

# SEASONAL VARIATION OF PHYTOPLANKTON FUNCTIONAL GROUPS IN TUYEN LAM RESERVOIR, CENTRAL HIGHLANDS, VIETNAM

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## Abstract

*Seasonal changes in freshwater phytoplankton assemblages at Tuyen Lam Reservoir in the Central Highlands of Vietnam were classified into 23 functional groups based on physiological, morphological, and ecological characteristics. A total of 168 species were recorded during 10 surveys from 2015 to 2019 at 7 sampling sites, with Chlorophyta dominating in number of species. Phytoplankton abundance varied from  $0.18 \times 10^5$  to  $21.2 \times 10^5$  cells/L during the study period, mainly due to cyanobacteria. Seven of the 23 functional groups were considered to be dominant (relative density > 5%). The dominant functional groups were groups M and G in the dry season and groups M, G, P, and E in the rainy season. Group M (*Microcystis aeruginosa*) was the most common in both seasons, while group P (*Closterium*, *Staurastrum*, *Aulacoseira*), group E (*Dinobryon*, *Synura*), and group G (*Sphaerocystis*, *Eudorina*) were more common in the rainy season. The Shannon diversity index ( $H'$ ) showed that phytoplankton communities were relatively diverse and that most of the study sites were lightly polluted. However, the ecological status has deteriorated at some locations due to the overgrowth of group M, leading to eutrophication in this reservoir. This study highlights the usefulness of functional groups in the study of seasonal changes in phytoplankton dynamics. Functional groups are applied for the first time at Tuyen Lam Reservoir and can be used to predict early-stage cyanobacterial blooms in future studies.*

**Keywords:** Central Highlands reservoir; Functional groups; Phytoplankton; Seasonal changes; Shannon diversity index.

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## 1. INTRODUCTION

As the main primary producers of the aquatic food chain, phytoplankton act as a key component in maintaining the structure and functioning of aquatic ecosystems (Yao et al., 2020). For phytoplankton assemblages, species coexistence is a prominent trait of aquatic ecosystems, which can explain their interactions with environmental factors and their influence on ecosystem structure and functioning and can increase the predictability of community responses to environmental changes (Amorim & Moura, 2021). Seasonal variations in the composition and structure of phytoplankton communities can represent important indicators for assessing the status of freshwater ecosystems, especially the eutrophication status of reservoirs (Yao et al., 2020).

In addition to the traditional method of identification based on species-level classifications, feature-based approaches and functional groups have been used to describe both phytoplankton community structure and changes to that structure, as proposed by Reynolds et al. (2002). Functional groups can be defined as groups of different species with similar functional characteristics that respond to environmental changes and exhibit the same effects on ecosystem functioning without losing fundamental features and responses (Amorim & Moura, 2021; Kruk et al., 2021; Reynolds et al., 2002). The classification consists of a system of 39 functional groups based on the effects of changes in aquatic ecosystems on the physiological, morphological, and ecological adaptations of phytoplankton occurring simultaneously in the same environment (Padisák et al., 2009; Reynolds et al., 2002). The concept of phytoplankton functional groups has been widely used to understand the spatial and temporal variations in species composition of phytoplankton communities and to assess the environmental status of various ecosystems, such as rivers, lakes, and reservoirs globally (Amorim & Moura, 2021). The functional groups P (*Staurastrum* sp. and *Closterium acerosum*) and Y (*Cryptomonas ovata* and *Cryptomonas erosa*) were characteristic of the phytoplankton communities of Gaozhou Reservoir, South China, in the winter and spring, whereas the functional groups NA (*Cosmarium* sp. and *Staurodesmus* sp.) and P (*Staurastrum* sp. and *Closterium acerosum*) were characteristic in the summer and autumn (Yao et al., 2020). Flagellate groups (Lm, Y, W1, and W2) and functional groups typical of shallow eutrophic environments (J, X1, and Sn) were dominant throughout the study period (Rangel et al., 2009).

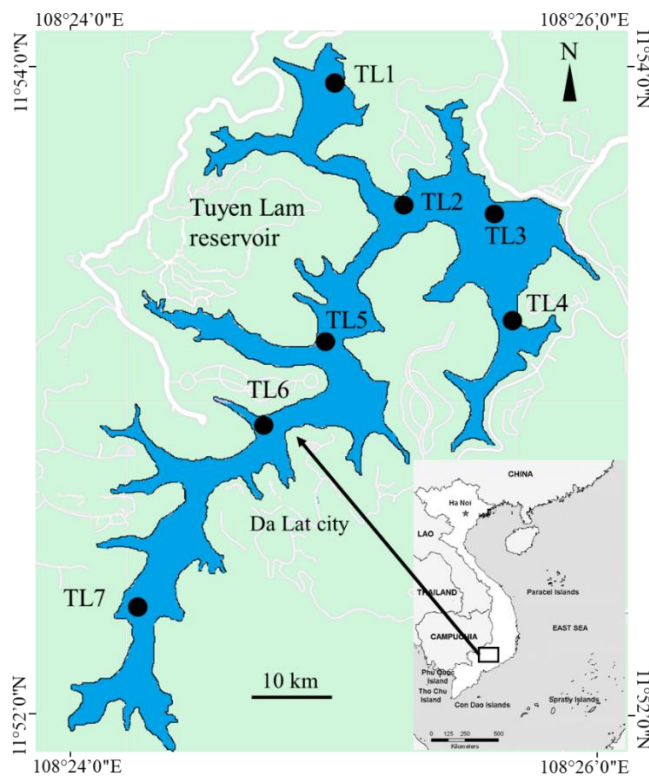
Tuyen Lam Reservoir is a large artificial reservoir, being one of the first irrigation projects in Lam Dong Province in the Central Highlands of Vietnam. It is not only a multipurpose reservoir, used for domestic and industrial water supply, irrigation systems, and ecotourism, but with high biodiversity, it is also home to many aquatic species (Tran et al., 2015). However, a large nutrient load has been dumped into the reservoir due to extensive soil erosion and domestic and farming wastewater, causing organic pollution and affecting aquatic ecosystems, especially phytoplankton communities (Le et al., 2017; Tran et al., 2015). Additionally, little is known about the seasonal variation in phytoplankton functional groups in this reservoir. Therefore, the objectives of this study are to describe the phytoplankton composition in the reservoir and to identify the phytoplankton functional groups and their seasonal changes. The results can provide useful

basic information for understanding relationships in the food web and can be effectively used to develop strategies for managing cyanobacterial blooms in reservoirs.

## 2. MATERIALS AND METHODS

### 2.1. Study area

Tuyen Lam Reservoir (TLR) is located in Lam Dong Province, Vietnam, and was constructed in 1983 for drinking water supply and irrigation purposes (Figure 1). TLR is the largest artificial freshwater reservoir in the city of Dalat, with an area of about 304 hectares and a mean depth of  $9.88 \pm 1.28$  m. TLR receives water from a system of streams originating in the surrounding high mountains. The climate of the TLR is typically tropical monsoonal, with two distinct seasons (dry and rainy) (Tran et al., 2015).



**Figure 1. Sampling station locations at Tuyen Lam Reservoir**

### 2.2. Sample collection and analysis

Samples were collected twice a year from seven sampling stations (denoted TL1 to TL7) at the TLR in May (representing the dry season) and October (representing the rainy season) from 2015 to 2019. Phytoplankton samples were collected from the surface waters by towing a conical net with a 25  $\mu$ m mesh size. Subsequently, the samples were kept in 150 ml plastic bottles for qualitative analysis, and 2 L of surface water was used for phytoplankton enumeration. All samples were fixed with 5% formalin in the field.

The samples were examined at a magnification of 40x with an Olympus BX41 optical microscope equipped with differential interference contrast. Samples were morphologically identified to the species level following the guidebooks of Bellinger and Sigeo (2015), Desikachary (1959), Duong (1996), Duong and Vö (1997), Komárek and Komárková (2002), van Vuuren (2006), and Wehr et al. (2015). The classification of phytoplankton into functional groups is based on the work of Padisák et al. (2009) and Reynolds et al. (2002). Keys of functional groups were determined in alphabetical order to reflect their characteristics in distinguishing properties and ecologies (Reynolds et al., 2002). Verification of currently accepted taxonomic names followed AlgaeBase (Guiry & Guiry, 2012). The abundance of phytoplankton was estimated with a Sedgewick-Rafter counting chamber using 1 L raw water samples according to the method developed by Sournia (1978). A minimum of 400 taxa (cells or colonies) of each species should be counted to keep the counting error at or below 10% (Bellinger & Sigeo, 2015; Sournia, 1978).

### 2.3. Data analysis

The Shannon index ( $H'$  index) (Shannon, 1948) was used to investigate the phytoplankton diversity, as follows:

$$H' = - \sum_i^s \frac{n_i}{N} \log_2 \frac{n_i}{N} \quad (1)$$

where  $s$  the total number of species,  $n_i$  is the number of individuals or amount (e.g., biomass or density) of each species (the  $i$ th species), and  $N$  is the total number of individuals (or amount) for the site.

Staub et al. (1970) established a relationship between  $H'$  index values and different levels of pollution in aquatic ecosystems (Table 1).

**Table 1. Classification of pollution levels based on  $H'$  index**

$H'$ range	Pollution level
0–1	Heavy
1–2	Moderate
2–3	Light
3–4.5	Slight
> 4.5	Pollution-free

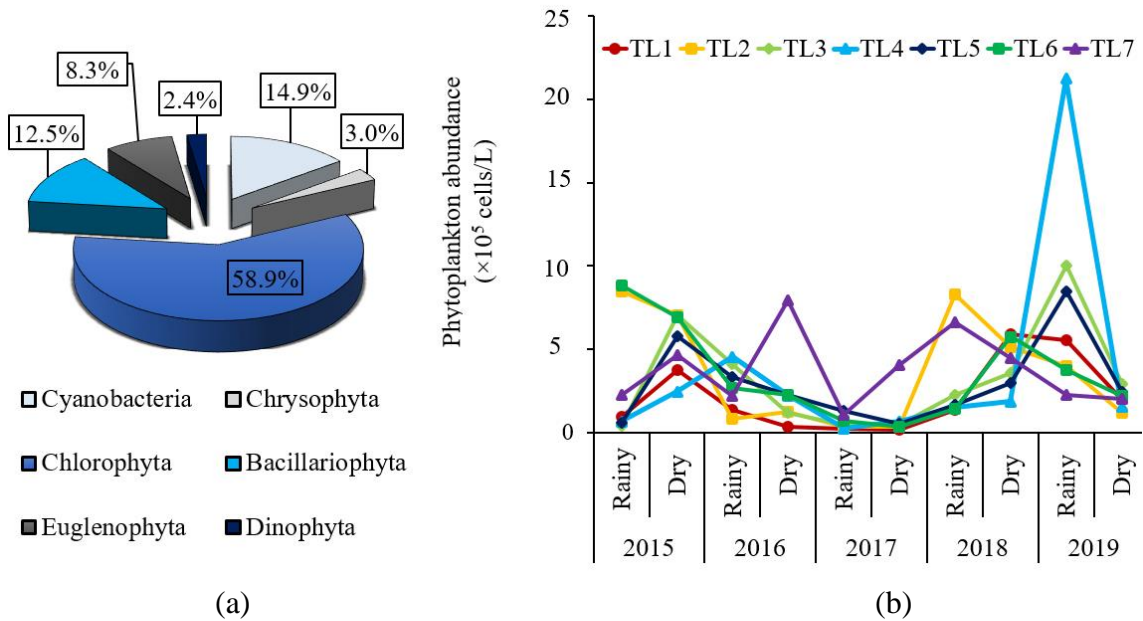
Source: Staub et al. (1970).

The experimental results for each month are summarized and presented as charts using Microsoft Excel. The  $H'$  index was calculated using the PRIMER VI analytical package developed by Plymouth Marine Laboratory (UK).

### 3. RESULTS AND DISCUSSION

#### 3.1. Phytoplankton community

In total, 168 phytoplankton species were identified in the samples collected from the TLR, including six separate phyla: Cyanobacteria, Chrysophyta, Chlorophyta, Bacillariophyta, Euglenophyta, and Dinophyta. Among the 168 phytoplankton species, 99 belong to Chlorophyta and account for 58.9% of the total. Chlorophyta contributed the highest number of species throughout the two seasons, followed by Cyanobacteria (25 species, 14.9%) and Bacillariophyta (21 species, 12.5%). Chrysophyta (5 species, 3.0%), Euglenophyta (14 species, 8.3%), and Dinophyta (4 species, 2.4%) accounted for only minor percentages (Figure 2a). Sample collections yielded 123 species in the rainy seasons and 139 species in the dry seasons. Species richness in the dry season was greater than in the rainy season, and Chlorophyta was more dominant than the others in both seasons during the study period.



**Figure 2. (a) The distribution of phytoplankton; (b) the abundance of phytoplankton in Tuyen Lam Reservoir in each season from 2015 to 2019**

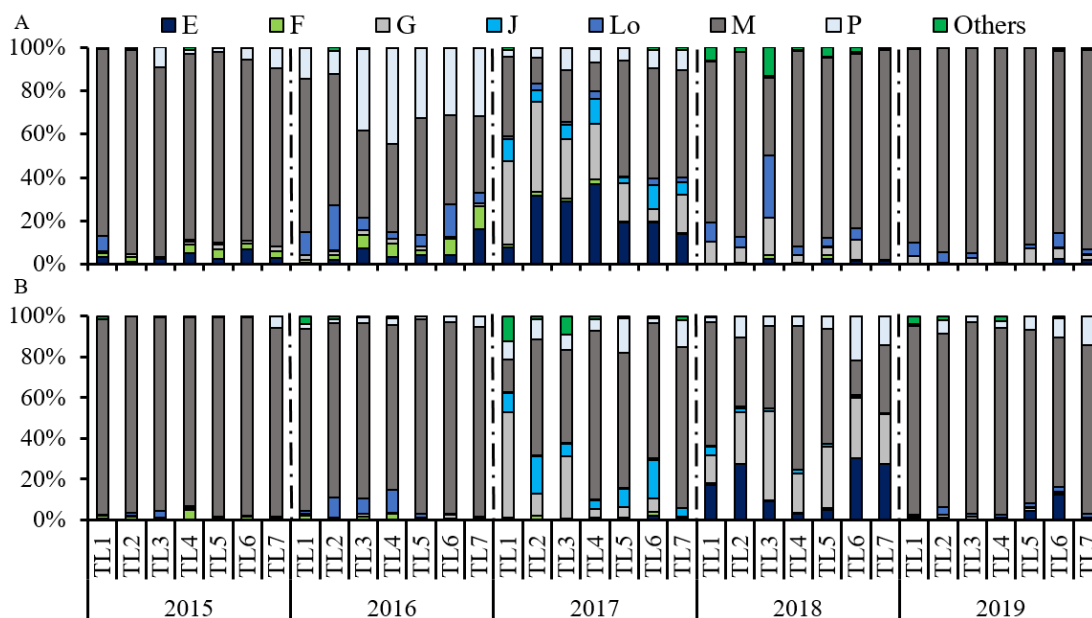
The density of phytoplankton ranged from  $0.18 \times 10^5$  to  $7.93 \times 10^5$  cells/L in the dry season and from  $0.2 \times 10^5$  to  $21.2 \times 10^5$  cells/L in the rainy season (Figure 2b), of which the highest abundance was recorded in the rainy season and the lowest abundance was recorded in the dry season. Phytoplankton abundance was high in 2015 and 2019 and tended to be volatile from 2016 to 2018. Some stations with high density were TL2 and TL6 in the rainy season in 2015, TL3 and TL4 in the rainy season in 2019, and TL7 in the dry season in 2016 because of the dominance of cyanobacteria species, such as *M. aeruginosa* and *M. wesenbergii*. The frequent occurrence in high abundance of some genera belonging to green algae, diatoms, or other cyanobacteria may be responsible for

the fluctuation of the total phytoplankton abundance from 2016 to 2018. For example, the appearance of *Desmidium baileyi*, *Staurastrum arctiscon*, *Aulacoseira granulate*, and *Woronichinia naegeliana* contributed most to the density values in the rainy season in 2016, while in the 2018 dry season, *Sphaerocystis schroeteri*, *Dinobryon sertularia*, *Synura adamsii*, and *Aulacoseira granulata* were frequently recorded in high abundance.

The distribution structure of the phytoplankton assemblages in TLR was typical of lentic environments, with Chlorophyta and Cyanobacteria dominant in species composition and abundance, as found in previous studies in this area (Le et al., 2017; Tran et al., 2015). More specifically, the main groups of the phytoplankton community of the highland reservoirs are Cyanobacteria, Chlorophyta, and Bacillariophyta.

### 3.2. Seasonal variation of phytoplankton functional groups

A total of 23 functional groups were recorded in the study area (Table 2), of which J, M, P, and W1 were the functional groups most rich in species throughout both seasons. In total, 21 representative functional groups were identified in the rainy season and 22 groups were identified in the dry season. Seven groups (E, F, G, J, Lo, M, and P) were classified as dominant groups, defined as contributing a minimum of 5% of total phytoplankton abundance at least once during the study period. The total density of these seven groups accounted for more than 87% of the total phytoplankton density at each station. Therefore, the composition of the phytoplankton community was analyzed using these seven dominant functional groups. Among these groups, phytoplankton species belonging to functional group M (represented by *M. aeruginosa*) were the most common at all sites in both seasons (Figure 3).



**Figure 3. Composition and abundance of the representative functional groups of phytoplankton in Tuyen Lam Reservoir from 2015 to 2019**

Note: (A) in the rainy season; (B) in the dry season.

**Table 2. Phytoplankton functional groups with representative species recorded in Tuyen Lam Reservoir during the study period**

No.	Functional Groups	Representative species
1	A	<i>Rhizosolenia longiseta</i>
2	C	<i>Cyclotella meneghiniana</i> , <i>Navicula cryptocephala</i>
3	D	<i>Cymbella</i> sp., <i>Surirella biseriata</i> , <i>Surirella robusta</i> , <i>Surirella ovata</i> , <i>Synedra ulna</i>
4	E	<i>Dinobryon divergens</i> , <i>Dinobryon sertularia</i> , <i>Mallomonas</i> sp., <i>Synura adamsii</i>
5	F	<i>Botryococcus braunii</i> , <i>Mucidosphaerium pulchellum</i> , <i>Oocystis borgei</i> , <i>Planktosphaeria gelatinosa</i>
6	G	<i>Eudorina elegans</i> , <i>Sphaerocystis Schroeteri</i>
7	H1	<i>Anabaena circinalis</i> , <i>Anabaena</i> sp.
8	J	<i>Coelastrum microporum</i> , <i>Pediastrum duplex</i> , <i>Scenedesmus quadricauda</i> , <i>Xanthidium acanthophorum</i>
9	K1	<i>Aphanocapsa delicatissima</i>
10	Lo	<i>Chroococcus</i> sp., <i>Merismopedia tenuissima</i> , <i>Woronichinia naegeliana</i> , <i>Peridinium cinctum</i>
11	LM	<i>Ceratium hirundinella</i>
12	M	<i>Snowella</i> sp., <i>Microcystis aeruginosa</i> , <i>Microcystis botrys</i> , <i>Microcystis wesenbergii</i>
13	MP	<i>Oscillatoria princeps</i> , <i>Oscillatoria</i> sp., <i>Gomphonema angustatum</i>
14	N	<i>Cosmarium contractum</i> , <i>Cosmarium moniliforme</i>
15	NA	<i>Euastrum spinulosum</i>
16	P	<i>Closterium gracile</i> , <i>Staurastrum arctiscon</i> , <i>Staurastrum natator</i> , <i>Aulacoseira granulata</i> , <i>Pinnularia major</i>
17	T	<i>Mougeotia</i> sp.
18	S1	<i>Planktothrix agardhii</i> , <i>Pseudanabaena mucicola</i>
19	S2	<i>Anthrospira</i> sp., <i>Raphidiopsis curvata</i>
20	W1	<i>Euglena acus</i> , <i>Euglena oxyuris</i> , <i>Euglena</i> sp., <i>Lepocinlis ovum</i> , <i>Phacus longicauda</i> , <i>Phacus ovalis</i> , <i>Phacus tortus</i>
21	W2	<i>Trachelomonas armata</i> , <i>Trachelomonas hispida</i>
22	X1	<i>Ankistrodesmus falcatus</i> , <i>Ankistrodesmus gracilis</i> , <i>Chlorella</i> sp.
23	X2	<i>Chlamydomonas</i> sp.

In the rainy season, it was obvious that group M was the most common group, accounting for more than 90% of phytoplankton abundance in 2015 and 2019. The period between 2016 and 2018 witnessed a downward trend in group M phytoplankton abundance, but it increased in 2019 at most sites. Phytoplankton abundance was high for group P from 2015 to 2017, with the greatest value being 44% at TL4 in 2016. Phytoplankton abundance in groups E and G rose rapidly in 2017, with high densities

from 14% to 41% in 2017. Groups Lo, F, and J were also observed at various sites but in low abundance. In the dry season, group M was typically dominant, making up more than 90% of total phytoplankton abundance in 2015, 2016, and 2019. The other groups showed only slight fluctuations between 2015 and 2019. The high biomass of group M fluctuated continuously from 2015 to 2016, but then declined substantially between 2017 and 2018. Subsequently, the phytoplankton biomass grew rapidly in 2019. Group P was observed to have an upward trend from 2016 to 2019, but presented the opposite pattern in the rainy season. Groups E and G had high abundances, ranging from 11% to 52% in 2017 and 2018, whereas the others had generally low abundances at all sites.

The seasonal changes of phytoplankton functional groups reflect variation in physicochemical parameters and the succession of different functional groups that determine the phytoplankton community structure. The total abundance of phytoplankton functional groups changed substantially among sites and seasons. Generally, the seasonal variations of the main functional groups were in groups M and G in the dry season and groups M, G, P, and E in the rainy season. Group M occupied the absolute dominant position in phytoplankton density, including species belonging to *Microcystis* represented by *M. aeruginosa*, which limited the growth of other functional groups and caused cyanobacterial blooms. Green algae and diatom species belonging to group P (*Closterium*, *Staurastrum*, and *Aulacoseira*), group E (*Dinobryon* and *Synura*), and group G (*Sphaerocystis* and *Eudorina*) thrived when nutrients were available and temperatures were low, while cyanobacteria abundance gradually decreased from 2016 to 2018. Groups G, E, and P were dominant in the rainy seasons of 2016 and 2017, and they were found abundantly in the 2017 and 2018 dry seasons. In addition, group Lo (*Peridinium*, *Woronichinia*, and *Merismopedia*), including species belonging to Cyanobacteria and Dinophyta, grew faster in the rainy season than in the dry season, especially in 2016 and 2018.

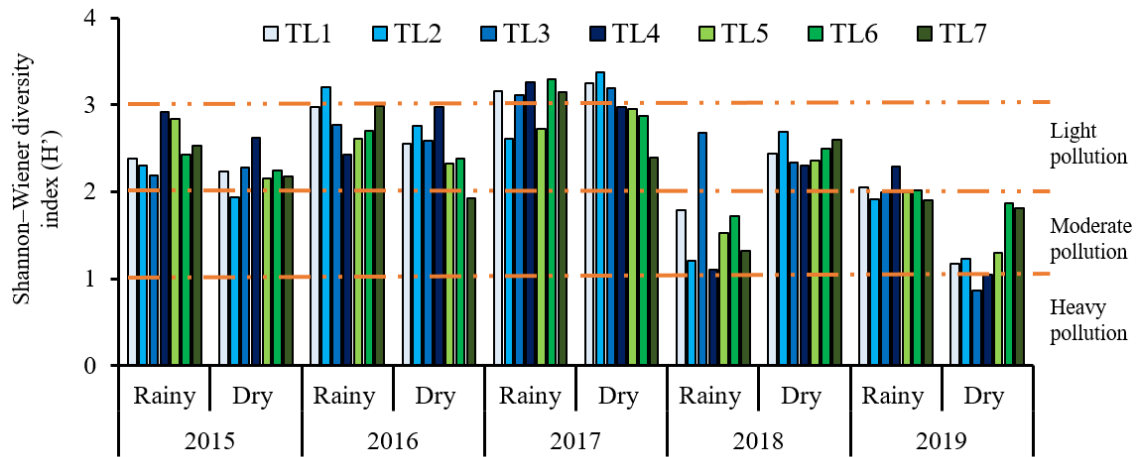
Traditionally, phytoplankton composition has been studied by the variation of biomass of major taxonomic classes. However, this approach does not reflect the actual ecological functioning of an ecosystem since each species has different structural and functional characteristics related to life strategies (Reynolds et al., 2002). In Vietnamese waters, previous studies have only used morphological classification to describe phytoplankton structure and assess ecological status (Le et al., 2017; Tran et al., 2015). In this study, the phytoplankton functional groups were applied for the first time to investigate the seasonal variation of phytoplankton communities and then used to evaluate the ecological quality of the TLR. Our results highlight the potential of phytoplankton functional groups in investigating the seasonal phytoplankton dynamics in the TLR.

### 3.3. Biological index of phytoplankton assemblage

The biological index of the phytoplankton assemblage is represented by the  $H'$  index depicted in Figure 4. The  $H'$  index ranged from 1.10 to 3.30 and from 0.86 to 3.38 in the rainy and dry seasons, respectively. Overall, the  $H'$  index was at moderate status, and  $H'$  values, representing the relative diversity of phytoplankton communities, were more than 2 at sampling stations over the years of monitoring, except for sites TL2 and



TL7 in the 2015 and 2016 dry seasons and the 2019 rainy season. In particular, most of the  $H'$  values had poor or bad status during the rainy season of 2018 and the dry season of 2019, indicating low biodiversity in the phytoplankton communities. Moreover, the relationship between the  $H'$  index and the different pollution levels based on Staub et al. (1970) showed that most of the sites are at light-to-moderate pollution levels in both seasons over the years of monitoring, except for station TL3 ( $H' = 0.86$ ), which was heavily polluted in the dry season of 2019 (Figure 4).



**Figure 4.  $H'$  index of phytoplankton community in Tuyen Lam Reservoir in rainy and dry seasons from 2015 to 2019**

Tuyen Lam reservoir suffers from serious cyanobacterial bloom, which the thriving cyanobacterial functional group M caused during the study period. Group M, represented by *M. aeruginosa* and *M. wesenbergii*, caused cyanobacterial blooms and low biodiversity in the water. The bloom occurrence degraded the ecological environment in the 2018 rainy season and the 2019 dry season. Some studies have indicated that the dominance of the M group depends on high water temperature, the increase in phosphorous concentration, light, and water exchange (Rangel et al., 2009; Yoshinaga et al., 2006). The diverse composition of green algae species, consisting of groups E, F, G, and P, contributed to an increase in the  $H'$  index ( $H' > 3.0$ ), and the diverse phytoplankton communities, such as in the rainy seasons of 2016 and 2017, limited the growth of cyanobacteria.

#### 4. CONCLUSION

The concept of phytoplankton functional groups was used to assess the phytoplankton community structure, providing insight into its seasonal variation. The phytoplankton analysis revealed that green algae functional groups, such as P, J, and F, had the highest species richness, while group M, belonging to cyanobacteria, had the highest density during the study period. Seasonal trends of phytoplankton composition patterns and abundance differed among survey years. Functional groups P, E, and G were dominant from 2016 to 2018, especially in the rainy seasons, while groups M and G were

dominant in 2015, 2016, and 2019, particularly in the dry seasons. Generally, the H' index was at a moderate status, and the relative diversity of phytoplankton communities could be explained by the appearance of functional groups. In addition, most of the stations were at light-to-moderate pollution levels in both seasons over the years of monitoring, as exhibited by the H' index. Functional groups were explained mainly by environmental factors, so the combination with environmental parameters in a further study will be necessary to understand phytoplankton dynamics in this reservoir and to provide useful information for protecting drinking water.

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