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Original Article

Spatio-temporal variation in fish diversity and assemblage patterns in the Lower Tapee River, Southern Thailand

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Abstract

The Tapee River is the longest river in Southern Thailand. Data from five years (2015-2019) of fish monitoring at five sampling stations along the lower reach were used to examine variation in fish diversity and fish assemblages through diversity analyses and multivariate techniques. Sampling was conducted every three months, representing the dry and wet seasons as well as two transition periods. One hundred and eight (108) fish species were recorded, including freshwater, brackish-water and marine species. The samples were dominated, both in terms of species richness and abundance, by fishes from family Cyprinidae. No significant differences in four diversity indices (species richness, Shannon–Weaver H', abundance, and evenness J') were found by either spatial or temporal approaches. The W-statistic from abundance-biomass curve suggests heavy disturbance of most fish communities. During the rainy season and dry-to-rainy transition, fish assemblages in the lowermost station near the river mouth clearly differed from assemblages in the upper stations. Results can be used as a baseline for resource management to maintain the integrity of the Tapee River.

Keywords: Tapee River, fishes, Shannon–Weaver H'-index, W-statistic, assemblages

1. Introduction

Due to the numerous anthropogenic stressors to aquatic habitats, it is becoming more important to monitor their biodiversity so that we can understand the impacts of the stressors and find suitable mitigation measures (Antognazza *et al.*, 2021). Measuring trends of fish diversity and examining changes in fish assemblages over a long period are considered the simplest ways to detect the integrity of aquatic habitats (Gavioli, Milardi, Castaldelli, Anna-Fano, & Soininen, 2019). Among aquatic habitats, lowland river reaches are regarded as the most productive ecosystems and are rich with fish diversity, both from the riverine fishes as well as brackish and marine visitors, due to the proximity of the estuary/delta. Intact lowland rivers provide rich habitats for many fish species and play an important role in their life cycle. It is generally accepted that, at the watershed scale, the diversity of the fish community tends to increase from headwaters to the lower reaches of the river (Fu, Wu, Chen, Wu, & Lei, 2003, Kindong *et al.*, 2020). Freshwater fish inhabiting the lowest reach are basically stenohaline and semi-migratory species that move according to salinity and flood strength (Kindong *et al.*, 2020; Welcomme, Winemiller, & Cowx, 2006).

The Tapee River is located in Southern Thailand, which lies within the Indo-Burmese ecoregion. Large and well-known rivers such as the Mekong and the Chaopraya are also located within this region (Figure 1). The Tapee is the longest river in the south, running 230 km from the headwater at Khao Luang Mountain, Nakhon Si Thammarat Province, and entering the Gulf of Thailand at Ban Don Bay, Suratthani Province. In the lower portion, the river has an average depth of 6.5 m and an average width of 80 m (Sakset, Seehirunwong, & Preecha, 2021; Senarat, Kettratad, Poolprasert, Yenchum, & Jiraungkoorskul 2015). Fishes and

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Figure 1. Location and map of the Lower Tapee River; numbered circles indicate fish sampling stations.

other aquatic animals are among the important goods produced from this river. The fisheries are artisanal, and common fishing gears include gillnets, longlines, cast-nets and traps. Most of the catch (90%) is used for household consumption, and the remaining 10%, which are mostly high-value species such as gobies and giant freshwater prawn, are sold to the markets (Sangkhapaitoon, Tongwattanakorn, Kaewsritong, Seehirunwong, & Bintoheem, 2011). There are approximately 250 freshwater fish species found among the river basins of Southern Thailand, and the number found in the Tapee River has fluctuated between 80 and 100 species. Of these, the cyprinid fishes are the most abundant taxa, though their number varies by location and season (Lerssulthichawal, & Kwanjai, 2016; Sangkhapaitoon *et al.*, 2011).

Water quality in the Tapee River is ranked as clean-moderate. However, risks have been reported due to the wastes from residential communities, agriculture and industries, which inevitably impact the river's natural integrity, including its fish communities (Sakset *et al.*, 2021; Senarat *et al.*, 2015). Impacts of these anthropogenic stressors often result in population declines or gradual disappearance of some fish species, particularly those with specific requirements (Kapusta *et al.*, 2019). Moreover, Tubtimtong (2017) reported that conversion of floodplain to agricultural area is among the most crucial threats to fishes in the Tapee River. We recognize the importance of fishes to the livelihood of people residing along the Tapee River and the numerous current external threats. However, there are no published long-term data on fish communities of the Tapee River, which would allow a more insightful understanding of their condition and integrity. This study, therefore, aims to investigate the status of fishes in the lower Tapee River.

We focused on the lower reach, as the number of fish species generally increases from upstream to downstream. The lower reach of the river is typically a vast area incorporating the seasonal floodplain and also under marine influence, and consequently supports a complex fish composition comprising freshwater and brackish water species as well as marine visitors (Jutagate *et al.*, 2010, 2011). It is hypothesized that there are spatio-temporal fluctuations in species composition and diversity indices of fishes, as well as their assemblage patterns in the lower portion of the Tapee River. This understanding is crucial for monitoring changes of fish communities and for resource management, in compliance with UN-SDG 15 to ensure the conservation, restoration and sustainable use of inland freshwater ecosystems.

2. Materials and Methods

2.1 Sampling stations and protocols

The study area covered the lower reach of the Tapee River, located in Suratthani Province. The length of this reach is 113.6 km upstream from the river mouth. Four (4) stations in Suratthani Province were selected along the longitudinal gradient of the river (Figure 1) with different characteristics as detailed in Table 1. Data were obtained from the catch monitoring program of the Inland Fisheries Research and Development Division, Department of Fisheries, between 2015 and 2019. Sampling was carried out four times a year to represent four seasons: transition period 1 (TP1, January-March), dry (D, April-June), transition period 2 (TP2, July-September), and rainy (R, October-December), in which the sampling was conducted in January, April, July and October, respectively. Gillnets with a series of mesh sizes (20, 30, 40, 55, 70, and 90 mm) were used for sampling. Nets were deployed for 12 hours (6 p.m. - 6 a.m.) during a sampling day, with three series of gillnets used at each station. Fish specimens were identified to species *in situ* according to the field guide (Vidthayanon, Karnasuta, & Nabhitabhata, 1997). Individual specimens were then weighed (to nearest 0.1 g) and measured for length (0.1 cm TL). Catches, both in terms of number and weight, were standardized and the standardized units presented herein are "per 100 m^2 per night" (European Committee for Standardization, 2005).

Table 1. Description and location of sampling stations in the Tapee River

Station	Description	UTM
1	Uppermost station, surrounded mostly by forest, at Ban Hua Tha, Phrasaeng District.	47p 528698E 950251N
2	The river runs through a community area at Ban Mo Ked, Bannasan District. There is the evidence of bank erosion in this area and the bottom is characterized by scattered pools.	47p 530874E 961095N
3	The river runs through an agricultural area at Ban Udomrat, Khiansa District. Vast floodplain area during TP1 season.	47p 523641E 972206N
4	Lowermost station, which is affected by the intrusion of saline water during the tidal period, especially during the dry season. The station is surrounded by agricultural activities at Ban Klong Noi, Muang District.	47p 528523E 1009675N

2.2 Data analysis

Trends and fluctuations in diversity indices throughout the study period were examined. Each sampling event was represented by abundance, species richness and two diversity indices (Shannon–Weaver H' and evenness J'), calculated by equations 1 and 2.

$$H' = -\sum_{i=1}^{S} p_i ln(p_i) \quad (1)$$

$$J' = {H'}/{H'_{max}} \quad \text{and} \quad H'_{max} = lnS \quad (2)$$

where p_i is the proportion of individuals belonging to the ith species; S is species richness (i.e., number of species present); and H'_{max} is the maximum possible value of H' (i.e., if every species was equally likely) (Hill, 1973). Moreover, Abundance Biomass Comparison (ABC) curves and the W-statistic were used to examine abundance and biomass as well as stress in the fish assemblage of each station. The W-statistic is estimated by

$$W = \sum_{i=1}^{S} \frac{(B_i - A_i)}{[50(S-1)]} \quad (3)$$

where S is species richness, A_i is the abundance of species rank i, and B_i is the biomass of species rank i (note that A_i and B_i need not be the same species, as species are ranked separately for each measurement) (Warwick, 1986). Statistical differences among seasons and stations were tested by the Kruskal Wallis test at $\alpha = 0.05$. Dunn's post-hoc test was applied if a significant difference was found. The permutation MANOVA PERMANOVA (Anderson, 2001) was used to test whether season or station affected the difference in fish family composition. Hierarchical agglomerative clustering analysis with the Bray–Curtis similarity index was applied to log-transformed abundance data to characterize the patterns for Q-mode (i.e., sampling event clustering). Differences among clusters were tested statistically with analysis of similarities (ANOSIM). All statistical analysis was done by R (R Development Core Team, 2020), with the package vegan (Oksanen *et al.*, 2020).

3. Results and Discussion

Over the entire five-year study period, 15,861 fish were collected in our samples, representing 108 species from 38 families (Supplement 1, available at https://www.fisheries.go.th/local/index.php/main/view_activities/1261/121243). Cyprinidae was the most diverse family (34 species), followed by Siluridae and Bagridae (six species each) and Mastacembelidae (five species). In terms of abundance, *Labiobarbus siamensis* was most common (3,005 individuals), followed by *Cyclocheilichthys armatus* (1,048), *Rasbora tornieri* (1,021), *Puntioplites proctozystron* (838) and *Oxygaster anomalure* (779), all from family Cyprinidae. Six (6) fish species were found in every station, namely *Pristolepis fasciata*, *Oxyeleotris marmorata*, and the cyprinids *Barbonymus altus*, *B. gonionotus*, *B. schwanenfeldii* and *P. proctozystron*. Twenty-two (22) species of brackish-water fishes were collected, mostly from station 4. The large proportions of cyprinid fishes in terms of number of species, abundance and weight can be explained by the fact that this family represents more than 40% of fish diversity in Southeast Asia (Beamish, Sa-ardrit, & Tongnunui, 2006). The two catfish groups also showed high diversity in our samples; over 100 species in Family Siluridae have been recorded in South and Southeast Asia (Ditcharoen *et al.*, 2020), and Bagridae is the largest family of Thai catfishes, with 28 species found in Thailand (Yeesin *et al.*, 2021). It is noteworthy that the 108 species found in this study is the highest number recorded for the Tapee River; in previous studies, fewer than 100 species were recorded. (Lerssulthichawal & Kwanjai, 2016; Sangkhapaitoon *et al.*, 2011). The high species richness also implies that this river is among the fish diversity hotpots in the Indo-Burmese region. None of the sampled fishes are listed as endangered species by the IUCN. Three exotic species were found in this study; the tilapia *O. niloticus* and the hybrid *Clarias* catfish were likely escapees from aquaculture farms, while suckermouth catfish *Hypostomus plecostomus* were likely released by aquarium keepers (Vidthayanon *et al.*, 1997).

Indices of fish abundance and diversity in each season are shown in Table 2. Although fluctuations in all indices were found for both temporal (season) and spatial (station) approaches, the Kruskal-Wallis test showed no significant differences (P-value > 0.05; Table 2). Species richness and H' fluctuated in similar patterns. Both indices were high in transition period 1 (TP1) in all stations, except the uppermost station 1, where the highest values were observed in the rainy season. At stations 1 – 3, fish abundance fluctuated in similar trends, with lowest abundance in the dry season and highest abundance in the rainy season, which could be explained by the migration of brackish-water and marine fishes (Jutagate *et al.*, 2010, 2011). At station 4, in contrast, the lowest abundance was observed in the rainy

Table 2. Spatio-temporal changes in fish abundance and diversity indices for the Lower Tapee River between 2015 and 2019.

(a) Species richness (P-values of the Kruskal Wallis test for station = 0.16 and season = 0.36)

Station	TP1 season	Dry season	TP2 season	Rainy season
Station 1	17 ± 6	20 ± 5	19 ± 1	21 ± 8
Station 2	25 ± 4	21 ± 4	21 ± 5	20 ± 8
Station 3	24 ± 4	21 ± 5	20 ± 4	22 ± 8
Station 4	22 ± 3	19 ± 3	23 ± 3	20 ± 6

(b) H-index (P-values of the Kruskal Wallis test for station = 0.38 and season = 0.96)

Station	TP1 season	Dry season	TP2 season	Rainy season
Station 1	2.41 ± 0.26	2.78 ± 0.08	2.58 ± 0.41	2.80 ± 0.19
Station 2	3.00 ± 0.18	2.84 ± 0.17	2.68 ± 0.25	2.67 ± 0.38
Station 3	2.93 ± 0.24	2.73 ± 0.39	2.69 ± 0.15	2.68 ± 0.31
Station 4	2.68 ± 0.20	2.66 ± 0.18	2.91 ± 0.10	2.84 ± 0.31

(c) Abundance (P-values of the Kruskal Wallis test for station = 0.45 and season = 0.31)

Station	TP1 season	Dry season	TP2 season	Rainy season
Station 1	34.6±25.8	28.0±10.5	39.2±26.4	40.4±36.6
Station 2	37.4±14.0	29.6±9.2	42.0±31.8	44.2±49.7
Station 3	41.2±12.9	34.6±7.8	36.6±17.9	39.2±28.7
Station 4	42.0±24.0	31.2±6.1	38.0±10.8	25.2±8.0

(d) J-index (P-values of the Kruskal Wallis test for station = 0.38 and season = 0.12)

Station	TP1 season	Dry season	TP2 season	Rainy season
Station 1	0.32 ± 0.05	0.31 ± 0.03	0.29 ± 0.04	0.31 ± 0.03
Station 2	0.29 ± 0.02	0.31 ±0.02	0.30 ± 0.03	0.32 ± 0.06
Station 3	0.29 ± 0.01	0.30 ± 0.02	0.30 ± 0.02	0.30 ± 0.06
Station 4	0.29 ± 0.02	0.31 ± 0.02	0.30 ± 0.01	0.32 ± 0.03

(e) W-statistic (P-values of the Kruskal Wallis test for station = 0.10 and season = 0.84)

Station	TP1 season	Dry season	TP2 season	Rainy season
Station 1	0.00 ± 0.02	0.01 ± 0.01	0.00 ± 0.01	0.00 ± 0.01
Station 2	0.00 ± 0.02	-0.01 ± 0.01	0.00 ± 0.01	0.00 ± 0.02
Station 3	-0.01 ± 0.01	-0.01 ± 0.01	-0.01 ± 0.01	-0.01 ± 0.02
Station 4	-0.01 ± 0.01	-0.01 ± 0.01	-0.01 ± 0.01	0.00 ± 0.01

season. Although fluctuations in species richness, H’ and abundance were observed, the fishes were generally evenly distributed in each station throughout the study period, i.e., less fluctuation in J-index, and the J-index values ranged between 0.21 and 0.41. Seasonal trends in diversity indices were clearly observed in this study, though non-significant, and can be explained by the flood pulse concept (Junk, Bayley, & Sparks, 1989). The high species richness, H’, and abundance in stations 2 to 4 during the transition period from rainy to dry season (TP2) should be largely driven by flood pulse, similar to other tropical river systems elsewhere. Baumgartner, de Oliveira, Agostinho, and Gomes (2018) used a 16-year dataset to show a significant positive correlation between water level and diversity indices. An increase in water level in the lower river portion, as in this study, commonly causes expansion of flood area along the river banks. These flooded areas then become temporary shelter as well as spawning and nursery grounds for freshwater fishes, including many brackish-water species, for which movement to the flooded areas is synchronized with the rising water level and the flood peak (Agostinho, Pelicice, Marques, Soares, & de Almeida 2011; Poulsen *et al.*, 2004). Marine visitors such as mullets *Planiliza* sp. were found during the rainy season and TP1, when seawater intruded into the river; a similar phenomenon has been observed in the nearby Pakpanang River (Jutagate *et al.*, 2010, 2011). The lowest species richness and H’-index in uppermost station 1 occurred during TP1, implying that the fish from this station migrated downstream to the floodplain for spawning and foraging activities, as has been reported for many freshwater fishes in tropical rivers, for example, the Mekong (Poulsen *et al.*, 2004) and Pakpanang (Jutagate *et al.*, 2010, 2011).

The W-statistic value of the ABC plot (Figure 2) can be either negative (-) or positive (+), indicating heavily- or less-disturbed assemblages, respectively, and a value close to zero (0) indicates a moderately disturbed assemblage (Yamane, Field, & Leslie, 2005). Our W-statistic results, therefore, revealed low to moderate disturbance of fish communities in station 1, but heavy disturbance in the other stations. Positive W-statistic values in station 1 may reflect the fact that the station is surrounded mostly by forest. Meanwhile, the disturbed assemblages (with negative W-values) found in stations 2 to 4 imply the effects of fishing activities as well as the polluted conditions of the sampling stations (Dias & Tejerina-Garro, 2010; Yamane *et al.*, 2005), as these stations are either near communities or agricultural lands.

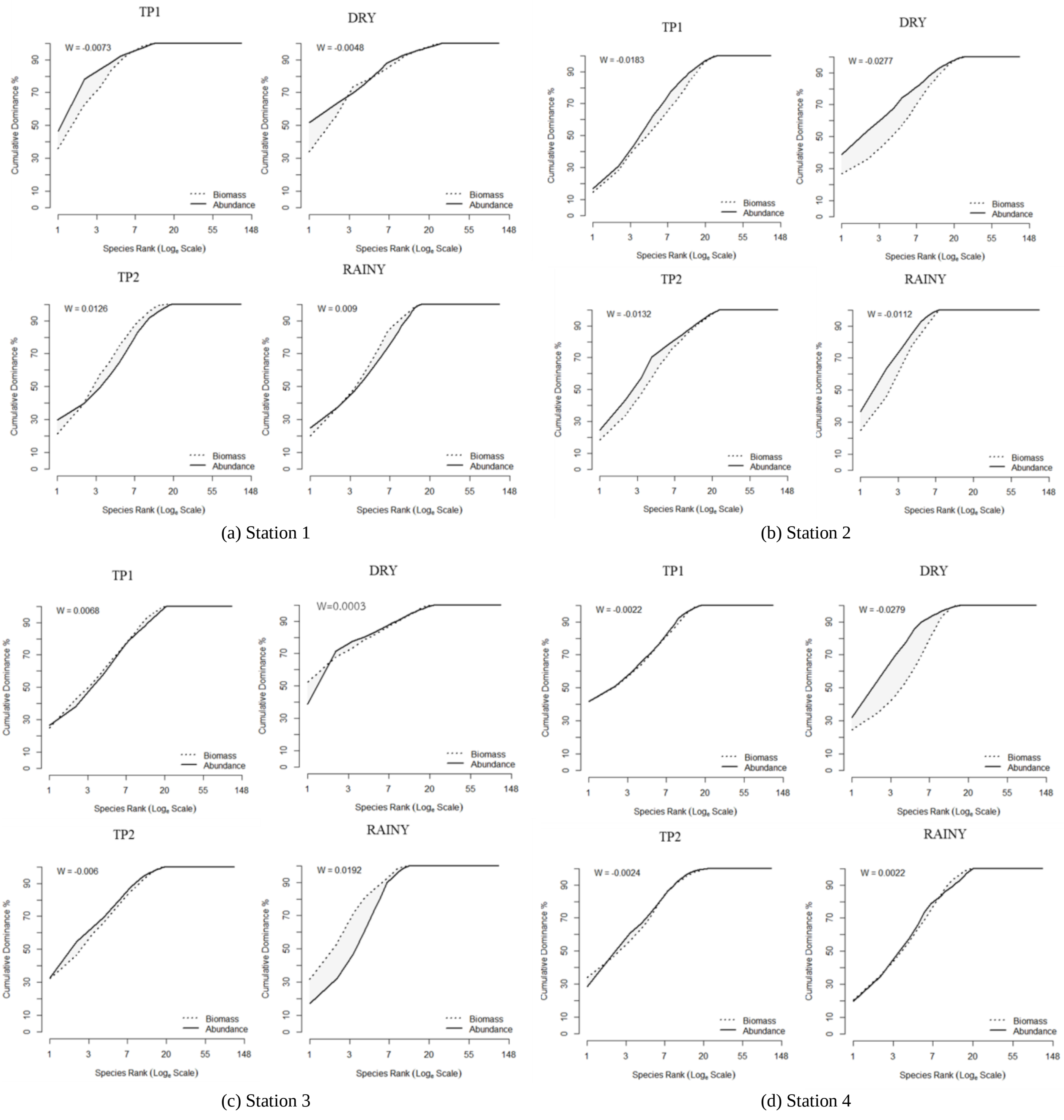

Figure 2. Example of the ABC plot of the fish sampling events in the Tapee River in 2019

Due to the very large number of species in our dataset, assemblage patterns were conducted at the family level (Figure 3). Fishes from Cyprinidae were, by far, dominant in every sampling event. The PERMANOVA test showed that family composition varied both in terms of season (P-value = 0.08) and station (P-value < 0.01). Furthermore, the ANOSIM result indicated that each cluster was significantly different (P-value = 0.001). Assemblages from the different sampling events were divided into five groups. Group Q1 contained a single sampling event at station 4 in 2019 during the rainy season. Group Q2 also comprised assemblage patterns from station 4, but during the dry season of 2015 and 2018 and during TP2 (dry-to-rainy transition) in 2016 and 2017. Group Q3 consisted of the samples from station 3 during the dry season (2017) and TP2 (2018 and 2019) and station 2 in TP2 (2018). Seven samples comprised Group Q4, which included all four stations: station 1 (TP2 in 2018), station 2 (rainy in 2019), station 3 (TP2 in 2019), and station 4 (Rainy in 2016 and 2017; TP1 in 2018 and 2019). The remaining samples were placed in Group Q5. Groups Q1 and Q2 were lower in proportion of cyprinid fishes compared to other clusters, while the proportion of other families in these two groups were quite similar. One difference between these two clusters was the presence of brackish-water visitors in Family Mugilidae, Toxotidae and Engraulidae in Q1, in contrast to the marine visitors in Family Ariidae and Pristigasteridae found in Q2. Group Q3 was dominated by both cyprinid and bagriid species, while cyprinids and silurids were dominant in group Q4. Except for the predominance of cyprinid fishes, the proportions of other families in group Q5 were quite similar.

Fish assemblages were patterned along the longitudinal gradient and can be explained as a reflection of habitat diversity, which increases along the upstream to downstream axis (Araújo, Pinto, & Teixeira, 2009). The assemblage patterns also varied according to season. During the rainy season there was a higher volume of freshwater and consequently an elevated abundance of freshwater fishes, whereas the higher number of secondary freshwater fishes (i.e., salt-tolerant and brackish-water fishes) during the dry season could be a result of increasing movement and feeding activity of these fishes (Saccol-Pereir & Fialho, 2010). The family of secondary freshwater fishes found in this study comprised Soleidae and Gobiidae. Meanwhile, the families of marine migrants included Arridae, Leiognathidae and Mugilidae. The lowermost station 4 was clearly separated from the others and was represented by group Q1 during rainy season and by group Q2 during the dry season and during the transition period from dry to rainy season (TP2), which can be explained by the intrusion of marine water during these seasons. This finding is similar to the results obtained in the Pakpanang River, another important river in Southern Thailand (Jutagate *et al.*, 2010, 2011). The lower proportion of cyprinids in these two groups could be explained by the fact that most fishes in this family are either unable to tolerate marine waters or unable to cross small marine barriers (Winfield & Nelson, 2012). Marine and brackish-water visitors found in station 4 likely entered the river for feeding activity (Jutagate *et al.*, 2010). Although highest in proportion in group Q3, Bagridae catfishes were also found in substantial numbers in other groups, and their presence could be due to the difference in salinity tolerance of fishes in this family (Vidthayanon *et al.*, 1997; Yeesin *et al.*, 2021).

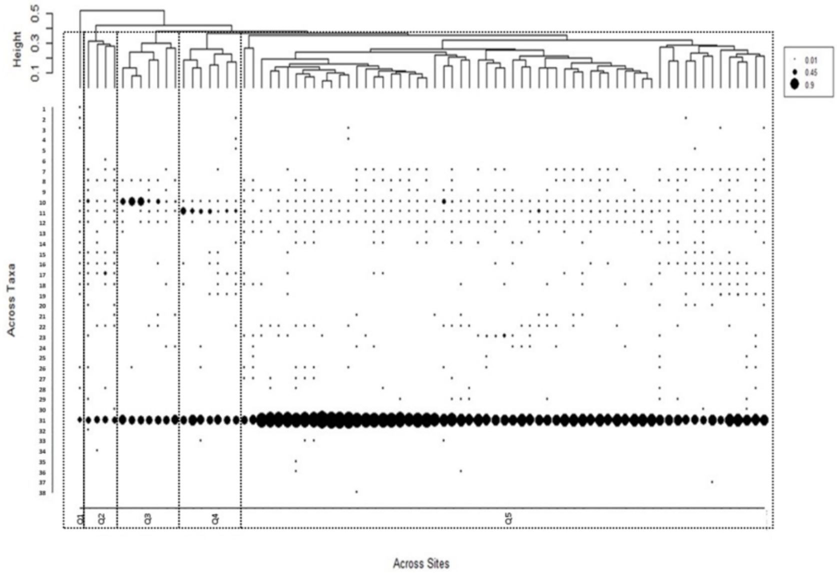

Figure 3. Dendrogram of fish assemblages in the lower reach of Tapee River from four sampling stations in four seasons, 2015-2019

Note: (i) Number of the Families in the vertical axis as 1 = Mugilidar; 2 = Toxotidae; 3 =Engraulidae; 4 = Clupeidae; 5 = Pristigasteridae; 6 = Gerreidae; 7 = Eleotridae; 8 = Notopteridae; 9 = Ariidae; 10 = Bagridae; 11 = Siluridae; 12 = Sisoridae; 13 = Belonidae; 14 = Pristolepididae; 15 = Syngnathidae; 16 = Tetraodontidae; 17 = Gobiidae; 18 = Mastacembelidae; 19 = Leiognathidae; 20 = Scatophagidae; 21 = Soleidae; 22 = Ambassidae; 23 = Anabantidae; 24 = Schibeidae; 25 = Clariidae; 26 = Cobitidae; 27 = Osphronemidae; 28 = Loricariidae; 29 = Pangasiidae; 30 = Terapontidae; 31 = Cyprinidae; 32 = Cichlidae; 33 = Channidae; 34 = Datnioididae; 35 = Helostomatidae; 36 = Heteropneustidae; 37 =Synbranchidae; 38 = Gyrinocheilidae;

(ii) Sampling events (Station-Season-Year: 20xx) in the cluster in the horizontal axis as Q1 (St4-R-19); Q2 (St4-R-15, St4-TP2-17, St4-TP2-16, St4-R-18); Q3 (St3-TP2-17, St3-D-17, St3-R-18, St2-R-17, St3-R-17, St1-R-19, St3-R-19); Q4 (St1-TP2-18, St2-R-19, St3-TP2-19, St4-R-16, St4-TP1-19, St4-R-17, St4-TP1-18); Q4 (The remaining sampling events)

4. Conclusions

A higher number of fish species (108) was recorded than in any previous study of the Tapee River. Diversity indices were at moderate levels and varied by sampling site and season, though the differences were not statistically significant. Brackish-water and marine species were found in the lowermost station near the mouth, where the river enters the Gulf of Thailand. This factor clearly caused fish assemblage patterns at this station, in particular during TP1 and the rainy season, to differ from the stations upstream. Our results aid in the understanding of the fish assemblages present in the Tapee River, and can be used to support future monitoring and conservation management of this important resource.

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