

## Variations of phytoplankton in the lower part of the Tapee River Basin (TRB), Surat Thani province, Thailand

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**ABSTRACT:** This paper illustrates phytoplankton variations in the lower part of the Tapee River Basin (TRB), Surat Thani Province, Thailand, including species composition, relative abundance, diversity indices, patterns of distribution, and assessing aquatic ecosystem or water conditions, as well as considering potential measures for aquatic resources management effectively. Spatial and temporal sampling was designed to collect data at five study stations one time a season (two days a time) during three different seasons: dry, early rainy and heavy rainy seasons from December 2017 to August 2018. In each study station, the samples were collected by water sampler at three sides of rivers with three different water depths. Univariate and multivariate analyses were used to evaluate the data. The findings showed that a total of 63 phytoplankton genera belonging to eight Divisions were found. Three dominant genera were *Actinastrum* spp., *Spirulina* sp. and *Aulacoseira* sp. An average abundance was 1,917.8 units/L which has tended to increase from upstream to downstream. Average values of Pielou's evenness index ( $J'$ ) and Shannon-Wiener's diversity index ( $H'$ ) were 0.58 and 2.41, respectively, which could be classified as the medium diversity and distribution levels. Overall of Applied Algal Research Laboratory Phytoplankton Score (AARL - PP score) was 6.6, showing that water quality condition was generally meso-eutrophic and moderately-polluted. Based on the findings of this study, it was recommended that the properly aquatic resources management to maintain effectively ecosystems and fish stocks should be conducted. For example, monitoring program to regularly assess water quality should be done throughout the year, and restocking native herbivorous fish species would be the best conducted at station 5, and during the dry season.

**Keywords:** variation; aquatic ecosystems; diversity indices; phytoplankton; Tapee River Basin (TRB)

### Introduction

Phytoplankton is an important organism in water sources, in terms of primary producer of food chain and bio-indicator of water quality (Tian et al., 2021). The productivity of the aquatic animals in the waters will be low or high, depending on the plenty of primary productivity (Harris, 2012; Parmar, 2016). The enhanced productivity will increase consumer abundance and attracts higher trophic level organisms (Munk, 2003; Molinero et al., 2008). Sakset (2011) reported that fish production values in the reservoirs are directly related with the gross primary production values. Inspects of bio-indicator, phytoplankton has been long used as an effective water bio-indicator (Palmer, 1969; APHA, AWWA, and WPCP, 1989; Bellinger and Sigee, 2015) that is sensitive to environmental changes. Rivers with weak water currents always contain phytoplankton in division Chlorophyta and Euglenophyta (Whitton, 1975). *Melosira* and *Cyclotella* are usually found in clean water, whereas *Nitzschia*, *Microcystis* and *Aphanizomenon* are usually found in polluted waters (APHA, AWWA, and WPCP, 1989). Rott et al. (2008) classified water bodies in Thailand

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as eutrophic level with Shannon diversity and evenness indices of phytoplankton. Moreover, Peerapornpisal et al. (2007) developed a method to assess the water quality in water bodies by using dominant phytoplankton scoring system, i.e., Applied Algal Research Laboratory Phytoplankton Score (AARL - PP score) which is a simple evaluation method without chemical requirement. The results were more than 90% consistent with physical and chemical parameters.

The Tapee River Basin is located along the southeastern seashore of Thailand. Its area covers around 13,454.51 km<sup>2</sup> and consists of two main rivers, i.e., the Tapee and the Phum Duang Rivers. Generally, the Tapee River is the longest river in Southern Thailand and runs from its source in the Khao Luang mountains of Nakhon Si Thammarat about 230 km through the center of Surat Thani before meeting the sea in Bandon Bay (Wikipedia, 2019) with the water depths of 6.5 m and the width of 80 m on average, while the Phum Duang River is the main tributary of the Tapee River located at the west of the Tapee watershed, originated from the Phrasaeng and Sok Rivers being in the Khiri Rat Nikhom District, and it joins the estuary of the Tapee River at the west of Surat Thani in Phunphin District (Wikipedia, 2021) with the water depths of 6.9 m and the width of 100 m on average. The basin is used for various activities, such as transportation, consumption, agricultural, and fisheries, etc. (Laudee and Prommi, 2011). According to such utilizations, various problems have been occurred in the basin. The main problems are the waste water from communities or small industries, chemical contamination from agriculture areas, and flooding from shallow rivers and streams (Hydro-Informatics Institute (Public Organization), 2012). Also, Hydro-Informatics Institute (Public Organization) (2012) reported that the general water quality in the basin was standard range of surface water quality class 2 and 3. However, it becomes to class 4 and 5 during summer especially in the lower part of basin contaminated from bacteria and chemicals effecting to other organisms. Importantly, in this area, most studies focused on monitoring water quality parameters, fishes, and basin utilizations. However, there are still less of study research on small aquatic organisms, particularly phytoplankton which actually plays an important role in aquatic ecosystems as the primary producers and water quality bio-indicators. Therefore, study on phytoplankton variations in the lower part of the Tapee River Basin (TRB) will be useful as the basic information for further studies, to monitor and determine the status of the aquatic ecosystems, which will be led to finding out the suitable aquatic resources management methods.

This paper illustrates phytoplankton variations among study stations, seasons, river sides, and water depths, in terms of species composition, relative abundance, diversity indices, patterns of distribution, and assessing ecosystem or water conditions with AARL - PP score, as well as considering potential measures for aquatic resources management effectively in the lower part of the Tapee River Basin which was seriously affected by human activities.

## Materials and methods

Spatial and temporal sampling design was used to collect data at five different ecosystem stations of the lower Tapee, and the Phum Duang Rivers; (Ban Tum Sing Khon (S1), Ban Bang Hon (S2), Sapan Phum Duang (S3), Sapan Tapee (S4) , and Sapan Chulachomklao (S5)) (**Figure 1**) during three different seasons from December 2017 to August 2018, including dry season (April, T1), early rainy season (August, T2), and heavy rainy season (December, T3). In each study station, phytoplankton samples were collected by the Kemmerer water sampler at three sides of rivers (left (L), middle (M), and right (R)) with three different depths of water, i.e., the surface (0.5-1 m below surface,

S), middle (M), and bottom (0.5-1 m above the ground, B). The water depths of the Tapee and the Phum duang Rivers during dry, early rainy and heavy rainy seasons were approximately 5.5, 7.5 and 9.5 m, and 6.5, 8.5 and 10.5 m, respectively. The water samples were collected once a season, and used two days a time. The samples were filtered through a plankton net with pore size of 20 micron. Filtered samples were preserved in 95% alcohol (equal volumes of alcohol and water sample) with the addition of 1 mL saturated copper sulfate solution ( $\text{CuSO}_4$ ) to retain color (APHA, AWWA and WPCP, 1989) and were then transported to the laboratory for identifying genera and counting the number of phytoplankton units of each genus by using a Sedgwick-Rafter counting chamber under a compound microscope following the methods and classifying based on Prescott (1973); Wongrat (1988); APHA, AWWA and WPCP (1989); Kumano (2002); Peerapornpisal et al. (2007); Bellinger and Sigeo (2015).

Univariate analysis; diversity indices, i.e., Margalef's species richness index ( $d$ ), Pielou's evenness index ( $J$ ), and Shannon-Wiener's diversity index ( $H'$ ,  $\log_e$ ) including number of genera and abundance, were used to assess diversity level of phytoplankton and to understand the trends of change along with the sections of the rivers and seasons.

Multivariate analysis; clustering analysis was used to classify similarity of phytoplankton communities among study factors which this analysis aimed to find groupings of similarities of samples among different study stations and seasons, and river sides and water depths. The samples within a group are more similar to each other than samples in different groups. The resulting cluster was shown in a tree-like diagram called dendrogram. The dendrogram was constructed based on Bray-Curtis similarity matrix (square root transformation). An analysis of similarity (ANOSIM) was performed to determine significant differences among groups of similarity. The statistic  $R$ -value describes the extent of similarity between each pair in the ANOSIM, with values close to unity indicating that the two groups are entirely separated and a zero value indicating no significant difference between the groups. A similarity percentage-species contribution (SIMPER) analysis was applied to test the genus affecting group similarity. Also, ranked species abundance curve was plotted to find out the distribution patterns of phytoplankton community. These procedures used were based on Clark and Warwick (1994) with PRIMER version 6.0 (Primer-E Ltd, Plymouth, UK). In addition, AARL-PP score was also used to assess the mass of water quality conditions based on Peerapornpisal et al. (2007).

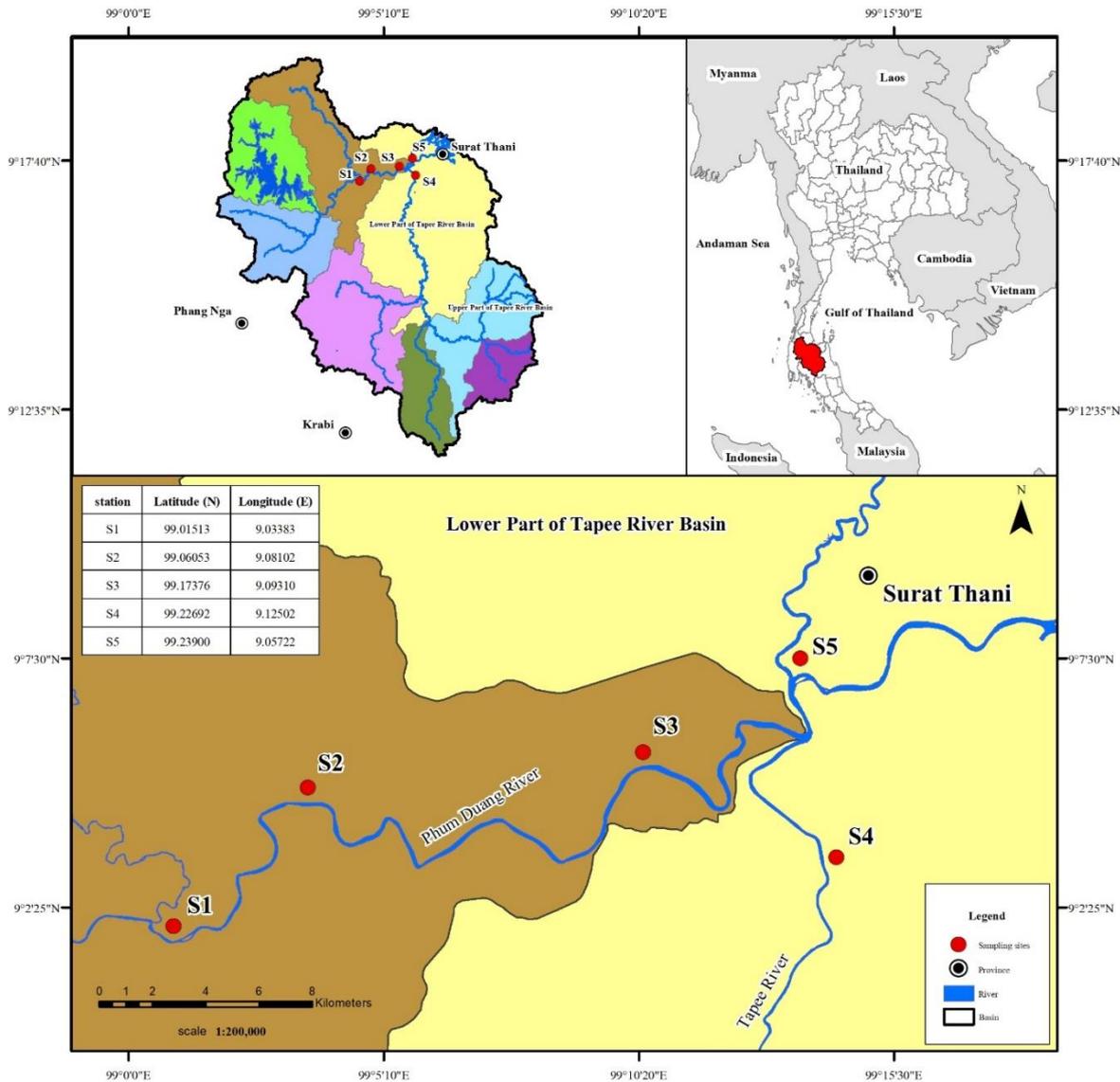


Figure 1 Study sites of phytoplankton variations in the lower part of the Tapee River Basin (TRB), Surat Thani Province (S1 = Ban Tum Sing Khon, S2 = Ban Bang Hon, S3 = Sapan Phum Duang, S4 = Sapan Tapee, and S5 = Sapan Chulachomklao)

Results and Discussion

Phytoplankton species composition

Appendix Table 1 shows a total of 63 phytoplankton genera belonging to eight Divisions: Bacillariophyta (19), Chlorophyta (23), Chrysophyta (4), Cyanophyta (7), Euglenophyta (5), Ochrophyta (2), Pyrrophyta (1), and Rhodophyta (1). The top-three dominant genera were *Actinastrum* spp., *Spirulina* sp. and *Aulacoseira* sp. The highest number of genera was found at S4 with a total amount of 55 genera, followed by S5 (53 genera), S1 (48 genera), S3 (45 genera), and S2 (44 genera), respectively. The results of this study was unlike with a previous research which was reported that 57 genera belonging to six Divisions were found in the Tapee River, and the dominant genera were *Staurastrum* sp. and *Cosmarium* sp. (Kaewsritthong et al., 2009). In aspects of seasonality, it was found that the

highest number of genera was found during dry season with a total amount of 59 genera, followed by early rainy season (54 genera) and heavy rainy season (48 genera). Appendix **Table 2** shows the highest genera at middle of the rivers (63 genera), followed by left side (61 genera) and right side of the river (59 genera). Also, the highest number of genera was found at the surface of water (60 genera) as same as at the bottom of water (60 genera), and the lowest number of genera was found at the middle of water (59 genera) which were likely similar to the others.

According to the dominant species, *Aulacoseira* sp. indicates mesotrophic status, *Spirulina* sp. indicates hyper-eutrophic status, and *Actinastrum* spp. indicates meso-eutrophic status of waters (Peerapornpisal et al., 2007). These species normally dominated at downstream of the Tapee River (S4, S5). However, in the Phum duang River where is located in the upstream (S1, S2, S3), the dominant species were *Synedra* sp., *Surirella* spp. and *Gyrosigma* sp. which indicate meso-eutrophic status of waters. The dominant species found of this study were different from those found in the similar river namely the Pak Panang River, which *Ulothrix* sp., *Peridinium* sp. and *Trachelomonas* sp. were reported as the dominant species. (Sakset et al., 2014) and indicating eutrophic status of waters (Palmer, 1977). Also, a red algae (*Audouinella* sp.) was found which prone to plankton, and have fallen from inadvertently grabbing underwater material from the Phum Duang River.

### Phytoplankton abundance

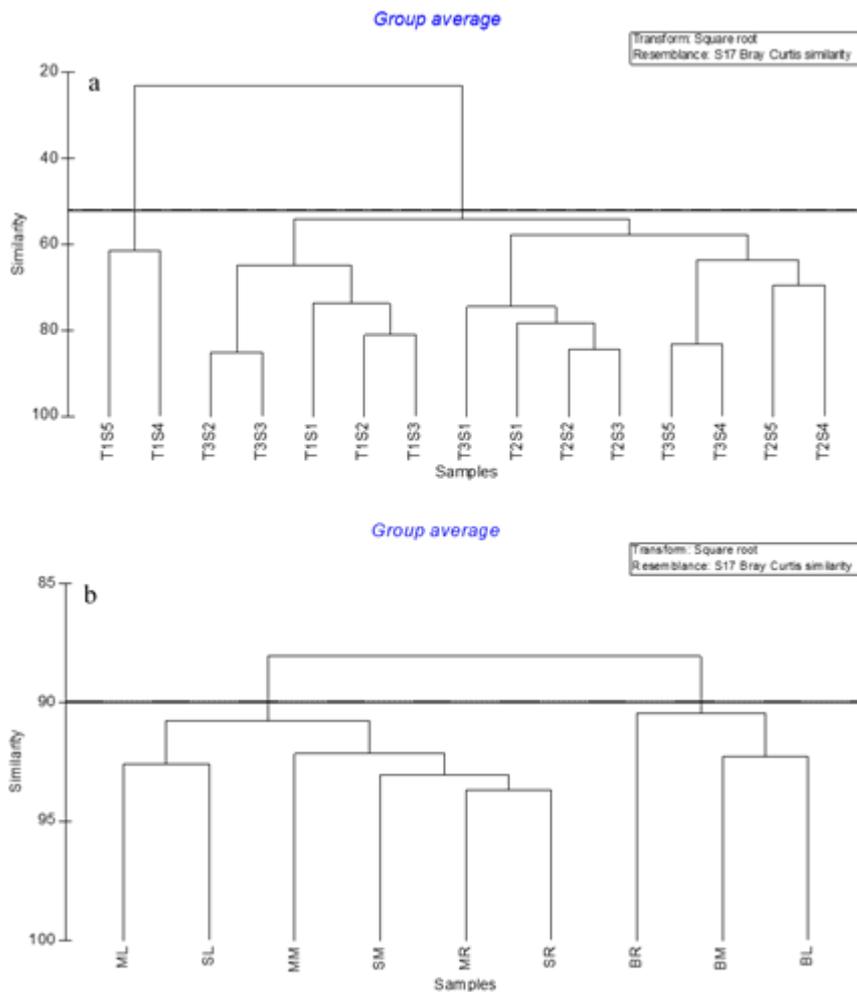
An average abundance was 1,917.8 units/L, with the top-three highest abundance were in the Chlorophyta, Bacillariophyta and Cyanophyta Divisions (799.8, 623.5 and 454.1 units/L, respectively). In view of study stations and seasons, the abundance has tended to increase from upstream (S1-S3, in the Phum duang River) to downstream (S4-S5, in the Tapee River) which the highest abundance was 6,585.3 units/L at S5, followed by 1,398.7, 674.3, 577.9 and 352.6 units/L at S4, S2, S3 and S1, respectively. Also, the highest abundance was 4,991.9 units/L during dry season (T1), followed by 461.2 and 300.2 units/L during heavy rainy (T3) and early rainy seasons (T2), respectively (Appendix **Table 1**). Considering by sides and water depths of the rivers, it was found similar abundance among study sides which the higher abundance was at the right of the rivers (2,009.9 units/L), followed by at the middle of the rivers (1,928.3 units/L) and at the left of the rivers (1,815.1 units/L). For the water depths, it was found that at the bottom of water (1,456.1 units/L) was less abundance of phytoplankton than at the middle of water (2,143.9 units/L) and surface of water (2,153.3 units/L) (Appendix **Table 2**). These changes of phytoplankton observed might be an effect of other favorable environment for the growth (Williams, 1992) such as nutrient loading, temperature and light availability (Wetzel, 2001) as well as water current and zooplankton grazing (Khan, 2003) in the water bodies. However, in the water bodies, differences in abundance at each water depth were more likely to be influenced by the amount of light than others. In addition, the results of this study found less abundance than in the Pak Phanang River study that found the average of 12,199 units/L (Sakset et al., 2014). Initially, in the lower part of TRB showed plenty of natural food from primary producers less than in the Pak Phanang River Basin.

### Clustering

The clustering analysis grouped phytoplankton similarity among stations and seasons into two groups cutting off at 59.69 % of similarity, likely by seasons (**Figure 2a**) with ANOSIM test of  $R = 1.0$  and  $P = 0.01$ ; group 1 was during dry season (T1) in the Tapee River (S4 and S5), group 2 was during dry season at S1-S3 in the Phum Duang River with rainy seasons at all stations. At species contributing of 10 % or higher, *Synedra* sp. and *Surirella* sp.

indicated similarity within group 1, while *Aulacoseira* sp. and *Pediastrum* sp. indicated similarity within group 2. Such change might be a result of rainfall and nutrient loads which is more suitable for blooming of these genera.

In terms of sides and water depths of the rivers, the clustering also separated phytoplankton similarity into two groups cutting off at 91.66 % of similarity, likely depending on water depths (Figure 2b) with ANOSIM test of  $R = 0.9$  and  $P = 0.01$ ; group 1 consisted of bottom water level at all sides of the rivers (BR, BM, and BL), group 2 contained of surface and middle water levels at all sides of the rivers (SR, SM, SL, MR, MM, and ML). *Actinastrum* spp. and *Spirulina* sp. indicated similarity within group 1, while *Actinastrum* sp. indicated similarity within group 2. *Actinastrum* sp. likely lives in mesotrophic water, while *Aulacoseira* sp., *Pediastrum* sp., *Synedra* sp. and *Surirella* sp. normally thrive in meso-trophic water, and *Spirulina* sp. generally blooms in hyper-eutrophic water (Peerapornpisal et al., 2007).



**Figure 2** Clustering of phytoplankton abundant similarity by stations and seasons (a), and sides and water depths of the rivers (b) in the lower part of the Tapee River Basin, Surat Thani Province

**Diversity indices**

The results of diversity indices namely; species richness index ( $d$ ), Pielou’s evenness index ( $J'$ ), and Shannon-Wiener’s diversity index ( $H'$ ) are shown in **Table 1** and **2**. The  $d$ ,  $J'$  and  $H'$  values were 5.39, 0.58 and 2.41 on average, respectively. The values rather varied among study stations and seasons, the value of  $d$  was in range of 4.67 (S5) -

5.76 (S1). The value of  $J'$  was 0.44 (S2) - 0.73 (S4). The value of  $H'$  was 1.68 (S2) - 2.94 (S4). In terms of seasonality, the higher value of  $d$ ,  $J'$  and  $H'$  was found during early rainy season (6.18, 0.69 and 2.77, respectively), while the lower value was found during dry season (4.84, 0.53 and 2.12, respectively). Considering by sides and water depths of the rivers, the value of  $d$ ,  $J'$  and  $H'$  were similar among sides which were in range of 5.52-5.97, 0.58-0.59, and 2.38-2.43, respectively. These indices were also similar among different water depths which were in range of 5.51-5.82, 0.57-0.62, and 2.33-2.53, respectively.

Considering the diversity levels in the water bodies, Harper and Hawksworth (1994); Purvis and Hector (2000) stated that there is no single measure or single dimension, e.g., species richness or abundance only, will always be appropriated to assess diversity levels, but that one should consider the species richness relating to the numbers of individuals at a station which has even distribution or stability. Moreover, Begon et al. (1990) also stated that the  $J'$  value ranges between 0.0 and 1.0, with 1.0 representing a situation in which all species are equally abundant, and the  $H'$  value is generally between 1.5 and 3.5, where a higher value indicates higher diversity, as well as the  $H'$  value can be implied to assess the ecosystem or environmental conditions. Wilhm and Dorris (1968) proposed a relationship between the  $H'$  value and pollution status of water that the  $H'$  value  $> 3$  is clean water. The value 1 - 3 is moderately polluted water, and the value  $< 1$  is heavily polluted water. Moreover, Tudorancea et al. (1979) advised that the  $H'$  value 1 - 3 is medium suitable for aquatic living, and the value  $> 3$  is highly suitable. Thus, the status of phytoplankton community in the study area was generally moderate diversity and distribution. The mass of water was moderately-polluted, and still suitable for aquatic organism growth and survival. Obviously, the species richness index at the bottom of this study were higher than others that because of number of individuals for each species found at that level was more equable than others.

**Table 1** Diversity indices by study stations and seasons in the lower part of the Tapee River Basin, Surat Thani

Province			
Factors <sup>1/</sup>	$d$	$J'$	$H'$
S1	5.76	0.49	1.89
S2	4.89	0.44	1.68
S3	5.07	0.48	1.82
S4	5.63	0.73	2.94
S5	4.67	0.46	1.84
T1	6.18	0.69	2.77
T2	5.25	0.64	2.49
T3	4.84	0.53	2.12
Average	5.39	0.58	2.41

<sup>1/</sup>  $d$  = species richness index,  $J'$  = Pielou's evenness index, and  $H'$  = Shannon-Wiener's diversity index, S1 = Ban Tum Sing Khon, S2 = Ban Bang Hon, S3 = Sapan Phum Duang, S4 = Sapan Tapee, S5 = Sapan Chulachomklao, T1 = dry season, T2 = early rainy season, and T3 = heavy rainy season

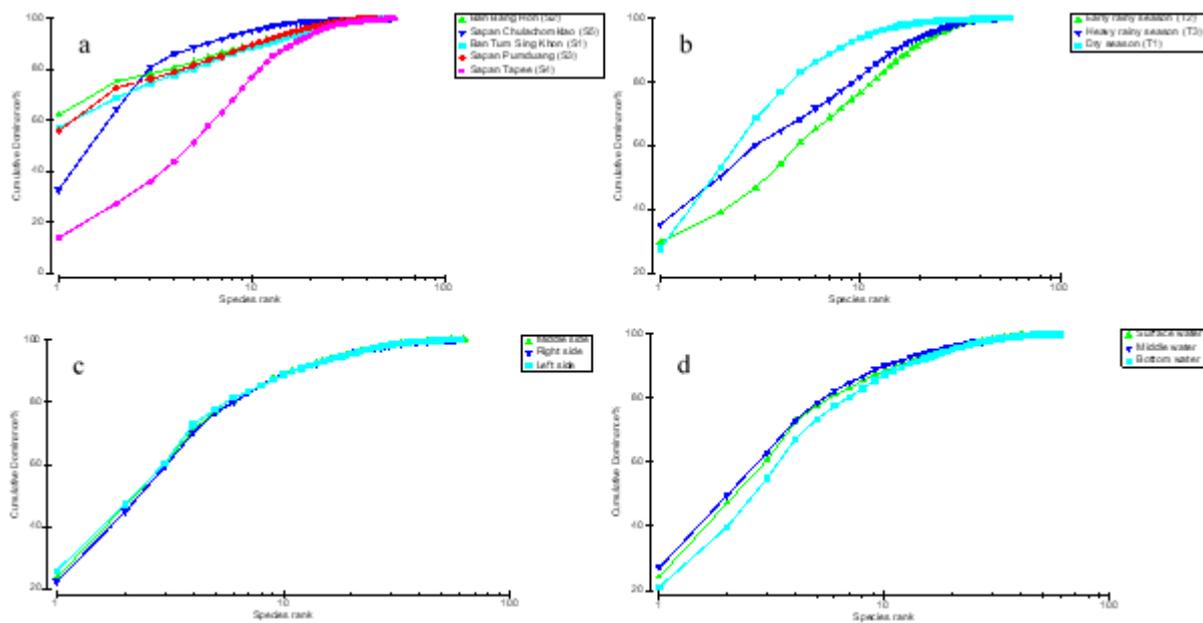
**Table 2** Diversity indices by study sides and water depths of rivers in the lower part of the Tapee River Basin, Surat Thani Province

Factors <sup>1/</sup>	<i>d</i>	<i>J'</i>	<i>H'</i>
Surface water	5.61	0.57	2.33
Middle water	5.51	0.59	2.39
Bottom water	5.82	0.62	2.53
Left of rivers	5.80	0.58	2.38
Middle of rivers	5.97	0.58	2.41
Right of rivers	5.52	0.59	2.43

<sup>1/</sup> *d* = species richness index, *J'* = Pielou's evenness index, and *H'* = Shannon-Wiener's diversity index

**Curve of species abundant distribution**

The results of ranked species abundant curve by stations on **Figure 3a** displays three pattern of distribution: the first pattern was high cumulative percentage of the first species at the S1-S3 (the Phum Duang River) which was dominated by certain species, i. e., *Synedra* sp., the second pattern was medium cumulative percentage of the first species at ST5, i. e., *Actinastrum* spp., and the third pattern was low cumulative percentage of the first species at ST4, i. e., *Aulacoseira* sp. that there was no dominant species in population. Also, pattern of distribution among different seasons, river sides, and water depths, the curves indicating that there was no dominant species in community (**Figure 3b-3d**).



**Figure 3** Curvatures of species abundant distribution of phytoplankton by stations rank (a), seasons (b), sides of rivers (c), and depths of water (d) in the lower part of the Tapee River Basin, Surat Thani Province

### Assessing water conditions with AARL-PP Score

The AARL-PP score on **Table 3** shows 6.6 in overall, indicating that the trophic status was meso-eutrophic level, and the water quality or ecosystem condition was, in general, moderate-polluted (scores 1.0-2.0 = oligotrophic status and clean, 2.1-3.5 = oligo-mesotrophic status and clean-moderate, 3.6-5.5 = mesotrophic status and moderate, 5.6-7.5 = meso-eutrophic status moderate-polluted, 7.6-9.0 = eutrophic status polluted and 9.1-10.0 = hypereutrophic status and much polluted (Peerapornpisal *et al.*, 2007)). This result is coincided with the study of Sakset (2011) in the Pak Phanang River Basin. Also, the result was classified to Class 3-4 of surface water quality standards of Thailand, and are consistent with the Pollution Control Department (2016) declaring that the lower Tapee, and the Phum Duang Rivers generally showed water quality of Class 3. However, the AARL-PP score showed better water status at S1 and S2 (5.2).

### Implying aquatic resources management measures

According to the findings, some potential measures for aquatic resources management are recommended. Establishing water quality monitoring program to regularly monitor water pollutions should be conducted around the year, especially during dry and heavy rainy seasons, focusing at station 3-5. Restocking native fish species for maintaining diversity and increasing production should be taken at stations and seasons which are the best benefit for survival. For example, restocking herbivorous fish species (such as *Barbonymus gonionotus* (Bleeker, 1849) which feeds on phytoplankton) should be conducted at S5 and during the dry season (T1) which plenty of phytoplankton can be found and be served as the natural food. Furthermore, it is suggested that a good sampling point for phytoplankton study in the lower Tapee River Basin should be at the surface and the middle of the waters because it can randomly obtain the amount of species and abundance greater than at the bottom of water. Moreover, it can be randomized at any side of the rivers due to no significant differences in abundance of phytoplankton.

### Conclusions

A total of phytoplankton genera found in the lower part of the Tapee River Basin were 63 genera with average abundance of 1,917.8 units/L. The number of genera and abundance has trended to increase from upstream to downstream, and higher during dry season. The phytoplankton community in the area could be considered at medium diversity and distribution levels. Also, the diversity indices and scores of dominant genera indicating the ecosystem or water conditions were generally meso-eutrophic and moderately-polluted, and is still suitable for aquatic animal growth and survival. Furthermore, in terms of aquatic resources managements in order to maintain environment and stocks; regular monitoring water pollution should be done throughout the year, and restocking of native herbivorous fish species should be conducted at station 5 and during the dry season, as well as a good sampling points for phytoplankton study in this basin should be at the surface and at the middle of the water with any side of the river.

**Table 3** Applied Algal Research Laboratory Phytoplankton Score (AARL - PP score) in the lower part of the Tapee River Basin, Surat Thani Province

Study Factors <sup>1/</sup>	Dominant genera (Score)	AARL-PP Score	Trophic status; water quality status	Classified of water quality
S1	<i>Synedra</i> (6), <i>Surirella</i> (6), <i>Spirogyra</i> (5), <i>Eunotia</i> (2), <i>Gyrosigma</i> (7)	5.2	mesotrophic; moderate	Class 3
S2	<i>Synedra</i> (6), <i>Surirella</i> (6), <i>Gyrosigma</i> (7), <i>Eunotia</i> (2), <i>Melosira</i> (5)	5.2	mesotrophic; moderate	Class 3
S3	<i>Synedra</i> (6), <i>Surirella</i> (6), <i>Gyrosigma</i> (7), <i>Nitzschia</i> (9), <i>Eunotia</i> (2)	6.0	meso-eutrophic; moderate-polluted	Class 4
S4	<i>Aulacoseira</i> (6), <i>Pediastrum</i> (7), <i>Actinastrum</i> (5), <i>Scenedesmus</i> (8), <i>Dictyosphaerium</i> (7)	6.6	meso-eutrophic; moderate-polluted	Class 4
S5	<i>Actinastrum</i> (5), <i>Spirulina</i> (9), <i>Aulacoseira</i> (6), <i>Pediastrum</i> (7), <i>Dictyosphaerium</i> (7)	6.8	meso-eutrophic; moderate-polluted	Class 4
T1	<i>Actinastrum</i> (5), <i>Spirulina</i> (9), <i>Aulacoseira</i> (6), <i>Synedra</i> (6), <i>Pediastrum</i> (7)	6.6	meso-eutrophic; moderate-polluted	Class 4
T2	<i>Synedra</i> (6), <i>Mallomonas</i> (5), <i>Closterium</i> (6), <i>Surirella</i> (6), <i>Staurastrum</i> (3)	5.2	mesotrophic; moderate	Class 3
T3	<i>Synedra</i> (6), <i>Surirella</i> (6), <i>Closterium</i> (6), <i>Eunotia</i> (2), <i>Euglena</i> (10)	6.0	meso-eutrophic; moderate-polluted	Class 4
Left of rivers	<i>Actinastrum</i> (5), <i>Spirulina</i> (9), <i>Aulacoseira</i> (6), <i>Synedra</i> (6), <i>Pediastrum</i> (7)	6.6	meso-eutrophic; moderate-polluted	Class 4
Middle of rivers	<i>Actinastrum</i> (5), <i>Spirulina</i> (9), <i>Aulacoseira</i> (6), <i>Synedra</i> (6), <i>Pediastrum</i> (7)	6.6	meso-eutrophic; moderate-polluted	Class 4
Right of rivers	<i>Actinastrum</i> (5), <i>Spirulina</i> (9), <i>Aulacoseira</i> (6), <i>Synedra</i> (6), <i>Pediastrum</i> (7)	6.6	meso-eutrophic; moderate-polluted	Class 4
Surface water	<i>Actinastrum</i> (5), <i>Spirulina</i> (9), <i>Aulacoseira</i> (6), <i>Synedra</i> (6), <i>Pediastrum</i> (7)	6.6	meso-eutrophic; moderate-polluted	Class 4
Middle water	<i>Spirulina</i> (9), <i>Actinastrum</i> (5), <i>Aulacoseira</i> (6), <i>Synedra</i> (6), <i>Pediastrum</i> (7)	6.6	meso-eutrophic; moderate-polluted	Class 4
Bottom water	<i>Actinastrum</i> (5), <i>Spirulina</i> (9), <i>Aulacoseira</i> (6), <i>Synedra</i> (6), <i>Pediastrum</i> (7)	6.6	meso-eutrophic; moderate-polluted	Class 4
Overall	<i>Actinastrum</i> (5), <i>Spirulina</i> (9), <i>Aulacoseira</i> (6), <i>Synedra</i> (6), <i>Pediastrum</i> (7)	6.6	meso-eutrophic; moderate-polluted	Class 4

<sup>1/</sup> S1 = Ban Tum Sing Khon, S2 = Ban Bang Hon, S3 = Sapan Phum Duang, S4 = Sapan Tapee, S5 = Sapan Chulachomklao, T1 = dry season, T2 = early rainy season, and T3 = heavy rainy season

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Appendix Table 1 (Continued)

Divisions/Genera	Study stations*					Study seasons*			Total
	S1	S2	S3	S4	S5	T1	T2	T3	
<i>Synura</i> sp.	-	-	-	+	+	-	+	+	+
<b>Cyanophyta</b>	7.4	10.7	7.8	122.3	2122.5	1330.8	17.9	13.7	454.1
<i>Anabaena</i> sp.	+	+	-	+	+	+	+	-	+
<i>Cylindrospermopsis</i> sp.	-	-	-	-	+	+	-	-	+
<i>Merismopedia</i> sp.	+	-	-	+	+	+	-	+	+
<i>Microcystis</i> sp.	-	-	+	+	+	+	+	+	+
<i>Oscillatoria</i> spp.	+	+	+	+	+	+	+	+	+
<i>Spirulina</i> sp.	+	+	+	+	++	++	+	+	++
<i>Pseudoanabaena</i> sp.	+	+	+	+	+	+	+	+	+
<b>Euglenophyta</b>	6.3	12.3	18.4	37.9	16.9	5.9	18.4	30.8	18.4
<i>Euglena</i> spp.	+	+	+	+	+	+	+	+	+
<i>Lepocinclis</i> spp.	+	+	+	+	+	+	+	+	+
<i>Phacus</i> spp.	+	+	+	+	+	+	+	+	+
<i>Strombomonas</i> spp.	+	+	+	+	+	+	+	+	+
<i>Trachelomonas</i> spp.	+	+	+	+	+	-	+	+	+
<b>Ochromytha</b>	0.1	0.0	0.1	0.5	4.7	3.0	0.2	0.1	1.1
<i>Chattonella</i> sp.	-	-	+	+	-	+	+	+	+
<i>Dictyocha</i> sp.	+	-	-	+	+	+	+	-	+
<b>Pyrrophyta</b>	1.3	2.3	1.4	1.7	0.8	1.1	2.1	1.3	1.5
<i>Ceratium</i> spp.	+	+	+	+	+	+	+	+	+
<i>Peridinium</i> sp.	-	-	-	+	-	-	+	-	+
<b>Rhodophyta</b>	3.2	5.2	4.7	0.0	1.3	0.9	5.6	2.1	2.9
<i>Audouinella</i> sp.	+	+	+	-	+	+	+	+	+
Abundance (units/L)	352.5	674.5	578.0	1,398.5	6,585.5	4,992.0	300.3	461.1	1,917.8
Number of genera	48	44	48	55	53	56	54	48	63

<sup>1/</sup> S1 = Ban Tum Sing Khon, S2 = Ban Bang Hon, S3 = Sapan Phum Duang, S4 = Sapan Tapee, S5 = Sapan Chulachomklao, <sup>2/</sup> T1 = dry season, T2 = early rainy season, and T3 = heavy rainy season.

**Appendix Table 2** Genera and abundance (units/L) of phytoplankton by study sides and water depths of rivers in the lower part of the Tapee River Basin, Surat Thani Province

Divisions/Genera	Sides of rivers			Depths of water		
	Left	Middle	Right	Surface	Middle	Bottom
<b>Bacillariophyta</b>	606.9	593.0	670.5	640.7	701.6	528.1
<i>Amphora</i> sp.	+	+	+	+	+	+
<i>Aulacoseira</i> sp.	+	+	+	+	+	+
<i>Bacillaria</i> sp.	+	+	+	-	+	+
<i>Bellerochea</i> sp.	+	+	+	+	+	+
<i>Cerataulina</i> sp.	+	+	+	+	+	+
<i>Coscinodiscus</i> sp.	+	+	+	+	+	+
<i>Cyclotella</i> sp.	+	+	+	+	+	+
<i>Cymbella</i> spp.	+	+	+	+	+	+
<i>Diatoma</i> spp.	+	+	+	+	+	+
<i>Eunotia</i> sp.	+	+	+	+	+	+
<i>Gyrosigma</i> sp.	+	+	+	+	+	+
<i>Melosira</i> spp.	+	+	+	+	+	+
<i>Navicula</i> spp.	+	+	+	+	+	+
<i>Nitzschia</i> spp.	+	+	+	+	+	+
<i>Pinnularia</i> sp.	+	+	+	+	+	+
<i>Pleurosigma</i> sp.	+	+	+	+	+	+
<i>Rhizosolenia</i> sp.	+	+	+	+	+	+
<i>Surirella</i> spp.	+	+	+	+	+	+
<i>Synedra</i> sp.	+	+	+	+	+	+
<b>Chlorophyta</b>	758.5	819.7	821.3	955.1	847.2	597.2
<i>Actinastrum</i> spp.	++	++	++	++	++	++
<i>Ankistrodesmus</i> sp.	+	+	+	+	+	+
<i>Closterium</i> spp.	+	+	+	+	+	+
<i>Coelastrum</i> sp.	+	+	+	+	+	+
<i>Cosmarium</i> sp.	+	+	+	+	+	+
<i>Dictyosphaerium</i> sp.	+	+	+	+	+	+
<i>Eudorina</i> sp.	+	+	+	+	+	+
<i>Golenkinia</i> sp.	+	+	+	+	+	+
<i>Micractinium</i> sp.	+	+	+	+	+	+
<i>Micrasterias</i> sp.	-	+	-	-	-	+
<i>Oocystis</i> sp.	+	+	+	+	+	+
<i>Pediastrum</i> spp.	+	+	+	+	+	+
<i>Pleurotaenium</i> sp.	+	+	+	+	+	+
<i>Scenedesmus</i> spp.	+	+	+	+	+	+
<i>Selenastrum</i> sp.	+	+	-	-	-	+
<i>Spirogyra</i> spp.	+	+	+	+	+	+
<i>Spondylosium</i> sp.	-	+	-	+	-	-
<i>Staurastrum</i> spp.	+	+	+	+	+	+
<i>Staurodesmus</i> sp.	+	+	+	+	+	+
<i>Tetraedron</i> spp.	+	+	+	+	+	+
<i>Treubaria</i> sp.	+	+	+	+	+	+
<i>Ulothrix</i> sp.	+	+	+	+	+	+
<i>Xanthidium</i> spp.	+	+	+	+	+	+
<b>Chrysophyta</b>	14.6	14.3	20.8	15.7	16.1	17.9
<i>Centritractus</i> sp.	+	+	+	+	+	+
<i>Dinobryon</i> spp.	+	+	+	+	+	+
<i>Mallomonas</i> sp.	+	+	+	+	+	+
<i>Synura</i> sp.	+	+	+	+	+	+

Appendix Table 2 (Continued)

Divisions/Genera	Sides of rivers			Depths of water		
	Left	Middle	Right	Surface	Middle	Bottom
<b>Cyanophyta</b>	412.6	480.6	469.1	517.6	552.8	292.0
<i>Anabaena</i> sp.	+	+	+	+	+	+
<i>Cylindrospermopsis</i> sp.	+	+	+	+	+	-
<i>Merismopedia</i> sp.	+	+	+	+	+	+
<i>Microcystis</i> sp.	+	+	+	+	+	+
<i>Oscillatoria</i> spp.	+	+	+	+	+	+
<i>Spirulina</i> sp.	++	++	++	++	++	+
<i>Pseudoanabaena</i> sp.	+	+	+	+	+	+
<b>Euglenophyta</b>	19.0	14.8	21.3	18.7	20.2	16.2
<i>Euglena</i> spp.	+	+	+	+	+	+
<i>Lepocinclis</i> spp.	+	+	+	+	+	+
<i>Phacus</i> spp.	+	+	+	+	+	+
<i>Strombomonas</i> spp.	+	+	+	+	+	+
<i>Trachelomonas</i> spp.	+	+	+	+	+	+
<b>Ochromytha</b>	0.6	0.6	2.0	0.6	1.5	1.2
<i>Chattonella</i> sp.	+	+	+	+	-	+
<i>Dictyocha</i> sp.	+	+	+	+	+	+
<b>Pyrrophyta</b>	1.0	1.7	1.8	1.7	1.7	1.1
<i>Ceratium</i> spp.	+	+	+	+	+	+
<i>Peridinium</i> sp.	+	+	-	+	+	-
<b>Rhodophyta</b>	2.0	3.5	3.1	3.2	3.0	2.4
<i>Audouinella</i> sp.	+	+	+	+	+	+
Abundance (units/L)	1,815.1	1,928.3	2,009.9	2,153.4	2,143.8	1,456.2
Number of genera	61	63	59	60	59	60