 millimeters. This was also the period during which Tropical Storm Dianmu's high rainfall lead to high discharge levels in the Raphiphat canal, thereby prolonging the inundation of flooded over water bank-level until the late end the year (winter season) [11] (Figure 2).

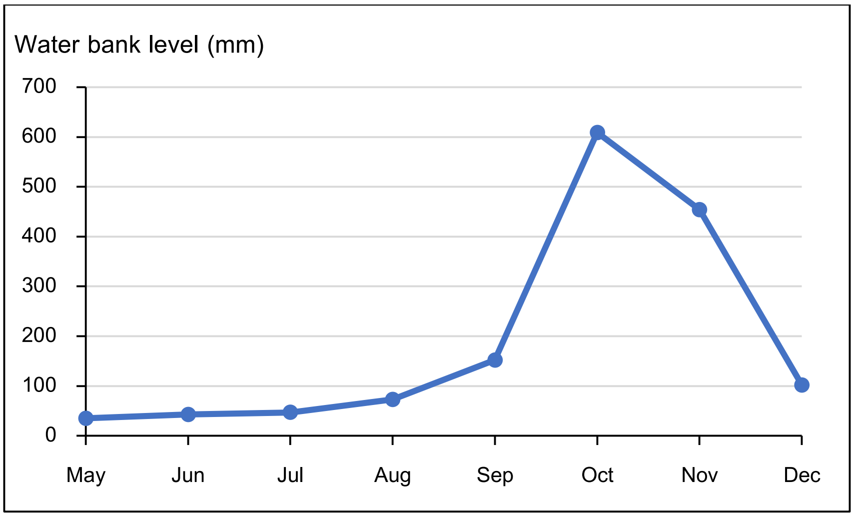


Figure 2 Seasonal dynamics of water bank level in each month, May-December 2021.

Data analysis

Species richness was calculated by using Margalef's index, R [12, 13] as shown in Eq. (1).

$$R = (S-1)/\ln(n) \qquad \text{........ (1)}$$

where S is the total number of species in each sample and n is the total number of individuals for all species. Species diversity index was calculated by Shanon-Wiener's index, H' [12, 13] as shown in Eq. (2).

$$H' = -\sum (p_i \log p_i) \qquad \text{........ (2)}$$

where p_i is the relative abundance, i.e. the number of individuals for species i divided by total number of individuals for all species. The relative evenness index, J', was calculated by Pielou's index [12, 13] as shown in Eq. (3).

$$J' = H'/H_{max} \qquad \text{........ (3)}$$

where p_i is the proportion of individuals belonging to the i^{th} species; S is species richness (number of different species present), and H'_{max} is the maximum possible value of H' (i.e., if every species was equally likely) and H'_{max} = lnS [14]. Because all indices noted are non-normally distributed (p>0.05), statistical differences among sampling times and stations were tested by the Kruskal-Wallis test; the Dunn's post-hoc test was applied if significant difference was found at α = 0.05. The permutation MANOVA (PERMANOVA) [15] was applied to test whether the factors month and station affected the difference in fish species composition (designated as dependent variable).

The degree of similarity index of fish structure community between sites sampling and months was calculated using the Bray-Curtis similarity coefficient, based on the number of individuals of each species. Prior to analyses, abundance data were transformed to log (X+1) to normalize distribution and stabilize variances. The resultant similarity matrix was subjected to cluster analysis (group average mean linkage) and non-multidimensional scaling (NMDS). How well the sample relationship by the dimensions as indicated by stress values calculated by the NMDS procedure, in which NMDS will provide a useable picture of sample relationship when the value is < 0.2 [13]. Statistical analyses were done by R [16], with the package vegan [17] and ade 4 [18].

Results

Spatial and temporal assemblage structures and species diversity

A total of 14 families and 33 species of fish were found during this study. The most diverse family was Cyprinidae (11 species), followed by Pangasiidae (5 species); Bagridae (3 species); Notopteridae, Siluridae, Channidae (2 species); the remaining eight families contained one species each. Of 4,998 individuals collected, *Puntioplites proctozysron* was the most abundant species (10.96%), followed by *Barbonymus gonionotus* (9.60%), *Oreochromis niloticus* (7.36%), *Barbonymus altus* (5.42%), and *Channa striata* (5.10%). The remaining species each represented less than 5% of the combined sample. Relative abundance of each collected fish species (in terms of number and weight in the combined sample) and percent occurrence (among sampling events) are presented in Tables 1-3.

In terms of occurrence frequency, 21 species were found in every sample, and 9 species had an occurrence frequency of over 50%. Sampling site ST1 was most abundant (1,045), followed by site ST2 (836), site ST3 (683), site ST4 (593), site ST5 (500), site ST6 (477), site ST7 (436), and site ST8 (428).

Table 1 List of species, ONEP's threatened status and number of individuals of each species at each site found in the Raphiphat canal

Family	Species	code	Common name	ONEP's threatened status	Location	Amount	Occurrence (%)
Dasyatidae	*Fluvitrygon signifer*	Flsi	Freshwater tingray		1,2,3	7	0.14
Notopteridae	*Chitala ornata*	Chor	Clown knifefish		1,2,3,4,5,6,7	45	0.90
	Notopterus notopterus	Nono	Grey Featherback		1,2,3,4	28	0.56
Danionidae	*Rasbora myersi*	Ramy	Silver rasbora		1,2,3,4,5,6,7,8	196	3.92
Cyprinidae	*Cyclocheilichthys enoplos*	Cyen	Soldier river barb		1,2,3,4,5,6,7,8	366	7.32
	Puntioplites proctozystron	Pupr	Smith's barb		1,2,3,4,5,6,7,8	548	10.96
	Barbonymus altus	Baal	Red tinfoil barb		1,2,3,4,5,6,7,8	271	5.42
	Barbonymus schwanefeldii	Basc	Schwanefeldii tinfoil barb		1,2,3,4,5,6,7,8	142	2.84
	Barbonymus gonionotus	Bago	Silver barb		1,2,3,4,5,6,7,8	480	9.60
	Hampala macrolepidata	Hama	Hampala barb		1,2,3,4,5,6,7,8	103	2.06
	Systomus orphoides	Syor	Red cheek barb		1,2,3,4,5,6,7,8	165	3.30
	Labeo chrysophekadion	Lach	Black shark		1,2,3,4,5,6,7,8	157	3.14
	Labeo rohita	Laro	Rohu	Alien species	1,2,3,4,5,6,7,8	69	1.38
	Labiobarbus siamensis	Lasi	-		1,2,3,4,5,6,7,8	188	3.76
	Osteochilus vittatus	Osvi	Bonylip barb		1,2,3,4,5,6,7,8	110	2.20
Bagridae	*Hemibagrus wyckioides*	Hewy	Asian red tailed catfish		1,2,3,4,5,6,7,8	55	1.10
	Mystus mysticetus	Mymy	Iridescent mystus		1,2,3,4,5,6,7,8	116	2.32
	Mystus singaringan	Mysi	Longfinned mystus		1,2,3,4,5,6,7,8	45	0.90

Remark: ST1−ST8 = Sampling stations for collecting fish

Table 1 *(cont.)* List of species, ONEP's threatened status and number of individuals of each species at each site found in the Raphiphat canal

Family	*Species*	code	Common name	ONEP's threatened status	Location	Amount	Occurrence (%)
Siluridae	*Kryptopterus geminus*	Krge	Blue sheatfish		1,2,3,4,5,6	52	1.04
	Ompok biculatus	Ombi	Butter catfish		1,2,3,4,5,6	50	1.00
Pangasiidae	*Pangasianodon hypophthalmus*	Pahy	Striped catfish		1,2,3,4,5,6,7,8	200	4.00
	Pangasius hypophthalmus x *Pangasius gigas*	Pahg	-	Alien species	1,2,3,4,5,6,7,8	73	1.46
	Pangasius pleurotaenia	Papl	-		1,2,3,4,5,6	39	0.78
	Pangasius larnaudii	Pala	Spot pangasius		1,2,3,4,5,6,7	34	0.68
	Pangasius macronema	Pama	Shark catfish		1,2,3,4,5,6,7	141	2.82
Clariidae	*Clarias macrocephalus* x *Clarias gariepinus*	Clmg	Hybrid catfish	Alien species	1,2,3,4,5,6,7,8	180	3.60
Mastacembelidae	*Mastacembelus favus*	Mafa	Spiny eels		1,2,3,4,5,6	86	1.72
Pristolepididae	*Pristolepis fasciatus*	Prfa	Striped tiger leaffish		6,7,8	32	0.64
Anabantidae	*Anabas testudineus*	Ante	Climbing perch		4,5,6,7,8	92	1.84
Channidae	*Channa striata*	Chst	Striped snakehead		1,2,3,4,5,6,7,8	255	5.10
	Channa micropeltes	Chmi	Giant snakehead		1,2,3,4,5,6,7,8	101	2.02
Cichlidae	*Oreochromis niloticus*	Orni	Nile tilapia	Alien species	1,2,3,4,5,6,7,8	368	7.36
Loricariidae	*Pterygoplichthys pardalis*	Ptpa	Amazon sailfin catfish	Alien species	6,7,8	204	4.08

Remark: ST1–ST8 = Sampling stations for collecting fish

Table 2 Seasonal dynamics of fish community structure (species relative abundance in %) in flooded (F) and pre-flooded (PF) seasons

Season / Species	Pre-flooded				Flooded			
	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Fluvitrygon signifer	0.0	0.0	0.0	0.2	0.0	0.0	0.3	0.2
Chitala ornata	0.0	0.0	0.0	2.1	1.0	0.5	0.5	1.5
Notopterus notopterus	0.0	0.0	0.0	0.9	0.3	0.5	0.3	1.1
Rasbora myersi	1.4	0.0	2.7	4.2	6.6	7.9	2.8	3.4
Cyclocheilichthys enoplos	2.8	0.0	4.6	3.5	7.7	8.4	10.5	8.0
Puntioplites proctozystron	20.4	20.0	15.0	10.2	15.3	12.6	6.7	8.1
Barbonymus altus	8.8	11.6	9.0	3.7	3.8	4.0	4.0	5.8
Barbonymus schwanefeldii	2.8	4.0	1.9	2.3	2.4	4.7	2.7	2.6
Barbonymus gonionotus	13.0	11.2	16.4	14.2	11.0	10.5	8.2	5.8
Hampala macrolepidata	0.5	0.0	0.0	0.0	0.0	4.0	2.8	3.2
Systomus orphoides	4.6	0.0	1.9	0.0	0.0	1.7	5.2	5.5
Labeo chrysophekadion	0.9	0.0	0.0	2.1	1.7	5.7	3.0	4.8
Labeo rohita	0.0	0.0	0.0	1.4	1.6	0.8	1.9	1.9
Labiobarbus siamensis	5.1	4.0	2.2	2.6	1.6	0.0	6.6	4.4
Osteochilus vittatus	1.9	2.0	1.9	1.6	1.0	0.0	3.2	3.1
Hemibagrus wyckioides	0.0	0.0	0.8	0.7	1.2	0.0	1.9	1.4
Mystus mysticetus	1.9	2.4	3.0	3.0	2.6	2.5	1.3	2.6
Mystus singaringan	0.0	1.2	1.1	2.6	0.9	0.7	0.9	0.6
Kryptopterus geminus	0.0	0.0	0.0	0.2	0.0	0.0	1.9	2.1
Ompok biculatus	0.0	0.0	0.0	0.2	0.0	0.0	2.1	1.7
Pangasianodon hypophthalmus	3.7	3.6	3.6	2.3	1.4	4.9	5.9	3.9
Pangasius hypophthalmus x *Pangasius gigas*	0.0	0.0	0.0	0.2	0.0	0.0	3.9	1.9
Pangasius pleurotaenia	0.0	0.0	0.0	0.0	0.0	0.0	1.8	1.3
Pangasius larnaudii	0.0	0.0	0.0	0.2	0.0	0.0	1.5	1.1
Pangasius macronema	0.9	0.0	1.1	2.3	8.3	5.4	1.4	2.1
Clarias macrocephalus x *Clarias gariepinus*	0.0	5.2	5.2	5.3	2.8	6.1	3.4	2.4
Mastacembelus favus	0.0	0.0	0.0	2.3	4.0	3.2	1.0	1.6
Pristolepis fasciatus	0.0	0.0	0.0	0.0	0.0	0.0	1.3	1.2
Anabas testudineus	4.6	3.2	2.2	2.3	2.3	0.0	0.9	2.3
Channa striata	3.7	5.6	5.5	4.4	3.5	0.0	6.9	6.7
Channa micropeltes	0.9	3.2	0.0	1.4	2.1	2.7	2.8	1.7

Table 2 *(cont.)* Seasonal dynamics of fish community structure (species relative abundance in %) in flooded (F) and pre-flooded (PF) seasons

Season / Species	Pre-flooded				Flooded			
	May	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Oreochromis niloticus	6.9	12.8	13.9	15.5	11.1	10.1	1.8	4.1
Pterygoplichthys pardalis	15.3	10.0	7.9	7.9	5.7	2.9	0.4	2.0
Species richness	19	15	19	29	24	21	33	33

Table 3 Number of individuals of fish each station (species relative abundance in %) in flooded (F) and pre-flooded (PF) seasons

Species	ST1		ST2		ST3		ST4		ST5		ST6		ST7		ST8	
	PF	F	PF	F	PF	F	PF	F	PF	F	PF	F	PF	F	PF	F
Fluvitrygon signifer		1	1	4		1										
Chitala ornata	3	11	1	9	1	7	1	5	1	2	2	1		1		
Notopterus notopterus	1	7	1	10	1	5	1	2								
Rasbora myersi	6	28	6	26	5	29	8	27	4	21	2	15		10		9
Cyclocheilichthys enoplos	15	56	11	57	7	49	2	45	2	40		29	1	29		23
Puntioplites proctozystron	55	63	38	63	27	53	19	48	16	40	14	32	12	30	12	26
Barbonymus altus	27	44	21	34	20	20	10	20	9	18	7	14	2	12	1	12
Barbonymus schwanefeldii	11	26	9	22	6	18	5	14	1	9	1	10		5		5
Barbonymus gonionotus	46	59	34	50	24	47	25	41	19	29	14	27	8	27	7	23
Hampala macrolepidata		21		20		17		18		11	1	9		4		2
Systomus orphoides	10	27	4	27	2	24		20	1	20		11		10		9
Labeo chrysophekadion	4	29	2	26	2	24	1	19	1	18		13	1	9		8
Labeo rohita	4	24	1	16	1	9		6		4		2		1		1
Labiobarbus siamensis	15	34	8	28	4	24	2	23	6	17	4	10	1	6		6
Osteochilus vittatus	11	21	5	18	2	15	1	14	2	11	1	4		2	1	2
Hemibagrus wyckioides	4	17	2	10		7		6		4		2		2		1
Mystus mysticetus	6	8	4	7	4	7	3	7	3	14	8	13	3	12	3	14
Mystus singaringan	5	3	3	2	3	1	1	2	2	9	2	4	1	4	1	2
Kryptopterus geminus		19		14	1	8		5		4		1				
Ompok biculatus		14		12		9	1	8		4		2				
Pangasianodon hypophthalmus	13	33	7	23	7	22	3	17	1	15	4	13	2	19	3	18

Table 3 *(cont.)* Number of individuals of fish in each station (species relative abundance in %) in flooded (F) and pre-flooded (PF) seasons

Species	ST1		ST2		ST3		ST4		ST5		ST6		ST7		ST8	
	PF	F	PF	F	PF	F	PF	F	PF	F	PF	F	PF	F	PF	F
Pangasius hypophthalmus x *Pangasius gigas*		18		14		9		8		6		6	1	6		5
Pangasius pleurotaenia		14		8		7		4		4		2				
Pangasius larnaudii		10		10		6		3		3		1	1			
Pangasius macronema		36		25		21	8	18	3	13	4	11	1	1		
Clarias macrocephalus x *Clarias gariepinus*	8	26	6	24	4	20	3	16	4	14	9	14	10	6	11	5
Mastacembelus favus	3	24	1	20	2	14	2	10	1	5	1	3				
Pristolepis fasciatus												13		10		9
Anabas testudineus							2	6	3	7	3	12	11	15	17	16
Channa striata	12	29	6	29	5	30	2	27	4	23	11	18	9	19	12	19
Channa micropeltes	6	17	2	9	2	11		13		13	4	5	1	10	1	7
Oreochromis niloticus	28	33	16	30	14	25	20	21	16	23	19	22	24	24	28	25
Pterygoplichthys pardalis											25	22	44	29	52	32
Number of Species	293	752	189	647	144	539	120	473	99	401	136	341	133	303	149	279

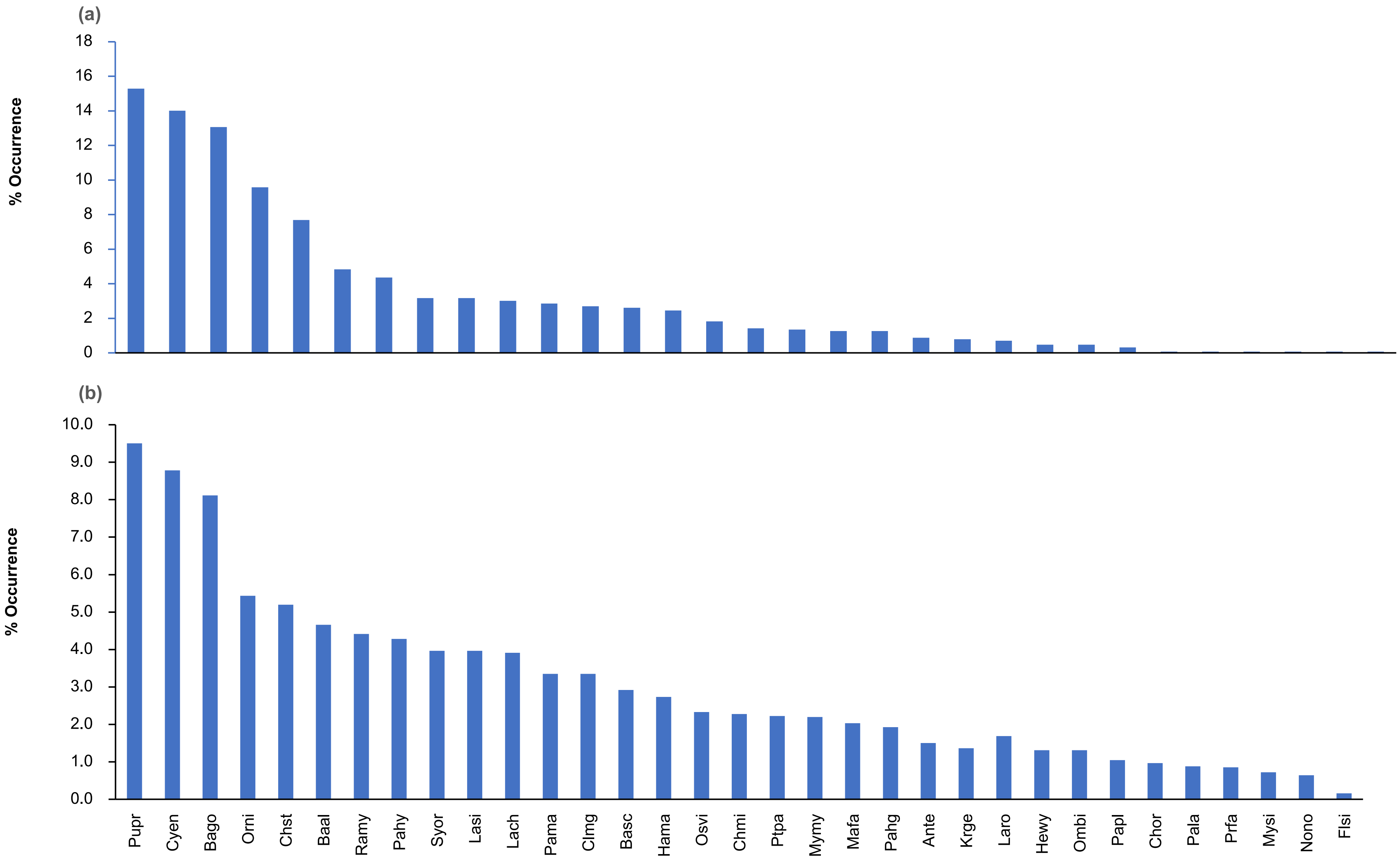


Figure 3 Percent occurrence of fishes from each month of sampling during the study period: (a) Pre-flooded season; (b) Flooded season; species abbreviations as detailed in Table 2.

The common fish species were presented in Table 2. The ten species *Puntioplites proctozystron*, *Barbonymus altus*, *Barbonymus schwanefeldii*, *Barbonymus gonionotus*, *Labiobarbus siamensis*, *Mystus mysticetus*, *Pangasianodon hypophthalmus*, *Channa micropeltes*, *Oreochromis niloticus*, and *Pterygoplichthys pardalis* were common in all sampling stations. In the pre-flooded season, samples were comprised mainly of 5 species (>5% occurrence); *Puntioplites proctozystron* (15%), *Barbonymus gonionotus* (14%), *Oreochromis niloticus* (13%), *Pterygoplichthys pardalis* (10%), and *Barbonymus altus* (8%). In the flooded season, samples were also comprised mainly of 5 species (>5% occurrence); *Puntioplites proctozystron* (9.5%), *Cyclocheilichthys enoplos* (8.8%), *Barbonymus gonionotus* (8.1%), *Oreochromis niloticus* (5.4%), *and Channa striata* (5.2%) (Figure 3).

Means for species diversity index (H´), species richness (R), and relative evenness index (J´) in each month and each station are presented in Tables 3 and 4, respectively. The H´ index ranged from 1.41 (station 4 in May) to 3.29 (station 1 in December), with an average of 2.46±0.47. The average species richness was 15.74±7.18 and varied between 4.10 (station 4 in May) and 29.56 (station 4 in December). The average J´ index was 0.91±0.03 and varied between 0.813 (station 7 in May) and 0.423 (station 1 in December). Significant temporal differences (Table 3) were found for H´ index (p = 0.145) species richness (p = 0.003), and J´ index (p = 0.002). Meanwhile, H´ index (p = 0.984) species richness (p = 0.722), and J´ index (p = 0.087). showed significant spatial differences (Table 4).

Table 3 The species diversity index (H´), species richness index (R), and the relative evenness index (J´) at each month

Parameter	p-value	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
H´	0.145	1.802±0.27	2.03±0.21	2.22±0.23	2.47±0.33	2.52±0.28	2.56±0.11	3.03±0.10	3.03±0.27
R	0.003	7.50±2.49	9.29±2.64	11.52±2.72	16.16±4.72	16.45±4.75	14.85±1.68	25.03±2.90	25.42±5.77
J´	0.002	0.87±.038	0.89±0.03	0.90±0.15	0.89±0.03	0.90±0.21	0.94±0.01	0.94±0.01	0.94±0.02

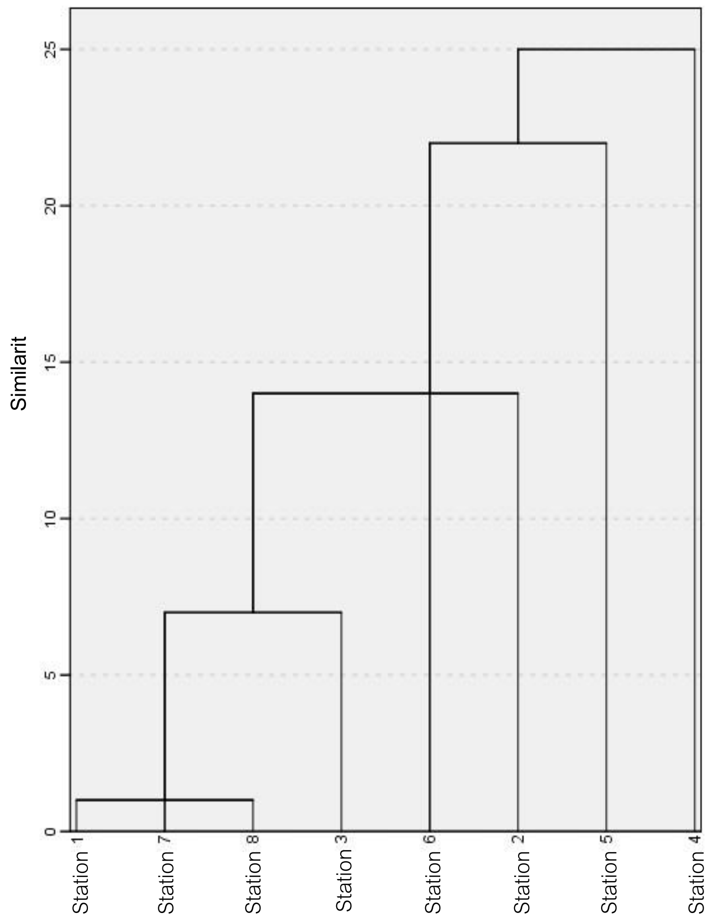
Table 4 The species diversity index (H´), species richness index (R), and the evenness index (J´) at each sampling station

Parameter	p-value	ST1	ST2	ST3	ST4	ST5	ST6	ST7	ST8
H´	0.984	2.68±0.45	2.62±0.46	2.53±0.52	2.44±0.56	2.46±0.50	2.54±0.37	2.26±0.42	2.14±0.40
R	0.722	18.63±7.12	18.59±7.56	17.42±7.85	16.26±8.39	15.72±8.09	16.03±6.91	12.40±5.08	10.90±4.80
J´	0.087	0.93±.0.04	0.91±0.03	0.90±0.03	0.90±0.03	0.92±0.02	0.93±0.02	0.90±0.05	0.90±0.04

Assemblage patterns

The cluster analysis and non-multidimensional scaling (NMDS) of site showed that assemblage patterns could be divided into five groups. Sampling sites ST1, ST7, and ST8 were grouped together into group 1, and sampling sites ST2 and ST6 were grouped together into group 2, with a similarity level of 20%, whereas the other 3 sites were divided into 3 groups, i.e. group 3 (ST3), group 4 (ST4), and group 5 (ST5) (Figures 4a and 4b).

(a)



(b)

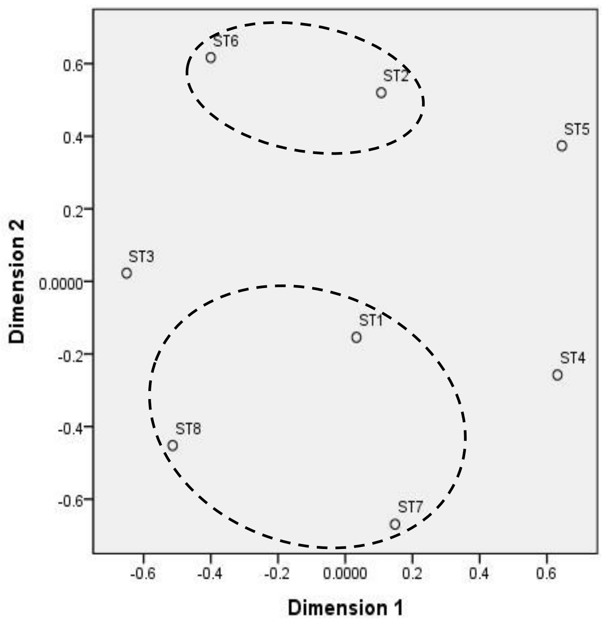


Figure 4 Dendrogram of cluster analysis based on number of individuals of each species each site (S1-S8) in Raphiphat canal during May-December 2021,

(a) Assemblages divided into five groups at 20% level of similarity,

(b) Non-multidimensional scaling analysis.

For the temporal approach, results showed that assemblage could be divided into two major groups with a similarity level of 20% (Figures 5a and 5b), in which the main classified factor was variation in the percentage of relative abundance species in each month. Group 1 consisted of 3 months *viz.*, June, October, and December. May and November were included in group 2.

(a)

(b)

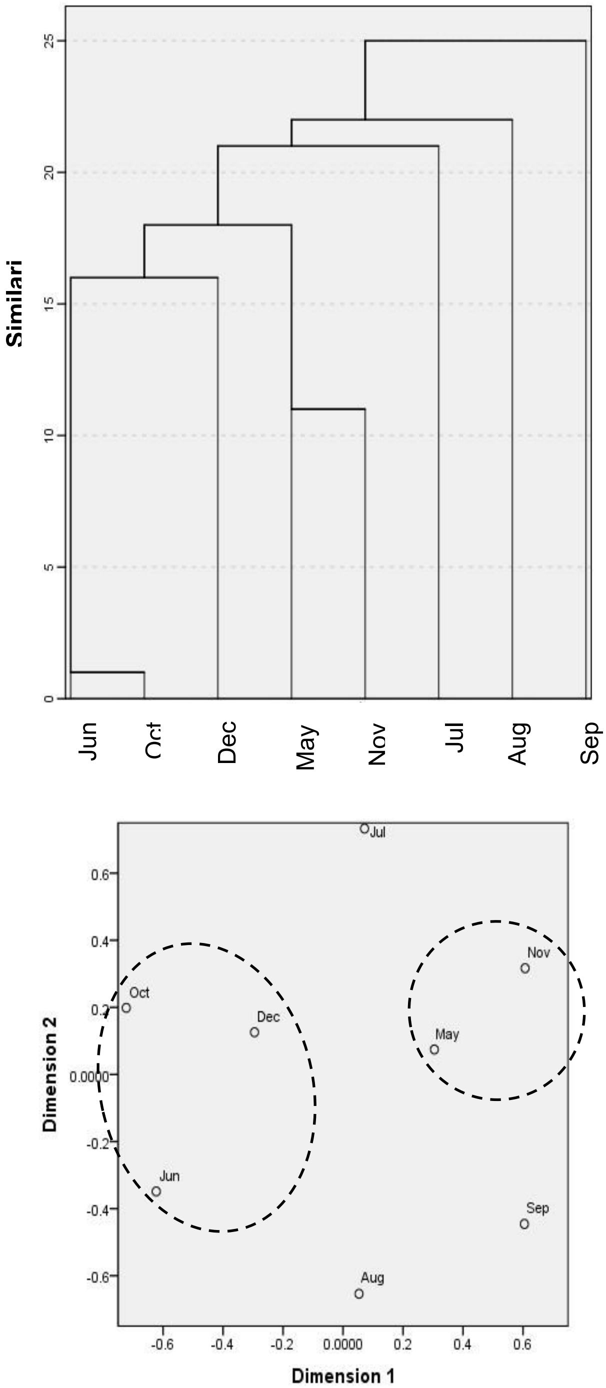


Figure 5 Dendrogram of cluster analysis based on number of individuals of each species each month of sampling in Raphiphat canal during May-December 2021,

(a) Assemblages divided into five groups at 20% level of similarity,

(b) Non-multidimensional scaling analysis.

Relationships between species abundance and richness and water levels

Significant links between each month's abundance or richness and water levels were observed in the Raphiphat canal. The cross-correlation analyses between the two time periods (pre-flooded and flooded) for the eight sites where both fish and water level data series' were available noted that there was a positive relationship between the temporal variation in both species abundance and richness (Figure 6). Overall, the fish community responses appeared to follow the flow regime (i.e. water led the fish). The correlation for fish abundance and species richness versus water levels at the maximum coefficient was estimated in August; in contrast, the correlation for fish abundance and species richness versus water level was estimated in October. It is noteworthy that the time lag between the water levels was estimated at about 1 month.

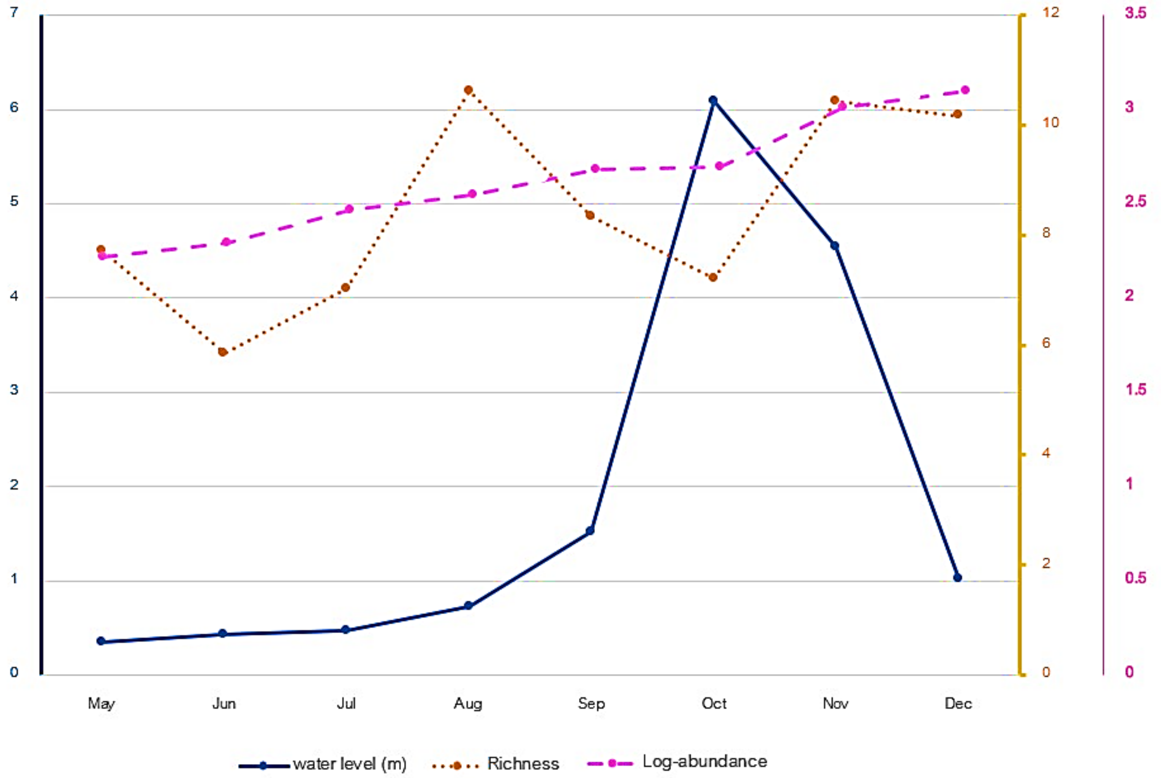


Figure 6 Relationships between water level and fish abundance and species richness in the Raphiphat canal. In cross-correlation plots, the blue line provides the values of the water bank-level, the dotted orange line provides the values of the species richness, and the dotted pink line provide the values of the log-abundance. The x-axis is the months for the period from May to December 2021.

Discussion

Richness and diversity

The effects of flood pulse on spatial and temporal dynamics of fish diversity in the Raphiphat canal were surveyed to understand their importance for fish distribution. Species richness and abundance during the pre-flooded and flooded seasons did differ considerably, especially after Tropical Storm Dianmu's high rainfall discharged high water levels. The present study, therefore, highlights the diversity and assemblages of fish in the Raphiphat canal. Cyprinid fish is very common in the Raphiphat canal, with more than 50% of the fish assemblage belonging to this group because it is the largest family of freshwater fish in Southeast Asia [19, 20]. The two most common species found in this study, *Puntioplites proctozystron* and *Barbonymus gonionotus*, are known as benthic and mesopelagic stream and river residents, behaviorally adapted to lotic environments [21]. Abundance and diversity indices in stations 3 to 5 were low during the beginning of the pre-flooded season (May, June and July), but increased in November and December in stations 1 to 4, implying that the fish moved out from the refuge that those stations provide when the water level rose at the onset of the rainy season. This pattern is similar to the migratory patterns of fish in the Pa Sak River, where fish inhabit deep pools during the dry season and move elsewhere at the onset of the rainy season [2]. High abundance and species richness conform to the stream water-bank level model, as both parameters tended to increase down-gradient, together with depth and habitat heterogeneity [22].

In the pre-flooded season, the abundance of fish and species diversity is found among followed by the base of the water-bank level margin. However, water levels rose quickly and the absence of shelters caused a considerable increase in both the abundance of fish and species diversity. Fish are more abundant in the flooded season than in the pre-flooded season. In other tropical river-lake floodplain systems, water depth and surface cover are the two most significant variables that were found to also explain higher species abundance and richness, for example in the Tonle Sap River and Lake [23]. In contrast, relatively lower richness and diversity values were found in ST4 and ST5 in May, where total species richness among these sites was similar. This was because sites in the middle part were representative of the canal habitat, mainly serving as a natural fish passageway for migratory species that seasonally migrate to complete their life cycle [24, 25].

Spatial and temporal variation

We found that freshwater fish within the Raphiphat canal were distributed along the south-north gradient, classifying the entire community into five assemblage clusters. The characteristic species of ST1 were mainly migratory white fish, such as cyprinids. These white fish are generally intolerant to anoxia, preferring migration as a means to escape adverse environmental conditions during the dry season [26]. Well-oxygenated water, such as the lotic main river channel and deep pools, is generally required for these species to shelter during the dry season [24]. In addition, the distribution of white fish in this cluster was part of the seasonal migration conducted to complete their life cycles, that is, accessing the Pa Sak River as dry season refugia used for rearing and feeding, and for spawning sites during the early flooding cycle [27]. In contrast, the characteristic species ST7 and ST8 were mainly migratory accessory air-breathing organ fish, such as tilapia and catfish. These accessory air-breathing organ fish can tolerate poor quality environments due to the presence of an accessory air-breathing organ that allows them to adapt to the environment [19]. The sensitive fish species have ancillary respiratory mechanisms such as the lung-like labyrinth organ present in *Pristolepis fasciatus*, *Anabas testudineus*, and *Oreochromis niloticus*, the supra-branchial organ present in *Pterygoplichthys disjunctive*, *Channa striata*, *Channa micropeltes*, or scale-less species (such as *Mystus mysticetus*, *Mystus singaringan*, *Pangasianodon hypophthalmus*, *Pangasius hypophthalmus* x *Pangasius gigas*, *Pangasius pleurotaenia*, *Pangasius larnaudiiand*, *Pangasius macronema* and *Clarias macrocephalus* x *Clarias gariepinus*) [28]. The underlying reason for these results was that the cluster was associated with the canal's southern section, which encompasses mostly lentic habitats and narrow areas compared to the width area of the canal (ST1), which has effective wind mixing conditions throughout the water column [23].

Cluster 2, consisting of ST2 and ST6, was characterized by widespread species. Overall, this cluster was represented by a high number of indicator species with different ecological attributes, such as longitudinal migratory white fish, floodplain residents, and lateral migrants. This result was likely due to the overall environmental stability in this section, that is, deeper water, larger surface cover, habitat connectivity through the permanent water bodies, and presence of the permanent wet large tributaries of the Pa Sak River [19].

Indicator species for cluster 3 in the northern section were mainly restricted to cyprinid white fish with general habitat preferences, such as *Puntioplites proctozystron* and *Barbonymus gonionotus*. These cyprinid white fish are generally intolerant to anoxia, preferring migration as a means to escape adverse environmental conditions during the dry season. Well-oxygenated water, such as the lotic main river channel and deep pools, is generally required for these species to shelter during the dry season [19].

The higher abundance during the inflow of water was likely attributed to high fish densities, as fish were widely dispersed by seasonal floods inundated over the water-bank level from the Rama VI dam, which makes them difficult to capture. Our cross-correlation analyses noted that the peak abundance and richness (Figure 6) were related to the peak flow occurring about in October. While the peak abundance occurs around December, the peak richness occurs between August and November. The period for the peak abundance and richness found from the cross-correlation analyses corresponds to the defined outflow (rising water levels) period for this study. Such seasonal patterns were also reported in other tropical river-floodplain fish communities, such as the Tonle Sap River and Lake [23], where greater abundance and richness with more species interactions was driven by the falling water levels (rising flows).

Conclusions

In conclusion, a total of 33 species of fish were collected from eight research stations in the Raphiphat canal. *P. proctozystron, B. gonionotus, C. enoplos,* and *O. niloticus* had 100% local distribution or were found in all research stations. Table 3 shows the Shannon-Wiener (H´) species diversity index value of all locations sampled in the Raphiphat canal. This index gives an illustration of the species diversity, the productivity of ecosystems, the pressures on ecosystems, and the stability of ecosystems [2]. A value of 1.729 < H´ < 3.140 means moderate diversity, sufficient productivity, with ecosystem conditions being fairly balanced, and medium ecological pressure. From the 8 sampled sites, none indicated high diversity. However, we collected a sample of the canal with a moderate H' index value. The highest one is Phra Narai Water Gate (Station 1). The relative species diversity and evenness index was highest here, indicating that this site had a greater proportion of abundance among fish species and a broader distribution pattern in each species than any other site. In the temporal analysis, fish were collected over eight months (covering the pre-flooded and flooded seasons). Table 4 shows the Shannon-Wiener (H´) species diversity index value of all locations sampled in the Raphiphat canal. A value of 2.516 < H´ < 9.168 means ultra-diversity, sufficient productivity, with ecosystem conditions being leap balanced, and heightened ecological pressure because of the effect of Tropical Storm Dianmu's high rainfall. Data from the 8 months indicated high diversity. However, we collected a sample of the canal with a moderate H´ index value. The highest one was in December. The relative species diversity and evenness index was highest indicating that this site had a greater proportion of abundance among fish species and a broader distribution pattern of each species than in any other month.

Understanding the dynamic nature of spatiotemporal variation and distribution patterns as well as indicator species in the Raphiphat canal fish communities is necessary to inform fisheries monitoring, management, and conservation programs. For fish diversity management and conservation initiatives, "freshwater fishes in the lower Chao Phraya River basin" must use this natural passageway to complete their seasonal life cycles between the stream canal and floodplains. In a similar way, the Rangsit plain could serve as a location for the management and conservation of accessory air-breathing organ fishes and alien species. For fisheries monitoring, the clusters and key indicator species identified in this study can be proposed for the long-term fish monitoring programs to understand spatiotemporal changes and update the status and trends of the Raphiphat canal fisheries. The suggested timing of peak abundance and richness in relation to the peak flows of the Raphiphat canal could also be part of fish regulation and conservation initiatives.

Finally, the naturally predictable seasonal rising and falling flood pulses as well as the longitudinal and lateral connectivity of the main habitats of the Pa Sak River and its tributary systems, including the Chao Phraya River, are likely the key drivers to maintaining seasonal fish migrations. Hence, the Raphiphat canal's seasonal assemblage diversity and productivity follow up seasonal change in the absence of recurrent storms or floods.

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