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Diversity of freshwater fish at Sago Palm Wetlands, Nakhon Si Thammarat Province, Thailand

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Abstract. *Chankaew S, Chunta S, Baimai V, Kiriratnikom S. 2022. Diversity of freshwater fish at Sago Palm Wetlands, Nakhon Si Thammarat Province, Thailand. Biodiversitas 23: 6335-6344.* Studies on the diversity of freshwater fish at Sago Palm Wetlands, Nakhon Si Thammarat Province, Thailand, were conducted in the period from March 2020 to November 2020. Fish samples were collected, encompassing the hot-dry season (March to June) and the rainy season (September to November) at 4 sampling zones, with 5 stations for each zone. Fish were caught using a seine net of 1 cm mesh size, 1.5 m in length, and 1m in width. All data were analyzed to find out the fish diversity indices. The multivariate method was used to determine cluster analysis. A total of 3634 fish specimens, representing 62 species belonging to 24 families, were recorded during the sampling period. Cyprinidae was the major family, with *Trichopsis vittatus* containing the highest index of relative importance (IRI). The species diversity index of fish was in the range of 0.66 to 2.67; the evenness index was in the range of 0.64 to 0.95, and the species richness index ranged from 0.36 to 6.86, indicating an intermediate-low uniformity, with a medium species number in the area. The cluster analysis of the Bray-Curtis similarity index shows a division of the fish community into 2 clusters in the hot-dry season and 3 clusters in the rainy season, having a similarity percentage ranging between 42% and 95%, respectively. Also documented were one introduced species and one endangered fish species during sampling. The findings suggest that Sago Palm Wetlands is still inhabited by numerous fish species and should be conserved to ensure its aquatic animal richness for the future. This data provides information about the fish habitat in the Sago Palm Wetlands and can be used to update the checklists of fish species in the Tapi River, the Pak Phanang River, and the Trang River Basins. It also can be useful for the planning of fishing activities and the provision of guidelines for future research and conservation purposes.

Keywords: Cluster analysis, diversity pattern, fisheries resources, index of relative importance

INTRODUCTION

Thailand contains areas with exceptionally high freshwater fish biodiversity, having 25 major watersheds and 254 sub-basins in an area of 514,000 square kilometers (Yenpoeng 2017). Approximately 10% of the world's freshwater fish species are found throughout Thailand, containing at least 858 freshwater fish species in 81 families. Fish resources in those natural waters play a crucial role in supporting social, economic and protein food sources for the 66 million people living in Thailand (Ingthamjitr and Sricharoendham 2016). In 2020, it was estimated that roughly 14.5% of Thai households earned their living from inland capture fisheries, with an estimated quantity of inland capture production being 116,850 tons, having a value of $223,920 US Dollars (DOF 2021). Increased changes in river ecosystems and demands for harvesting its aquatic life have resulted in the deterioration of aquatic habitat in several rivers and sub-basins, including valuable spawning and larval feeding grounds. These affected to changes in the number of aquatic animals are now causing the production of aquatic animals to decrease (Ghosh et al. 2020).

Nakhon Si Thammarat Province is one of the greatest benefits of bio-diverse provinces in Thailand. It is mostly a mountainous area, providing a water source of many canals, where a variety of wetland plants can be found along the banks of these canals. The endemic plant in the southern region is Sago palm (*Metroxylon* sp.), playing an important role as the main plant in the wetlands and growing in harmony with other plant species. Villagers in this area call this forest area "the Sago Palm Wetlands". Sago's palm has many benefits; its root system can absorb underground water, providing a water source for agriculture. It also helps prevent soil erosion by impeding strong water flows during the rainy season. The greatest benefit to the aquatic ecosystem is a point of origin food chain, in terms of a habitat and breeding ground for aquatic animals, the second consumer of the food chain and a source of protein for humans. Ecosystems in this Sago Palm Wetlands play a quantitative role, with local villagers freely catching fish for consumption or selling them as household income. Twenty-five species of economic freshwater fish are being caught from this area, including catfish, three-spot gourami, red-cheek barb, lipped barb and swamp eel (Chankaew and Chunta 2020). The most preferred freshwater fish hunted in the area is swamp eel, with fishermen earning an average income of more than 500 baht, per household, per day. Having no optimal controls towards fishing and developmental activities, including the creation of drainage canals and irrigation systems within the Sago Palm Wetlands, has caused negative changes in this aquatic ecosystem, which will ultimately pose an impact on food security (Chupan et al. 2020).

Aquatic resources are one of the natural renewable resources that a country must harness in its efforts for social and economic development. If the aquatic resources, particularly fish, are over-exploited beyond its natural carrying capacity, then the result is resource degradation and inability to fully utilize the ecosystem, according to the production potential of that water source. Ecosystems in the Sago Palm Wetlands can deteriorate if its resources are not properly managed. Presently, the Sago Palm Wetlands are being heavily exploited by the surrounding communities (Chankaew and Chunta 2020). This will only result in a detrimental effect on the ecosystem, resulting in the further decline of aquatic animals, once abundant in the past. There is concern that damage to natural water sources will have negative impacts on the species diversity of freshwater fish and populations of fish species. Several local fishermen have commented that nowadays, they catch fewer fish, and they are harder to catch. Few studies, however, are available about actual fish diversity distributed in the wetlands. This information is key to determining further improvements that will benefit the native freshwater fish and the community. It is the intention of this study to monitor and assess the status of aquatic animal resources in the Sago Palm Wetlands in terms of diversity, abundance, structural elements, and the spread of the fish community. Once completed, these data will be valuable as supporting data to analyze local situations, solve problem conditions, and consider appropriate approaches for managing aquatic animal resources to support sustainable use of aquatic animal resources.

MATERIALS AND METHODS

Study area

The study area lies in Sago Palm Wetlands, located in the middle of Nakhon Si Thammarat Province, Southern region of Thailand. The wetlands covered an area of 5 districts: Thung Song, Ronphiboon, Phrom Khiri, Tha Sala and Muang districts. This study area spans the confluence of the Pak Phanang River, Trang River, and Tapi Rivers. Sampling surveys were conducted from four sampling zones: Upper Pak Phanang River Basin (UP), the Lower Pak Phanang River Basin (SP), the Trang River Basin (TR), and the Tapi River Basin (TP). Five sampling stations were selected at random at each of zone. Sampling stations were noted by a global positioning system (GPS) device (Figure 1). Sampling sites (approximately 200m long) were selected to include multiple representative habitats: mid-channel, shoreline, run and riffle, small channels, and wetlands connected to ditches, shallow ponds, and pools.

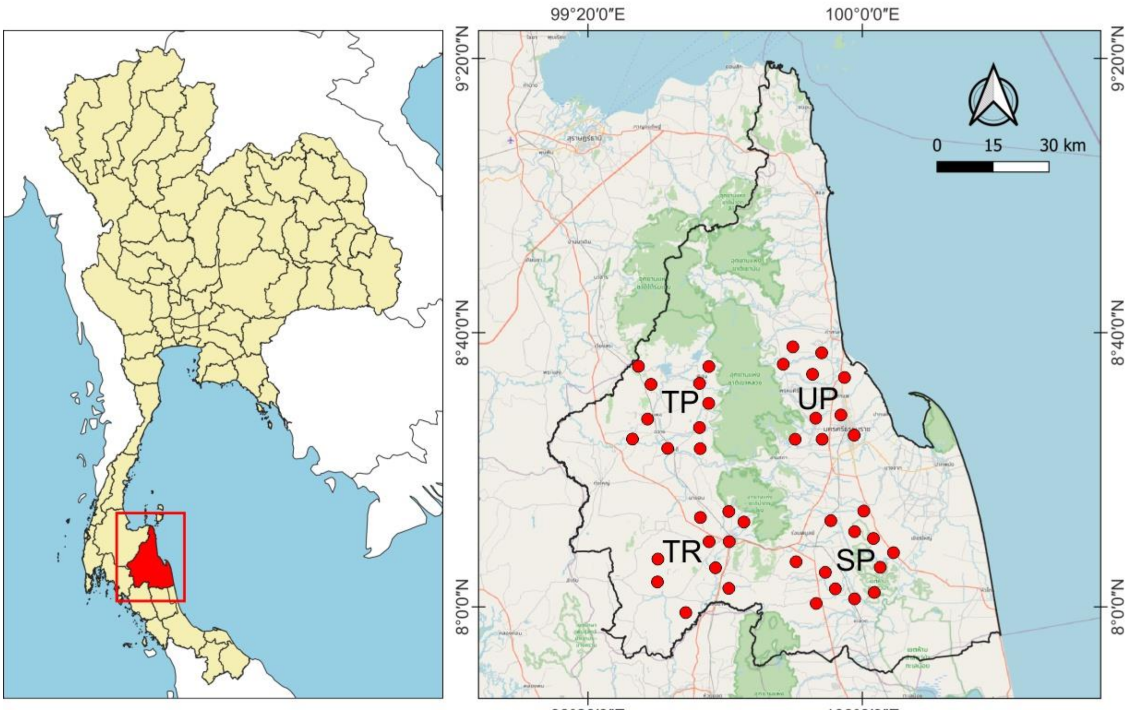


Figure 1. Map of sampling zone and sites in the study area in Sago Palm Wetlands of Nakhon Si Thammarat Province, Thailand; UP: Upper Pak Phanang River Basin, SP: Lower Pak Phanang River Basin, TR: Trang River Basin and TP: Tapi River Basin. Source**:** Adapted from Thailand's Commission for Hydrology (2020)

Fish sampling

Fish sampling was carried out at five fixed stations in each zone from March 2020 to November 2020. Fish specimens were collected two times, covering the hot-dry season (March to June) and the rainy season (September to November). A seine net with 1 cm mesh size, 1.5 m in length, and 1 m width, was used to collect fish at each site throughout the sampling period. Simple fish collection techniques were employed, using two people, one on each end of the seine net, walking in parallel through the water, with the seine net, forming a U-shape behind them. In each sampling station, the trawling was repeated three times.

Fish species identification and measurements

Collected specimens were immediately identified as fish species, then measured for weight and length. The weighing was done by a scale with a resolution of 0.01 g. The total length was measured with a measuring stick, having a resolution of 0.1 cm. Fish unidentified in the field (approximately 3-5 fish of each species) were immediately preserved in 10% formalin solution for later identification in the laboratory (FishBase 2018). Differences in morphology, for identification purposes, required the use of the classification system of FishBase, the Fish Species Analysis Manual of the Department of Fisheries (2012) and Nagao Natural Environment Foundation (2021). In addition, the threatened status of local fish species was examined using Thailand's threatened species database, according to Vidthayanon (2017).

Analysis of diversity fish community

The species diversity index was calculated using the Shannon-Wiener diversity index, with the formula as follows:

$$H' = -\sum_{i=1}^{s} p_i \ln p_i$$

Where:

H' : the value of Shannon-Wiener diversity index

S : the number of species

p_i : the proportion of total sample belonging to the i the species

ln p_i : the natural logarithm of pi

The evenness index, values indicating distribution of fish species of each site and season, was calculated using the Pielou's index, with the formula, as follows:

$$E = \frac{H'}{H_{max}}$$

Where:

E : the value of evenness index (range 0-1). The closer to 1, the higher in evenness.

H′ : the Shannon-Wiener's index

S : the total number of species

H'_{max}: the maximum species diversity

The similarity among plots was calculated, using the Sorensen qualitative index, with the formula, as follows:

$$SI = 100 \times \left[1 - \frac{\Sigma[n_i - n_s]}{\Sigma[n_i + n_s]}\right]$$

Where:

SI : the coefficient value of similarity index

n_i : the number of the i species

n_s : the number of the s species

Index of relative importance, is value indicating the relative importance of fish made by contribution of the catch in each sampling effort, calculated using the formula, as follow:

IRI = (%N + %W) %F

Where:

IRI : Index of relative importance

%N : percentage composition by number

%W : percentage composition by weight

%F : percentage frequency of occurrence

The species richness index was calculated, using the Margalef index, with the formula, as follows:

R = (S-1)/ln (n)

Where:

R : Richness index

n : the total number of fish found

S : the total number of fish species found

Water quality measurement

Dissolved oxygen, temperature, pH, and water turbidity were measured at each station immediately upon arrival (08.00-09.30 am in each site) using a multi-parameter water quality instrument. Surface water samples were collected 30 cm below the surface water using polythene bottles. Samples were transported to the laboratory for further analysis of total hardness, total alkalinity, orthophosphate, total dissolved solids, total ammonia nitrite and nitrate, using standard procedures (APHA 2017). The correlation between fish species and water quality was described by Canonical Correspondence Analysis (CCA) with the multivariate statistical package (MVSP) for windows.

Data analysis

The data test by the One-Sample Kolmogorov-Smirnov Test (p: 0.05) was used for evaluating normality (Table 2). The difference in ecological of the fish community was analyzed by two-way ANOVA (p: 0.05) with a dry and rainy season and sampling area as the main factors (Tukey's HSD honestly significant difference test, p: 0.05). Diversity and abundance of fish communities were grouped by the Bray-Curtis similarity index, found at each sampled site and season. Analysis results were presented by a dendrogram with hierarchical clustering. Statistical analysis was performed with the aid of the computer software SPSS version 20.

RESULTS AND DISCUSSION

Species composition

During the study period, 62 fish species, from a total of 3634 individuals, were collected in the twenty sampling stations. They were categorized into 10 orders, comprising 24 families. Of these, the most species-rich family was Cyprinidae, contributing 23 species (37.10%), followed by Osphronemidae (6 species, 9.68%), Clariidae (5 species, 8.10%), Channidae (4 species, 6.45%), and Siluridae (3 species, 4.84%). Families of Cobitidae and Nandidae were recorded with 2 species (3.23%) each. The rest of the families were identified with a total of 1 species (1.61%) for each family (Figure 2).

The fish community found in the Sago Palm Wetlands is of a higher diversity when compared to other wetlands in the same province (Kiriratnikom et al. 2014; Seehirunwong et al. 2020); including other wetlands in the same country (Rayan et al. 2020) and other wetlands in the same Peninsular (Sule et al. 2018). Differences in fish diversity may be due to the different characteristics and resource utilization in the area. The sago palms in the study area are naturally growing; therefore, they require little maintenance, no fertilizer and no pesticides suggesting that the ecosystem of Sago Palm Wetlands is less disturbed. This corresponds to the water quality values measured from the Sago Palm Wetlands, whereby all water quality parameters were within criteria suitable for fish survival throughout the year. The water level is a major threat to fish diversity, which changes depending on the season (Winn et al. 2021). Generally, fish diversity in water sources is not the same in rainy and dry seasons (Sefi and Abera 2021). Many studies indicated that the diversity of fish species in the rainy season is higher than in the dry season, for instance, Corpuz et al. (2016) and Setyaningrum et al. (2020). On the other hand, some studies report the diversity of fish species in the dry season to be higher than in the rainy season (Melaku et al. 2017; Sefi and Abera 2021).

In contrast, the results of this study indicated that no significant differences (p: 0.864) occur in the diversity pattern between the dry season and the rainy season. This hypothesis corresponds to the reports of Fernandes et al. (2013), who found the difference between the two seasons were not significant for fish assemblage structure in their sampled area. We assumed that the Sago Palm Wetlands are characterized by medium water bodies, approximately 153.12 hectares (Jaipluem et al. 2018), with water flowing year-round and having small water level changes when compared between the dry season and rainy season. Flowing water contributes to the circulation of nutrients, driving the Sago Palm Wetlands to be fertile and resulting in a greater diversity of organisms in the end. In addition, the root of Sago plants provided a potential habitat and breeding grounds for aquatic animals, creating fertility zone water sources. This conclusion is supported by Weeraphong et al. (2016), who surveyed the diversity of microalgae in the Sago Palm Wetland and found that the microalgae diversity index was relatively high, ranging from 3.67-1.57. According to more functionally diverse microalgae or phytoplankton communities lead to higher and more stable ecosystem productivity (Vallina et al. 2017).

The most abundant species belonging to the family Cyprinidae is not surprising because it is the largest freshwater fish group in the world and Southeast Asia (Imoto et al. 2013; Seanghong et al. 2021), consistent with several studies (Melaku et al. 2017; Soo et al. 2021; Noonin et al. 2022). One introduced species, *Oreochromis niloticus* in family Cichlidae, and one endangered species, *Rasbora urophthalmoides* in family Cyprinidae, were also recorded in this study. Contamination of exotic fish in the Sago Palm Wetlands probably came from human charity releases to help better people's fortunes. Fish escape from local aquaculture farms is unlikely since tilapia culture was not found nearby the study area. Moreover, managing fishing activities in this area is important to sustain *R. urophthalmoides* populations and conserve fishery resources.

Species abundance and distribution of water

The number of individual fish species is an important aspect of this study because it can provide information on the condition of the present fish species in the study location, indicating clearly and closely the actual situation. The number of individual fish species and caught weight are presented in Table 1 to give a more detailed picture of fish in the Sago Palm Wetlands. The total individual fish species in Sago Palm Wetlands (%N) was 81.17%.

Among the highest percentages composition by number were *Trichopsis vittatus* (16.48%N), following *Aplocheilus panchax* (8.94%N), *Dermogenys siamensis* (7.71%N), and *Rasbora daniconius* (6.88%N) respectively, with other species below 5%N. Composition by weight (%W) was 80.08%. The highest percentage composition by weight (%W) of fish species was *Channa striata* (14.58%W), *Monopterus albus* (10.01%W), *Notopterus notopterus* (9.51%W), *Anabas testudineus* (6.02%W) respectively, with other species below 5%W.

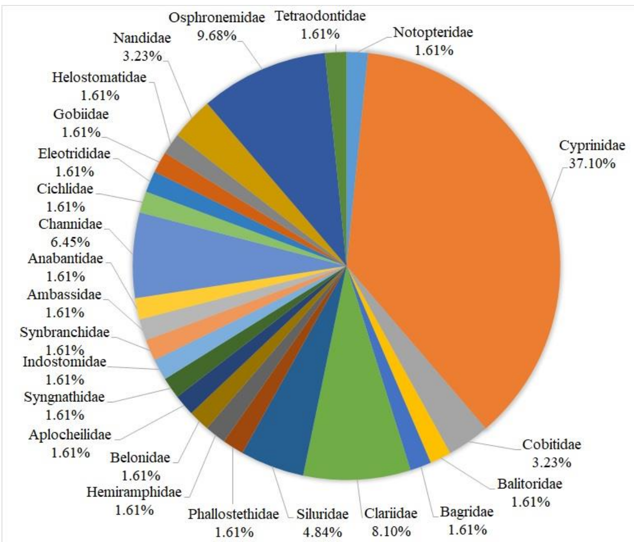


Figure 2. Percent composition of fish families caught by seine net at twenty stations in the Sago Palm Wetlands, during March 2020 to November 2020

Table 1. The fish species, fish numbers, weight, frequency and index of relative importance in the Sago Palm Wetland, Thailand

Order / Family	Species	Fish numbers (%N)	Weight (%W)	Frequency (%F)	IRI	IRI (%)
Osteoglossiformes / Notopteridae	*Notopterus notopterus*	1.46	9.51	32.50	356.53	4.52
Cypriniformes / Cyprinidae	*Parachela maculicauda*	4.21	1.08	50.00	264.50	3.35
	Devario regina	1.57	1.00	20.00	51.40	0.65
	Danio kerri	0.61	0.20	12.50	10.13	0.13
	Esomus metallicus	4.90	1.21	67.50	412.43	5.22
	Rasbora borapetensis	1.38	0.12	17.50	26.25	0.33
	Rasbora caudimaculata	0.91	0.01	7.50	6.90	0.09
	Rasbora daniconius	6.88	3.73	40.00	424.40	5.38
	Rasbora myersi	0.77	0.74	20.00	30.20	0.38
	Rasbora paviei	4.18	2.45	30.00	198.90	2.52
	Rasbora sumatrana	1.24	0.28	12.50	19.00	0.24
	Rasbora trilineata	2.61	0.44	15.00	45.75	0.58
	Rasbora urophthalmoides	0.74	0.01	10.00	7.50	0.10
	Trigonostigma espei	0.17	0.00	5.00	0.85	0.01
	Cyclocheilichthys apogon	0.83	1.50	32.50	75.73	0.96
	Hampala macrolepidota	0.11	0.12	7.50	1.73	0.02
	Oreichthys parvus	0.61	0.01	20.00	12.40	0.16
	Barbodes lateristriga	0.58	0.82	15.00	21.00	0.27
	Barbodes binotatus	0.85	1.54	22.50	53.78	0.68
	Puntigrus partipentazona	0.72	0.15	17.50	15.23	0.19
	Systomus orphoides	1.35	2.08	25.00	85.75	1.09
	Labiobarbus leptocheilus	0.63	1.06	35.00	59.15	0.75
	Osteochilus vittatus	4.05	9.34	57.50	769.93	9.76
	Osteochilus waandersii	0.11	0.26	7.50	2.78	0.04
Cobitidae	*Lepidocephalichthys hasselti*	1.02	1.02	17.50	35.70	0.45
	Pangio myersi	0.03	0.00	2.50	0.08	0.00
Balitoridae	*Nemacheilus selangoricus*	3.66	1.48	40.00	205.60	2.61
Siluriformes / Bagridae	*Hemibagrus capitulum*	0.19	1.83	12.50	2.25	0.32
Clariidae	*Clarias batrachus*	0.11	0.25	10.00	3.60	0.05
	Clarias leiacanthus	0.17	0.22	5.00	1.95	0.02
	Clarias macrocephalus	0.14	1.02	12.50	14.50	0.18
	Clarias meladerma	0.11	0.05	7.50	1.20	0.02
	Clarias nieuhofii	0.03	0.04	2.50	0.18	0.00
Siluridae	*Kryptopterus vitreolus*	0.36	0.08	10.00	4.40	0.06
	Ompok siluroides	0.41	0.84	22.50	28.13	0.36
	Silurichthys schneideri	0.08	0.07	7.50	1.13	0.01
Atheriniformes/ Phallostethidae	*Phenacostethus smithi*	0.28	0.00	5.00	1.40	0.02
Beloniformes / Hemiramphidae	*Dermogenys siamensis*	7.71	0.86	45.00	385.65	4.89
Belonidae	*Xenentodon canciloides*	0.44	0.37	25.00	20.25	0.26
Cyprinodontiformes / Aplocheilidae	*Aplocheilus panchax*	8.94	1.99	45.00	491.85	6.24
Gasterosteiformes / Syngnathidae	*Doryichthys martensii*	0.36	0.04	15.00	6.00	0.08
Indostomidae	*Indostomus crocodilus*	0.03	0.00	2.50	0.08	0.00
Synbranchiformes / Synbranchidae	*Monopterus albus*	0.94	10.01	37.50	410.63	5.20
Perciformes / Ambassidae	*Parambassis siamensis*	2.04	0.76	37.50	105.00	1.33
Anabantidae	*Anabas testudineus*	1.49	6.02	37.50	281.63	3.57
Channidae	*Channa limbata*	0.36	0.58	22.50	21.15	0.27
	Channa lucius	0.08	0.35	5.00	2.15	0.03
	Channa micropeltes	0.08	0.06	5.00	0.70	0.01
	Channa striata	0.96	14.58	20.00	310.80	3.94
Cichlidae	*Oreochromis niloticus*	0.25	0.40	5.00	3.25	0.04
Eleotrididae	*Oxyeleotris marmorata*	0.28	2.04	22.50	52.20	0.66
Gobiidae	*Brachygobius xanthomelas*	0.06	0.00	2.50	0.15	0.00
Helostomatidae	*Helostoma temminckii*	0.11	0.02	7.50	0.98	0.01
Nandidae	*Nandus nebulosus*	1.38	1.92	35.00	115.50	1.46
	Pristolepis fasciata	1.05	2.97	25.00	100.50	1.27
Osphronemidae	*Betta imbellis*	3.30	0.46	35.00	131.60	1.67
	Trichopodus microlepis	0.39	0.24	5.00	3.15	0.04
	Trichopodus pectoralis	0.41	2.21	15.00	39.30	0.50
	Trichopodus trichopterus	3.58	4.95	32.50	277.23	3.51
	Trichopsis pumila	1.21	0.07	17.50	22.40	0.28
	Trichopsis vittatus	16.48	4.45	87.50	1831.38	23.22
Tetraodontiformes / Tetraodontidae	*Dichotomyctere nigroviridis*	0.08	0.08	5.00	0.80	0.01

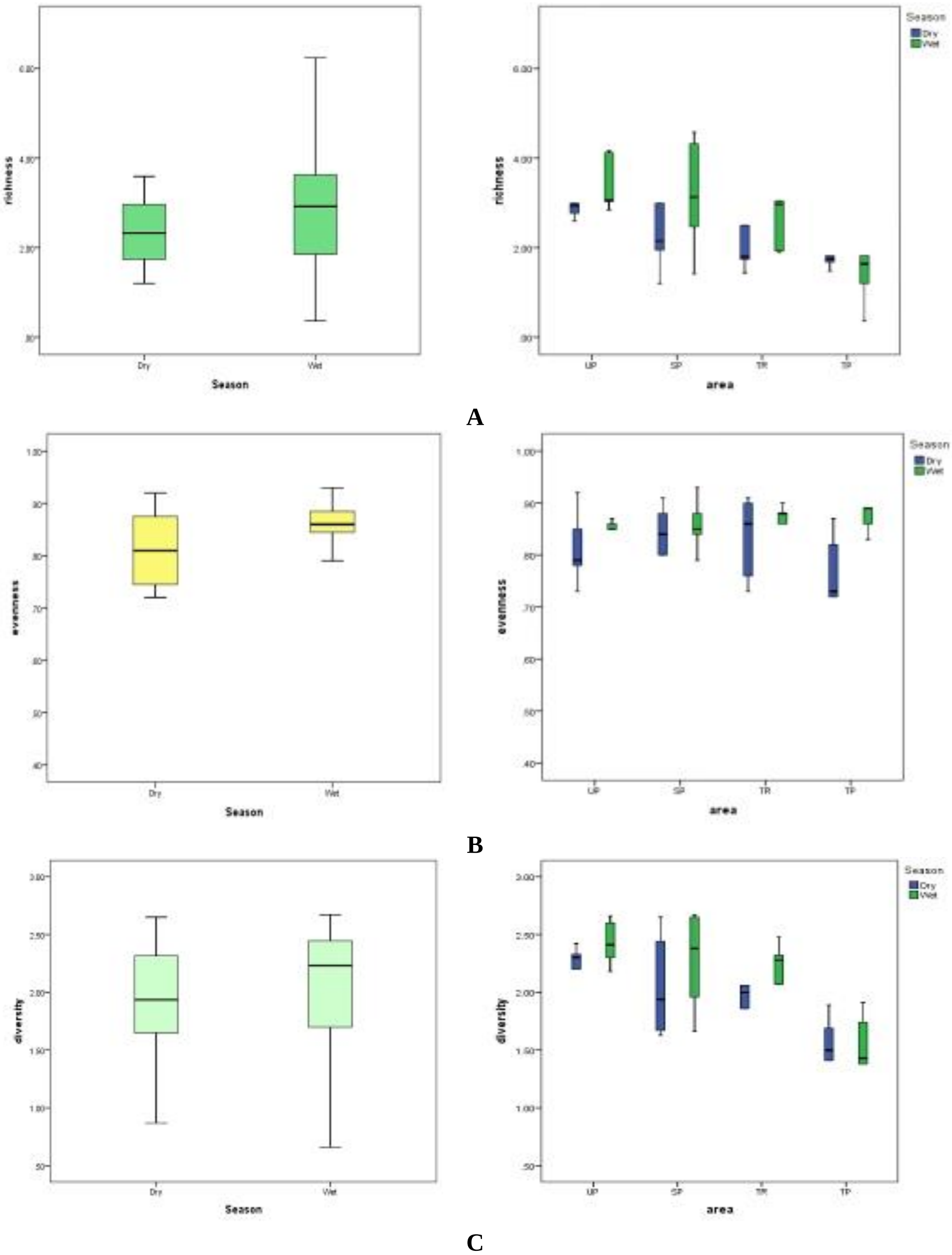


Figure 3. Spatial and seasonal comparative of richness index, evenness index, and diversity index in the Sago Palm Wetland, Nakhon Si Thammarat Province, Indonesia. A. Richness index; B. Evenness index; C. Diversity index

In terms of frequency occurrence and index of relative importance, results indicated that *T. vittatus* was most observed and dominant in the Sago Palm Wetlands, followed by the three species, *Parachela maculicauda*, *E. metallicus* and *O. vittatus*, having a frequency occurrence over 50%. The percentage of the index of relative importance (IRI) for all sampling zone of Sago Palm Wetlands was 81.41%. Among the highest percentages of IRI were *T. vittatus* (23.23%), *O. vittatus* (9.76%), *Aplocheilus panchax* (6.24%), *R. daniconius* (5.38%), *Esomus metallicus* (5.22%), and *Monopterus albus* (5.20%) and other species below 5%IRI. *T. vittatus*, found to be the most assembled in the Sago Palm Wetland, shows that this fish is effective for living in this area. Presenting of this fish was always associated with dense aquatic vegetation near the banks. It is also an unexploited fish due to poor consumer preference and a low commercial value fish (Shefat and Hossain 2020), it is therefore rarely caught and exploited by humans.

Diversity fish community

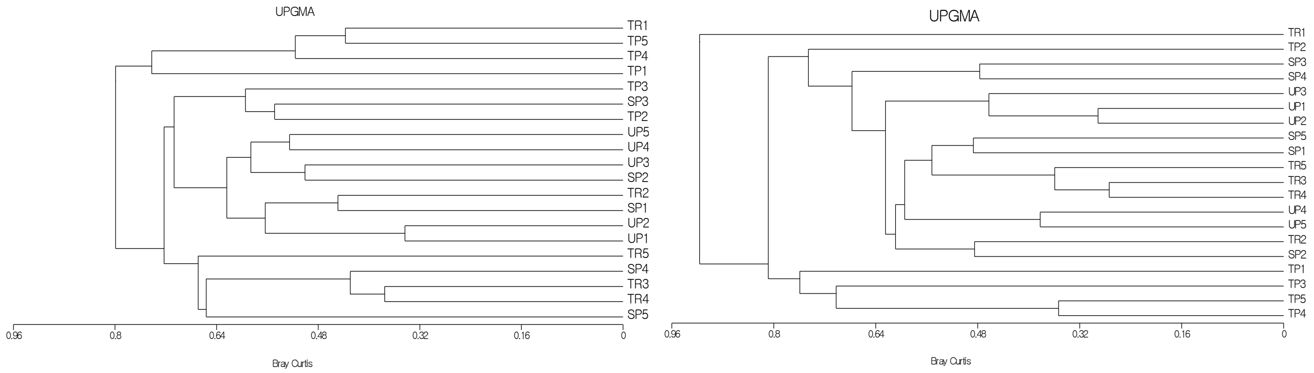
The relationship between the number of fish species in the study site analyzed by the diversity index provides an overview of the relative abundance of fish species and their communities. Diversity index values in each form and in each season, as well as among sample sites, are presented in Table 2. While a comparison in value of the richness index, diversity index, and evenness index based on seasonal and spatial variation is shown in Figure 3.

The Shannon-Wiener Diversity Index Value (H') shows that the Sago Palm Wetlands has a low-medium species diversity index value, with the value ranging from 0.66 to 2.67 (1<H'>3). This is because the number of fish species found in 4 sampled zones was, indeed, not much, ranging from 5 species to 35 species, while the total number of individuals recorded was also not very large, between 14 to 201 individuals. Evenness Index Value (E) showed that the study site generally had an Evenness Index, with evenness index values ranging ranged from 0.64 to 0.95 (evenness conditions that are between the numbers 0 and 1). The Richness Index Value (R) showed that the Sago Palm Wetlands have a medium and low Fish Richness Index. There are 3 sample zones in the medium category, namely, zone UP, SP and TR, with the average Richness Index value being at numbers 2.92 to 3.21 (2.5<R>4). The sample zone in the low category, namely zone TP, contained an average Richness Index value of 1.74 (R1<2.5). These three-diversity index values indicated that the diversity of fish in the Sago Palm Wetlands could be classified as intermediate-low, uniform with a medium species number in the area.

When the distribution of fish species in each sampling zone was compared, it was found that the species number and fish number of zones UP and SP were significantly higher than the zones TR and TP (p: 0.018 and p: 0.006, respectively). It seems that zones UP and SP were more abundant than zones TR and TP. Zone TP produced the lowest abundance. This condition is in accordance with a diversity index value of UP, SP and TR zone, which were significantly higher than TP zone (p: 0.000). However, there was no difference in the value of the evenness index and richness index among the four sample zones. Additionally, the study found no differences in the value of the richness index and diversity index between the dry and rainy seasons (p: 0.564 and p: 0.281, respectively). The evenness index value of the rainy season, however, was significantly higher than the dry season (p: 0.037). Therefore, this study assumes that UP and SP have the potential to be used as a primary source of productivity for most of the fish populations found in the Sago Palm Wetlands, better than other sample zones. This is due to characteristics of water resources in the UP and SP area, being a river bend, much wider than other areas, having many small streams flow down in this area, lending a greater opportunity for fish species.

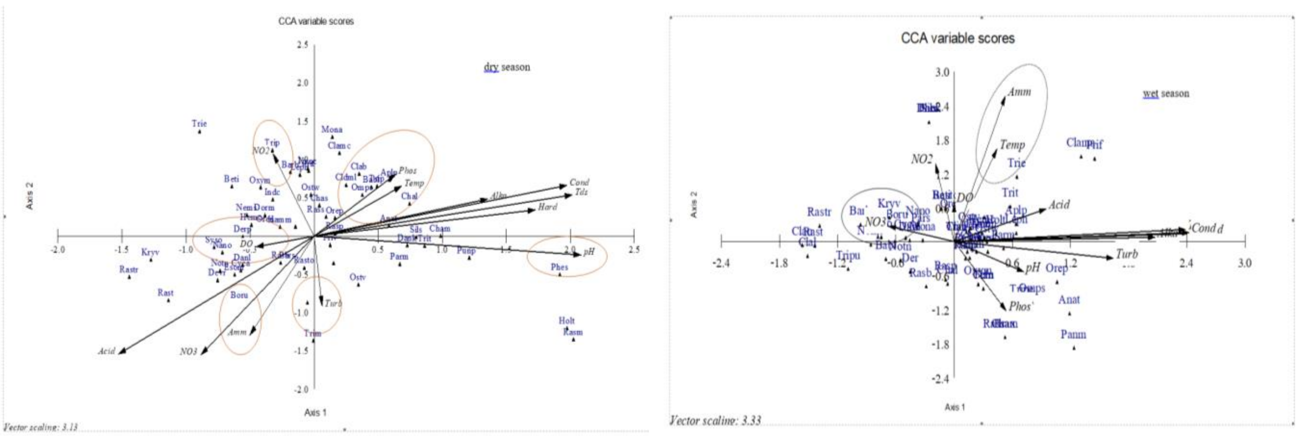
Table 2. Fish species composition percentages by number (%N), richness index, diversity index, evenness index of the Sago Palm wetland and K-S (NORMAL) test

Station / season	Number of species	Number of Fish (N)	Richness index	Shannon-Wiener diversity index	Evenness index
UP1 (D;W)	20; 16	200; 196	3.59; 2.84	2.33; 2.41	0.78; 0.87
UP2 (D;W)	14; 23	148; 197	2.60; 4.16	2.42; 2.66	0.92; 0.85
UP3 (D;W)	16; 21	152; 128	2.99; 4.12	2.20; 2.60	0.79; 0.86
UP4 (D;W)	15; 15	117; 101	2.94; 3.03	2.30; 2.30	0.85; 0.85
UP5 (D;W)	14; 16	110; 135	2.77; 3.06	1.93; 2.18	0.73; 0.79
SP1 (D;W)	28; 24	201; 151	5.09; 4.58	2.65; 2.67	0.80; 0.84
SP2 (D;W)	16; 23	152; 163	2.99; 4.32	2.44; 2.65	0.88; 0.85
SP3 (D;W)	8; 12	36; 86	1.95; 2.47	1.67; 1.96	0.80; 0.79
SP4 (D;W)	6; 6	64; 35	1.20; 1.41	1.63; 1.66	0.91; 0.93
SP5 (D;W)	10;15	66; 88	2.15; 3.13	1.94; 2.38	0.84; 0.88
TR1 (D;W)	5; 6	16; 14	1.44; 1.89	1.23; 1.57	0.76; 0.88
TR2 (D;W)	35; 32	142; 144	6.86; 6.24	2.58; 2.48	0.73; 0.72
TR3 (D;W)	8; 14	56; 72	1.74; 3.04	1.86; 2.28	0.90; 0.86
TR4 (D;W)	9; 10	85; 106	1.80; 1.93	2.00; 2.07	0.91; 0.90
TR5 (D;W)	11; 14	55; 80	2.50; 2.97	2.06; 2.32	0.86; 0.88
TP1 (D;W)	7; 7	58; 39	1.48; 1.64	1.69; 1.74	0.87; 0.89
TP2 (D;W)	10; 10	23; 23	2.87; 2.87	1.89; 1.91	0.82; 0.83
TP3 (D;W)	8; 5	47; 9	1.82; 1.82	1.50; 1.43	0.72; 0.89
TP4 (D;W)	7; 5	31; 28	1.75; 1.20	1.41; 1.38	0.73; 0.86
TP5 (D;W)	8; 2	64; 16	1.68; 0.36	0.87; 0.66	0.42; 0.95
		One-Sample Kolmogorov-Smirnov Test			
Kolmogorov-Smirnov Z	1.016	0.724	1.163	1.077	0.728
p-value	0.253	0.671	0.134	0.197	0.665



A B

Figure 4. Bray-Curtis similarity cluster within sampling stations in four samples of the Sago Palm Wetland zones, within two sampling periods: A. Dry season; B. Rainy season (March 2020 and November 2020)



A B

Figure 5. Canonical correspondence analysis (CCA) of the fish species and selected physicochemical parameters at four sampling zone in Sago Palm Wetland: A. Dry season; B. Rainy season

Similarity dendrogram showed the formation of two and three clusters with quite a high similarity structure of 75% similarity index between the fish community compositions in hot-dry and rainy seasons, respectively. One group was represented by 4 sampled sites of Tapi and Trang River Basin (TR1 TP5 TP4 and TP1) and the other group consisted of 16 sampling sites, which are all the remaining sampled sites in the hot-dry season. Where the sampled site with the least similarity was UP2 and UP1 (Figure 4A). There was also quite a high similarity structure with a 75% similarity index in the rainy season. However, it can be divided into 3 different zone groups. The first and the third group consists of 1 (TR1) and 4 (TP1, TP3, TP5 and TP4) sampled site, respectively. The second group consists of 15 sampling sites, which are all the remaining sampled sites, where the sampled site with the least similarity was TR3 and TR4 (Figure 4B).

Relationships of fish diversity and physico-chemical parameters

According to Canonical Correspondence Analysis (CCA), variables were able to explain the relationship of species distribution to environmental factors. Important environmental variables responsible for the fish community changes were identified with CCA are represented in Figure 5. From this study, we observed that the most important water quality variables affecting fish distribution were temperature, dissolved oxygen, pH, turbidity, orthophosphate, nitrite, nitrate and ammonia. These physicochemical variables also have been identified as important factors in fish assemblages in other tropical rivers (Dubey et al. 2012; Zulkafli et al. 2018; Rosette et al. 2020; Costa et al. 2021). Other physicochemical parameters of this lake did not show any significant statistical differences in determining fish distribution. However, all physiochemical parameters of water were within the standard levels suitable for freshwater fish survival and growth.

During the hot-dry season we observed that *T. vittatus* (Triv) were found in some areas where nitrite content (NO_2^-) was considered high. Several fish, including *Clarias macrocephalus* (Clam), *Ompok siluroides* (Omps), *Betta imbellis* (Beti), *Aplocheilus panchax* (Aplp) and *Channa striata* (Clas), were found in places where the orthophosphate levels (Phos) were high. Whereas, *C. limbata* (Chal) was commonly found in some places where the temperature was regarded as being high. *Phenacostethus smithi* was found in some areas where pH (pH) was regarded as being lowest. *Trichopodus microlepis* (Trim) was found in some areas where turbidity (turbi) was lowest. *Doryichthys martensii* (Dorm), *Systomus orphoides* (Syso), *Nandus nebulosus* (Nann) and *Danio kerri* (Dank) were found in some areas where dissolved oxygen (DO) was lowest. In the rainy season, *Barbodes binotatus* (Barb), *Kryptopterus vitreolus* (Kryv) and *Rasbora urophthalmoides* (Roru) were found in some places where nitrate content (NO_3^-) was considered highest. *Trigonostigma espei* (Trie) was found in some areas where temperature levels (temp) and ammonia content (amm) were regarded as being high. Therefore, this study clearly confirms that the quality of the water was related to the season and sampling time. Our assertion corresponds to the report of Li et al. (2012) and Abrial et al. (2014).

In conclusion, Sago Palm Wetlands is a typical wetland ecosystem of indigenous species of freshwater fish. A total of sixty-two species of fish belonging to 10 orders and 24 families were identified. Common species found, include *T. vittatus*, *P. maculicauda*, *E. metallicus* and *O. vittatus*. The diversity, evenness, and richness index values ranged from 0.66 to 2.67, 0.64 to 0.95 and 2.92 to 3.21, respectively, which indicated moderate low diversity and uniform with a medium species number in the area. The cluster analysis of the Bray-Curtis similarity index divides the fish community into 2 clusters in hot-dry season and 3 clusters in rainy season, having a similarity percentage ranging between 42% and 95%, respectively. There was also one introduced species and one endangered fish species documented during sampling. The findings suggest that Sago Palm Wetlands is still inhabited by numerous fish species and should be conserved to ensure its aquatic animal richness for the future.

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