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Impact of anthropogenic activities on water quality and plankton communities in the Day River (Red River Delta, Vietnam)

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Abstract Planktons are a major component of food web structure in aquatic ecosystems. Their distribution and community structure are driven by the combination and interactions between physical, chemical, and biological factors within the environment. In the present study, water quality and the community structure of phytoplankton and zooplankton were monthly investigated from January to December 2015 at 11 sampling sites along the gradient course of the Day River (Red River Delta, northern Vietnam). The study demonstrated that the Day River was eutrophic with the average values of total phosphorus concentration 0.17 mg/L, total nitrogen concentration 1.98 mg/L, and Chl a 54 μg/L. Microscopic plankton analysis showed that phytoplankton comprised 87 species belonging to seven groups in which Chlorophyceae, Bacillariophyceae, and

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Cyanobacteria accounted for the most important constituents of the river's phytoplankton assemblage. A total 53 zooplankton species belonging to three main groups including Copepoda, Cladocera, and Rotatoria were identified. Plankton biomass values were greatest in rainy season (3002.10-3 cell/L for phytoplankton and 12.573 individuals/m^3 for zooplankton). Using principal correspondence and Pearson correlation analyses, it was found that the Day River was divided into three main site groups based on water quality and characteristics of plankton community. Temperature and nutrients (total phosphorus and total nitrogen) are key factors regulating plankton abundance and distribution in the Day River.

Keywords Water quality · Plankton communities · Day River · Red River Delta · Tropical · Vietnam

Introduction

Human disturbances and global changes are considered as a major driver of environmental degradation (MEA 2003). Anthropogenic activities (deforestation, land use change, expansion of agriculture and development of industry, urbanization, and increasing wastewater) and global climate change (increasing average global temperature, changes in rainfall pattern) have put remarkable pressure on the ecological conditions and sustainability of many aquatic ecosystems (Paerl et al. 2014). Human activities have not only increased the quantities of nutrients but also changed forms and proportion of nutrients to the environment which can lead to adverse effects on water quality, such as eutrophication and food web structure (Glibert 2012; Vitousek et al. 2012; Duong et al. 2012; Isbell et al. 2013). In addition, increasing global temperature, changes in precipitation, evaporation, and runoff have altered the hydrology and thermal regimes that may affect physical, chemical, and biological processes of aquatic ecosystems (O'Connor et al. 2009; Rieman and Isaak 2010). Growth, dynamics, distribution, persistence of aquatic species, and the structure of their communities are strongly altered (Paerl et al. 2008, 2010, 2014; Rieman and Isaak 2010).

Planktons (phytoplankton and zooplankton), a major component of food web structure in aquatic ecosystems, are free-floating microscopic organisms, constituting diverse groups of organisms (D'Alelio et al. 2016). Phytoplankton is the dominant primary producers of organic carbon in aquatic ecosystems (Reynolds 2006). They account for less than 1% of the photosynthetic biomass on Earth but responsible for approximately half of the global net primary production (about 45–*50* Gt/C/year) (Field et al. 1998). They provide the principal source of primary nutrition for primary consumer such as zooplankton (Brett and Müller-Navarra 1997) and represent primary source of oxygen in many low-gradient rivers (Wehr and Descy 1998). Zooplankton are particularly important group of planktonic consumers that occupy a wide range of habitats, as they transfer energy produced from phytoplankton through photosynthesis to higher trophic levels (Litchman et al. 2013; Mitrovic et al. 2014). The distribution, community structure, and variation of plankton are clearly influenced by the combination and interactions between physical, chemical, and biological factors presented in a water body (Sabo et al. 2008; Cisneros et al. 2011; Lancelot and Muylaert 2011) such as rainfall, temperature, light and water discharge (Wehr and Descy 1998; De-Sousa et al. 2016; Bussi et al. 2016), nutrient enrichment, organic matter (Li et al. 2016; Paczkowska et al. 2017), and grazing (Mariania et al. 2013; Lucas et al. 2016). The warming of surface water and high nutrient levels which cyanobacterial abundance and dominance in aquatic ecosystems have caused many ecological and economic problems worldwide (Paerl et al. 2014).

Rivers are the most important freshwater resource in Vietnam, being used for hydropower, residential use, industry, agriculture, and numerous of other activities. Water quality deterioration due to rapid population growth, economic development, urbanization, and industrialization has become a critical issue of river management in Vietnam especially in urban and semi urban cities in North Vietnam (Luu et al. 2012). The Day River hydrosystem, which is located in the Red River delta, covers a surface area of 7665 km^2 with very high population density of 1370 inhabitants/km^2 (Pham et al. 2010; Do et al. 2014). The Day River flows through the lowland, metropolitan area of Hanoi Megacity (7.5 million inhabitants in 2015), and is subjected to high influx of untreated wastewater. Due to considerable industrial, agricultural, socioeconomic activities in the Day River basin, it has received high load of anthropogenic nutrients (Nghiem et al. 2010; Luu et al. 2012; Do et al. 2014). Previous studies implemented in the Day River mainly focused on physical-chemical parameters along the river system (Pham et al. 2010; Nghiem et al. 2010), nutrient budget, flow in of an agricultural watershed area (Luu et al. 2012; Orange et al. 2013; Pham et al. 2015), and hydrological regime in the Day River delta (Luu et al. 2010; Orange et al. 2013). However, relatively few studies have documented the effects of water pollution on the biological communities of the Day River. The present study, therefore, was carried out to examine the major pattern in dominant groups of plankton community throughout the year 2015 at 11 sites from the upstream to the downstream Day River. In addition, the relationships between environmental factors and plankton community were analyzed and discussed.

Material and method

Study sites, sample collection, and analysis

The Day River, a distributary of the Red River, has a length of 240 km; starts from the Hat Mon gate (about 25 km upstream of Hanoi); runs through Hanoi, Ha Nam, Nam Dinh, and Ninh Binh city/provinces; and discharges to the sea at Day River Mouth. After reconstruction of the Day dam in 1937, the Day River no longer receives water from the Red River but it gets water from five main tributaries such as the Bui, Nhue, Chau, Boi, and Dao Rivers. Thus, the upstream course (from Day dam to Ba Tha, about 71 km), the Day River, is considered as a dead river section (Luu et al. 2010). The Bui and Boi Rivers are located on the right bank and joint to the Day River at Ba Tha and Gian Khau, respectively. The Nhue, Chau, and Dao Rivers, which are located on the left side from the Day River, are fed by the Red River. The Nhue River is supplied by water from the Red River through Lien Mac sluice and also receives most of the untreated domestic and industrial wastewater from the Hanoi metropolitan area via the To Lich River (Trinh 2003). The Day River is narrow and shallow due to siltation.

The hydrographic network of the Day River is very complex, characterized by a dense system of small rivers and irrigation channels for agricultural activities (Luu et al. 2010). In general, 87% of the flow in the Day-Nhue river basin is taken from the Red River and only 13% originates within the catchment's area. For this reason, the hydrological regime of river system in the basin depends much on the operation of hydraulic works in the Red River through the dams or irrigation channels. The average discharge of the Day River is about 85 m^3/s at the Phu Ly town (Ha Nam province) (Luu et al. 2010). The Day River located within the tropical climatic zone with average annual rainfall is about 1800–2000 mm, 80% of which occurs during rainy season from May to October.

In the Day River basin, the land use is characterized by agricultural land (about 49.5%); the forest and industrial cultivation occupy about 19.1 and 13.8%, respectively, urban area takes only 4.9% (Nguyen 2005; Luu et al. 2012). About 80% of the total population in the basin participates in agricultural production activities (Luu et al. 2012). There were 4113 factories around the Day River basin with 79% of the factories located in Hanoi (upstream Day River), 10% in Nam Dinh, 5% in Ninh Binh, and 4% in Ha Nam (Nghiem et al. 2010).

Field sampling was carried out monthly at 11 sites (D1–D11) along the longitudinal gradient of the Day River from January to December 2015 (Fig. 1). A detailed description of the 11 sampling sites is presented in Table 1. For all compartments (environmental parameters, phytoplankton, and zooplankton communities), three replicate samples were randomly collected at each site in each month. Physical parameters (temperature, pH, dissolved oxygen (DO), and conductivity) were measured in situ using a multi-parameter probe (Hydrolab 5, USA). Water samples for NH_4-N, PO_4-P, total nitrogen (TN), total phosphorus (TP), and chlorophyll a (Chl a) analyses were collected the same day near the surface, filtered through Whatman GF/C filters (0.45 μm) in the field, and kept in cooling boxes in the dark at 4 °C, before they were immediately transferred to the laboratory for further analyses. Chemical analyses were conducted according to standard methods for the examination of water and wastewater (APHA 1999). The indophenol blue technique was used for ammonium (NH_4) determination by addition of citrate, phenol-nitroprusside reagent, and a basic solution of commercial hypochlorite. The Kjeldahl digestion method was used for total nitrogen (TN) analysis. Samples for total phosphorus (TP) were oxidized by $(NH_4)_2S_2O_8$ in H_2SO_4 to convert all P to PO_4 before PO_4 determination. The detection limit was 0.01 mg P/L. Water samples for Chl a determination were extracted in acetone and measured spectro-photometrically, and the concentrations

Fig. 1 Location of the sampling sites in the Day River

Table 1 Description of the studied sampling sites in the Day River

Site	Location	Longitude	Latitude
D1	9 km from the Day dam, Red River source	105.6451	21.0752
D2	39 km from the source, located before receiving water from the Bui river	105.7271	20.9365
D3	60 km from the source, located after the confluence to the Bui river	105.7072	20.8058
D4	88 km from the source	105.7471	20.6865
D5	115 km from the source, situated before discharging from the polluted Nhue river	105.8726	20.5745
D6	126 km from the source, located after receiving water from the Nhue river	105.9115	20.5158
D7	146 km form the source, located before discharging from the Boi river	105.9208	20.3624
D8	162 km from the source, after receiving water from the Boi river	105.9807	20.2653
D9	175 km from the source	106.0451	20.2174
D10	193 km from the source, after receiving water from the Dao river	106.1660	20.1420
D11	Near estuary	106.1030	19.9280

were determined using the equations represented by APHA (1999).

Samples for identification and counting of phytoplankton were collected together with the monthly water sampling, fixed immediately with Lugol's iodine solution, and stored in the dark until return to the laboratory. The phytoplankton community structure was determined under the light microscope (Olympus BX 51) with a digital camera (Olympus DP12). Phytoplankton species were identified according to their morphology using standard references including Duong (1996), Komárek and Anagnostidis (1989, 1999, 2005), Krammer and Lange-Bertalot (1986–1991), Van den Hoek et al. (1996), and Duong and Vo (1997). The cell sedimentation method was used for algal cell counting; and cell densities were estimated using a 1-mL Sedgewick-Rafter chamber (Karlson et al. 2010).

Zooplankton samples were collected in 2015 from May to September during the rainy season and from November to December during the dry season, together with water and phytoplankton sampling. Qualitative samples were collected using a 40-mm mesh-sized plankton net. For zooplankton abundance, a known volume (20–40 L) of water was collected and then filtered across a plankton net. Both qualitative and quantitative samples then were fixed in 4–5% formalin solution. The floras of Dang et al. (1980), Dang and Ho (2001), Boxshall and Halsey (2004), Lang (1948), Reddy (1994), Kutikova (1970), Wang (1961), and Shen (1979) were used as references for zooplankton identification. Organisms were indentified to the lowest taxonomic level possible under a microscope (Olympus SZ61 and Olympus SZX-ZB). The zooplankton abundance was counted in a Bogorov counting chamber. Densities were expressed as individuals/m^3 for all identified groups.

Data treatment

Annual average values of water quality parameters were calculated for each sampling site ($n = 12$). A two-tailed test was used to test for significant differences in relative abundance of phytoplankton and zooplankton between sampling sites and seasons. To quantitatively examine the relationship between the plankton communities and the environmental variables, Pearson correlation and principal component analyses (PCA) were applied. Statistical analyses were performed using the statistical package SPSS for Windows, version 23.

Results and discussion

Physico-chemical parameters of the Day River water

Water monitoring based on physico-chemical parameters is a first approach in water assessment. In the present study, variations in water quality were investigated during the year 2015 at 11 sampling sites along the length of the Day River. Annual mean values of temperature, dissolved oxygen, pH, conductivity, salinity, and total dissolved solids (TDS) measured in situ are shown in Table 2. Water temperature varied strongly seasonally and ranged between 16.7 and 34.1 °C with an average value of 27 °C in the year 2015. Temperature was low in January and February (16.7–18.8 °C) and reached a maximum in August (35 °C). There was no significant difference in temperature pattern between sampling sites throughout the year ($p > 0.05$). All sites presented neutral pH levels, and mean pH values of the Day River water did not show statistically significant differences between sites ($p > 0.05$); it ranged from 6.6 to 8.2. Salinities in the Day River ranged from 0.09 to 0.19‰ at all sites from D1 to D10 during the sampling period, while site D11, which is located in the estuary, exhibited the highest mean salinity value of 4.48‰. Site D11 is subjected to a strong tidal influence, as illustrated by the high variability in salinity (0.21–17‰). TDS showed a similar trend to salinity. Mean TDS values ranged from 0.17 to 5.28 g/L, extreme values were observed in the estuary site (D11). According to Orange et al. (2013), tidal movement has a significant impact on nutrient fluxes from the coastline up to the confluence between the Day and the Nhue Rivers. Regarding the DO concentration, the mean values varied from 1.48 to 6.27 mg/L. A significant difference was observed between sampling sites ($p < 0.05$), and there was a clear alteration in the DO concentrations from upstream to downstream. Extremely low DO concentrations were observed in the waters of the upstream Day River (sites: D1, D2, D3, and D4) with the mean values of 1.5, 1.4, 2.1, and 1.7 mg/L, respectively (Table 2). The sites located in the downstream river (D9, D10, and D11) presented at least two times higher values than in the upstream river (5.3, 6.5, and 6.3 mg/L, respectively). Many factors can influence DO concentrations in aquatic ecosystems including meteo-hydrological regimes, chemical reactions, anthropogenic inputs, decay processes, and respiration of living organisms. During the study period, the DO values did not display differences between dry and rainy seasons ($p > 0.05$). The lower values of DO observed in the upstream parts of the Day River were similar to those in polluted rivers (Tolich and Nhue rivers) (Duong et al. 2006; Pham et al. 2010; Trinh et al. 2012). These upstream sites, which are located in the urban, industrial zone of Hanoi, were in a hypoxic state in the year 2010 (Trinh et al. 2013). In the present study, D1 and D2 sites presented a constant and slow flow of black-colored waters having bad organic odor. This could be attributed to the high loads of degradation of organic matter and nutrients (NH_4 and TP) from various households and industry sources, reaching these areas and leading to low oxygen concentration or even anaerobic conditions (Trinh et al. 2013). Such low DO concentration levels observed in the upstream parts of the Day River suggested the degradation of an aquatic system and potentially anthropogenic influence (Seitz et al. 2009). The confluence with other tributary rivers together with self-purification mechanisms leads to an increasing level of oxygen in the downstream section of the Day River.

The Day River was characterized by high concentrations of dissolved ammonia, orthophosphate, TN, and TP; however, no clear seasonal variation

Table 2 Environmental variables at 11 studied sites in the Day River system during the year 2015 (average values and min–max values)

Sites	Temp (°C)	pH	DO (mg/L)	Sal (ppt)	Cond (μS/cm)	TDS (g/L)	TP (mg/L)	TN (mg/L)	N-NH4 (mg/L)	P-PO4 (mg/L)	Chl a (μg/L)
D1	**25.5**	**7.11**	**1.48**	**0.19**	**378**	**0.24**	**0.15**	**0.92**	**0.13**	**0.02**	**30**
	(16.7–31)	*(6.6–8.2)*	*(0.22–3.9)*	*(0.09–0.28)*	*(199.2–554.4)*	*(0.12–3.56)*	*(0.01–0.52)*	*(0.34–2.45)*	*(0.016–0.73)*	*(0.01–0.081)*	*(4–70)*
D2	**26.7**	**7.2**	**1.4**	**0.13**	**424**	**0.27**	**0.68**	**1.99**	**1.28**	**0.4**	**60**
	(17–32.4)	*(6.8–7.5)*	*(0.35–3.7)*	*(0.09–0.17)*	*(254–688.6)*	*(0.16–0.44)*	*(0.07–2.03)*	*(0.52–8.6)*	*(0.14–6.62)*	*(0.02–1.58)*	*(9–120)*
D3	**27.2**	**7.2**	**2.14**	**0.14**	**424.6**	**0.172**	***0.23***	**1.89**	**0.38**	**0.11**	**20**
	(16.9–32.4)	*(6.8–7.5)*	*(0.38–4.69)*	*(0.11–0.19)*	*(254–688.6)*	*(0.12–0.22)*	*(0.01–0.6)*	*(0.86–4.86)*	*(0.04–1.03)*	*(0.01–0.32)*	*(6–50)*
D4	**27.2**	**7.2**	**1.72**	**0.14**	**270**	**0.19**	**0.14**	**1.96**	**2**	**0.046**	**24**
	(16.9–33.9)	*(6.8–7.6)*	(0.66–3.28)	(0.11–0.19)	(43.6–386.3)	(0.14–0.25)	(0.02–0.27)	*(1.08–4.2)*	*(1.08–4.2)*	(0.01–0.098)	*(4–43)*
D5	**27.7**	**7.3**	**3.19**	**0.15**	**314.3**	**0.2**	**0.1**	**2.2**	**2.21**	**0.05**	**39**
	(17.9–35)	*(6.9–7.6)*	*(1.67–6.21)*	*(0.12–0.21)*	*(247–413.2)*	*(0.16–0.26)*	*(0.01–0.4)*	*(1.02–4.82)*	(1.02–4.8)	*(0.01–0.14)*	*(5–120)*
D6	**27.2**	**7.3**	**3.22**	**0.18**	**372.4**	**0.23**	**0.14**	**2.39**	**2.39**	**0.06**	**40**
	(17.3–33.9)	*(7–7.6)*	*(1.02–6.4)*	*(0.14–0.23)*	*(291.4–449)*	*(0.19–0.29)*	*(0.04–0.27)*	*(1.02–5.3)*	*(1.06–5.6)*	*(0.01–0.14)*	*(7–67)*
D7	**27.2**	**7.4**	3.97	**0.18**	**374**	**0.23**	**0.13**	**3.02**	**3.02**	**0.04**	**43**
	(17.3–34.3)	*(7.1–7.5)*	*(1.78–8.4)*	*(0.14–0.24)*	*(288.2–477)*	*(0.18–0.31)*	*(0.01–0.3)*	*(1.06–5.6)*	*(1.06–3.8)*	*(0.01–0.16)*	*(6–110)*
D8	**27.4**	**7.5**	**5.14**	**0.18**	**361.2**	**0.24**	**0.1**	**2.4**	**2.4**	**0.016**	**27**
	(18.3–34)	*(7.1–7.9)*	*(1.8–7.9)*	*(0.14–0.24)*	*(289.4–447)*	*(0.18–0.29)*	*(0.01–0.2)*	*(0.98–3.78)*	*(0.98–3.78)*	*(0.01–0.039)*	*(3–70)*
D9	**27.3**	**7.5**	**5.3**	**0.16**	**318.5**	**0.2**	**0.08**	**2.2**	**2.2**	**0.02**	**20**
	(18.1–34)	*(7.0–7.9)*	*(2.8–8.2)*	*(0.1–0.22)*	*(218.2–433)*	*(0.14–0.27)*	*(0.01–0.24)*	*(0.84–3.69)*	*(0.98–3.69)*	*(0.01–0.04)*	*(2–40)*
D10	**26.3**	**7.7**	**6.48**	**0.09**	**205.2**	**0.13**	**0.07**	**1.46**	**1.46**	**0.02**	**10**
	(18.8–31)	*(7.2–7.9)*	*(4.6–8.1)*	*(0.07–0.14)*	*(166–294)*	*(0.1–0.18)*	*(0.01–0.24)*	*(0.86–2.25)*	*(0.86–2.25)*	*(0.01–0.05)*	*(3–40)*
D11	**26.7**	**7.6**	**6.27**	**4.78**	**8189.8**	**5.28**	**0.11**	**1.36**	**1.36**	**0.02**	**10**
	(18.4–32.7)	*(7.2–7.8)*	*(4.7–7.8)*	*(0.21–17.1)*	*(128–27,955)*	*(0.27–17.88)*	*(0.01–0.3)*	*(0.72–1.98)*	*(0.72–1.98)*	*(0.01–0.036)*	*(2–24)*

of these concentrations was observed. As shown in Table 2, dissolved orthophosphate-P concentration varied from 0.02 to 0.4 mg P/L. Average TP concentrations ranged between 0.082 and 0.68 mg P/L during the whole monitoring period. Relatively higher TP concentrations were observed in the upstream (D1, D2, and D3) compared to the downstream sites. TN concentrations exhibited a similar trend with high mean concentrations in the Day River for all sampling sites, varying between 0.92 and 3.01 mg N/L. Mean values of ammonia concentrations ranged from 0.13 to 3.02 mg N/L with an average of 0.18 mg N/L for the whole river system. The results indicated that the average values of ammonia concentrations at most sampling sites were much higher than the limits recommended by the national regulations (0.3 mg/L) for surface water (QCVN 08: 2015). High levels of ammonia, phosphate, TN, and TP have been reported previously for this area (Pham et al. 2010; Trinh et al. 2013) and for other rivers within the Red River delta (Trinh 2003; Duong et al. 2006). The high values of these parameters in the Day River upstream part were also observed from previous studies (Trinh et al. 2013).

TN/TP ratios varied from 2.9 to 27 with very low values observed in the upstream sites of the Day River (D1, D2, and D3 sites). The low values of TN/TP ratios in these sites may be due to the sewage inputs and water runoff from agricultural and industrial activities, and it could reflect high rates of denitrification associated with increased anoxia (Pick and Lean 1987; Trinh et al. 2013). Mean concentration of Chl a ranged from 10 to 60 μg/L. Based on our results of the physical and chemical parameters and the classification method of eutrophic water systems proposed by OECD (1982), the Day River water quality can be classified to be in eutrophic condition. The results obtained in this study are consistent with those from other earlier studies carried out by Luu (2010), Pham et al. (2010), and Trinh et al. (2013) in the Day River basin. These studies showed that the untreated sewage from Hanoi metropolitan areas and water runoff from agriculture areas might be responsible for heavy organic matter and nutrient pollution (Luu 2010; Pham et al. 2010; Trinh et al. 2013) as well as enrichment of heavy metals (Trinh et al. 2013).

Biotic variables

Phytoplankton community

The Day River basin has been limited in published information concerning ecological aspects of plankton and their relation to environmental factors. Therefore, the results of the present study provide fundamental information on the spatial and temporal distribution of phytoplankton and zooplankton communities in the Day River. The phytoplankton composition of the Day River water is presented in Fig. 2 and Tables 3 and 4. From the

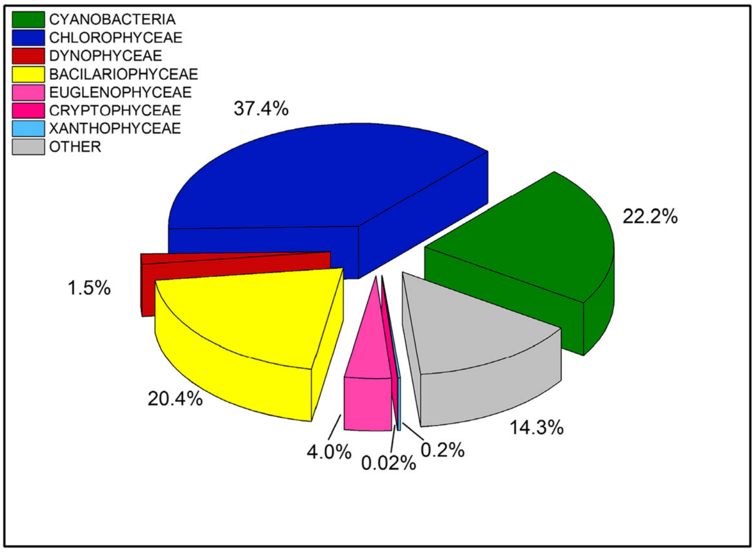

Fig. 2 Proportion of different phytoplankton groups in the Day River during the study period January to December 2015

Table 3 Results of Pearson's correlation analysis on the relationships between main plankton groups and environmental factors

	Temp	DO	Sal	pH	Turb	Cond	TDS	NH4	PO4	T-P	T-N	Chl a	Tot Phy	CYA	BAC	CHL	EUG	Tol Zoo	COP	CLA	ROT
Temp	1																				
DO	−0.036	1																			
Sal	−0.124	0.249**	1																		
pH	0.258**	0.592**	0.093	1																	
Turb	0.050	0.207*	0.130	0.252**	1																
Cond	−0.129	0.249**	0.999**	0.094	0.145	1															
TDS	−0.128	0.251**	0.999**	0.098	0.141	1.000**	1														
NH4	−0.091	−0.373**	−0.096	−0.173*	−0.083	−0.085	−0.085	1													
PO4	−0.197*	−0.294**	−0.070	−0.244**	−0.047	−0.057	−0.058	0.724**	1												
TP	0.203*	−0.025	−0.013	−0.003	−0.065	−0.016	−0.014	−0.032	0.055	1											
TN	−0.246**	0.059	−0.065	−0.204*	−0.061	−0.063	−0.064	0.435**	0.252**	−0.136	1										
Chl a	0.438**	−0.141	−0.171	−0.046	−0.125	−0.174*	−0.172*	0.065	0.040	0.401**	−0.017	1									
Tot P-hy	0.378**	−0.204*	−0.188*	−0.060	−0.076	−0.193*	−0.192*	0.009	−0.035	0.341**	−0.082	0.744**	1								
CYA	0.213*	−0.222*	−0.110	0.140	0.065	−0.113	−0.110	−0.002	−0.020	0.227*	−0.183*	0.454**	0.782**	1							
BAC	0.171	0.187*	−0.075	0.083	−0.002	−0.077	−0.076	−0.077	−0.105	0.080	0.192*	0.450**	0.498**	0.312**	1						
CHL	0.404**	−0.175	−0.137	−0.253**	−0.136	−0.139	−0.138	−0.007	0.013	0.356**	−0.125	0.651**	0.788**	0.374**	0.079	1					
EUG	0.227*	−0.270**	−0.085	−0.081	−0.081	−0.085	−0.084	0.081	0.042	0.273**	−0.248**	0.418**	0.536**	0.359**	−0.017	0.464**	1				
Tol Z-oo	0.327*	0.042	−0.271	0.052	−0.018	−0.272	−0.276	0.025	0.090	0.409**	0.159	0.112	0.225	0.177	0.332*	0.208	−0.099	1			
COP	−0.081	0.177	−0.011	0.095	−0.013	−0.012	−0.019	0.037	−0.236	−0.246	0.408**	−0.190	−0.189	−0.185	−0.022	−0.110	−0.226	0.519**	1		
CLA	0.466**	−0.049	−0.242	0.038	−0.007	−0.239	−0.249	0.110	0.110	0.330*	0.160	0.425**	0.286	0.174	0.314*	0.345*	−0.148	0.617**	0.254	1	
ROT	0.507**	−0.010	−0.093	−0.143	−0.052	−0.086	−0.092	0.020	0.439**	0.584**	−0.187	0.532**	0.490**	0.288	0.270	0.573**	0.208	0.689**	−0.175	0.196	1

***Correlation is significant at the 0.05 level (two-tailed); Correlation is significant at the 0.01 level (two-tailed)

Table 4 Phytoplankton groups and dominant species in the Day River during the year 2015

Phytoplankton groups	Dominant species
Cyanobacteria	*Merismopedia*, *Microcystis*, *Oscillatoria*
Chlorophyceae	*Scenedesmus acuminatus*, *Crucigenia* sp., *Pediastrum duplex*, *Pediastrum simplex*, *Pediastrum* sp., *Chlorella* sp., *Monoraphidium*
Bacillariophyceae	*Aulacoseira granulata*, *Cyclotella meneghiniana*, *Cyclotella stelligera*, *Cyclotella* sp., *Nitzschia palea*, *Nitzschia filiformis*, *Nitzschia* sp., *Navicula* sp., *Fragilaria* sp.
Cryptophyceae	*Cryptomonas* sp.
Dinophyceae	*Ceratium* sp., *Peridinium* sp.
Euglenophyceae	*Trachelomonas* sp., *Phacus* sp., *Euglena* sp.
Xanthophyceae	*Tribonema* sp.

analysis of phytoplankton, a total of 87 taxa belonging to seven groups were identified. These include Chlorophyceae, Bacillariophyceae, Cryptophyceae, Euglenophyceae, Dinophyceae, Xanthophyceae, and Cyanobacteria. The three groups of Chlorophyceae, Cyanobacteria, and Bacillariophyceae were the most abundant in the Day River with proportions of 37.4, 22.2, and 20.4%, respectively, in the community. Cryptophyceae, Euglenophyceae, Dinophyceae, and Xanthophyceae were found in smaller proportions. The phytoplankton community consisted of more than 68 genera; Bacillariophyceae had the highest diversity of genera (23 genera), whereas, the Xanthophyceae had the lowest diversity (1 genera). The general phytoplankton communities of the Day River observed in the present study were cosmopolitan and typical of eutrophic rivers. Chlorophyceae (green algae), an abundant component of phytoplankton community in the Day River, was dominated by small planktonic Chlorococcales including *Scenedesmus*, *Chlorella* sp., *Crucigenia*, *Pediastrum*, and *Monoraphidium*. The Chlorococcales genera *Coelastrum*, *Pediastrum*, *Crucigenia*, and *Scenedesmus* have been found to be abundant in eutrophic pond and lake systems in North Vietnam (Vu et al. 2012; Duong et al. 2012). The high abundance of Chlorophyceae in the Day waters could be attributed to high nutrient contents (Kshirsagar et al. 2012). The untreated industrial, agricultural, and municipal wastewater discharged to the Day River seemed to provide a favorable conditions for the growth of green algae. It is interesting to note that desmid green algae genera including *Actinastrum*, *Ankistrodesmus*, *Pediastrum*, and *Scenedesmus* are prominent in many tropical assemblages (Reynolds and Descy 1996). Following Chlorophyceae, the two groups Cyanobacteria and Bacillariophyceae were the second most important component of phytoplankton community of the Day River. The prevailing Cyanobacteria species in the Day River were small-cell species of coccoid cyanobacteria colony forms such as *Merismopedia* sp., *Microcystis aeruginosa*, and solitary filamentous forms such as *Phormidium* and *Anabaena* sp. The cyanobacteria are commonly associated with eutrophic waters, where they often produce blooms and toxins (Falconer 1996). Cyanobacterial abundance was shown to increase in waters enriched with organic matter loads (Kotut et al. 2010) with species able to tolerate anaerobic conditions. The dominant species belonging to the Bacillariophyceae group (diatom) during the study period were represented by centric species such as *Aulacoseira granulata*, *Cyclotella meneghiniana*, *Cyclotella stelligera*, *Cyclotella* sp., and pennate diatoms including *Nitzschia palea*, *Nitzschia umbonata*, *Navicula* sp., and *Fragilaria* sp. These assemblages have already been reported in the heavily polluted To Lich and Nhue rivers (Duong et al. 2006, 2012); their presences are characteristic of sewage-polluted waters, and the abundance of these organisms might explain a decrease in the water quality. Furthermore, the dominance of the small centric diatoms has been observed as a "typical characteristic" of nutrient-rich lowland rivers in tropical and European countries (Góme and Bauer 1998; Bahnwart et al. 1999; Tavernini et al. 2011). In addition to the dominant assemblages mentioned previously, there were other groups appearing in lower numbers in the phytoplankton community of the Day River. Species belonging to groups Cryptophyceae, Euglenophyceae, Dinophyceae, and Xanthophyceae can be found in both seasons and in different sites. Examples of such are *Cryptomonas* sp., *Phacus* sp., *Trachelomonas* sp., *Peridinium* sp., and *Tribonema* sp.

Figure 3 shows phytoplankton group proportions (average in 11 sampling sites) along the Day River in the rainy and dry seasons during the year 2015. For all sampling sites, the phytoplankton community consisted mainly of Chlorophyceae, Bacillariophyceae, and Cyanobacteria with clear differences in algal proportions between seasons and sites. During the dry season,

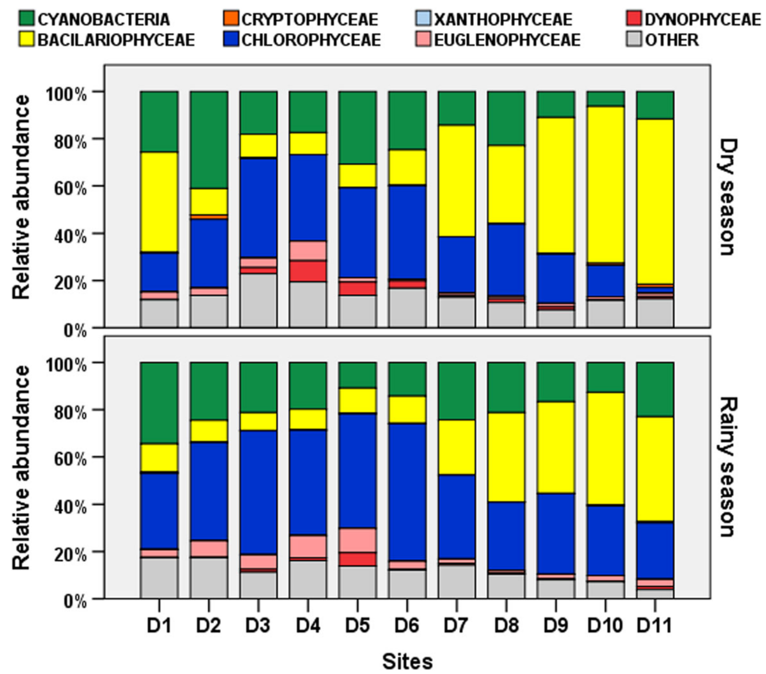

Fig. 3 Longitudinal phytoplankton group proportions (% from abundance data) at 11 sites in the Day River during the rainy season (May to October) and in the dry season (November to April) 2015

a distinct longitudinal variation in phytoplankton composition was observed. The Bacillariophyceae group with pennate forms became more important in the downstream river than in the upstream region. The centric diatoms were recorded frequently at the D1 to D3 sites where the water current was slow. It is interesting to note that the fast-flowing rivers are characterized by pennate diatoms whereas centric diatoms are abundant in low velocity currents and nutrient-rich large rivers, as described by Descy (1987). Chlorophyceae, which consisted mainly of small genera forms such as *Scenedesmus*, *Chlorella* sp., *Crucigenia*, *Monoraphidium*, and *Ankistrodesmus*, were dominant in the upstream part and then decreased downstream of the Day River. Cyanobacteria were present at all studied sites, with higher percentages occurring from sites D1 to D6 (17–41% of the total community), in contrast to the upper course; fast currents in lower region tended to limit the development of this group (6–11% of the total community). Low TN/TP ratios at the upper course of the Day River could promote the growth of cyanobacteria (Jin et al. 2011). In addition, the Cyanobacterial group, which grows rapidly in rich organic environments, was important in the upper part of the Day River, suggesting that these sites have poor water quality (Ngodhe et al. 2013). Euglenophyceae were found in higher proportions in the upstream sites than downstream of the Day River.

During the rainy period, the change in the relative abundance of phytoplankton groups between sites can be observed in more detail in Fig. 3. The abundance of Chlorophyceae along the river differed from that noted in the dry period, this group was dominant at all sampling sites. The main effect of seasons on the three dominant phytoplankton groups (Chlorophyceae, Cyanobacteria, and Bacillariophyceae) showed that Chlorophyceae abundance was significantly higher ($p < 0.05$) than that of diatoms and cyanobacteria in the rainy period. The increasing importance of green algae and cyanobacteria groups at all studied sites during the rainy season was probably due to high temperature and nutrient concentrations. Bacillariophyceae increased gradually (7 to 47% of the total phytoplankton community) from D1 to D11 sites; however, these values were lower compared to those obtained in the dry season.

Changes in phytoplankton abundance and Chl a concentrations from January to December 2015 in the Day River are shown in Fig. 4. The total phytoplankton abundance displayed significant temporal fluctuations ($p < 0.05$), three major peaks were detected in May, August, and November (317×10^5, 243.6×10^5, and

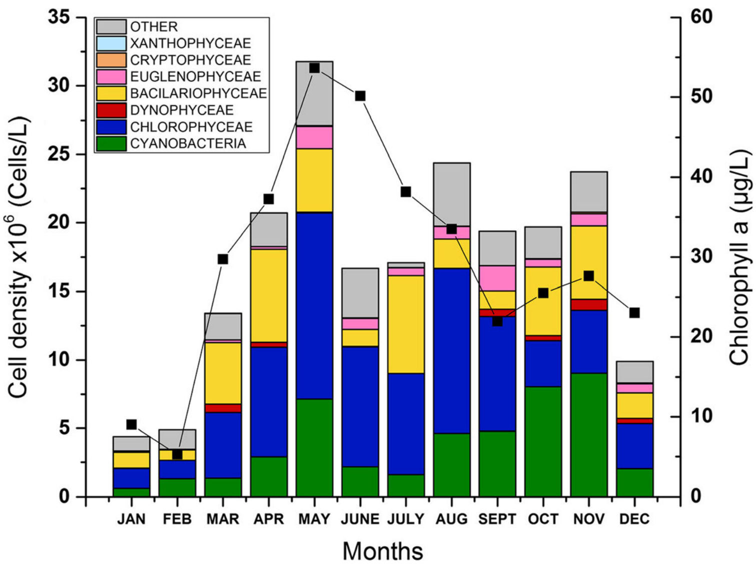

Fig. 4 Variation in phytoplankton density and chlorophyll a concentration in the Day River during the studied period in 2015

236.1×10^5 cell/L, respectively). Chl a concentrations of the Day River waters showed similar patterns as phytoplankton biomass in term of cell density with the highest Chl a concentration obtained in May (54 μg/L) when the phytoplankton cell density was found to be the highest. Although seasonal variation of phytoplankton density was investigated and noted in many studies; however, phytoplankton variations were not always consistent. For example, investigation studies from tropical waters have shown higher phytoplankton biomass in dry period rather than in rainy season (Nweze 2006). In contrast, Huang et al. (2004) working on the Pearl River estuary found that the abundance of phytoplankton in summer was much higher than in winter. Similar observations were reported by Lung'ayia et al. (2000), Ezekiel et al. (2011), and Matos et al. (2011). In the present study, it was observed that the phytoplankton biomass was significantly higher ($p < 0.05$) during the rainy period and lower in the dry season. The high abundance of phytoplankton in rainy period was mainly contributed by small forms of planktonic including Chlorococcales species (*Scenedesmu*s, *Chlorella* sp., *Crucigenia*) and small-cell species of Cyanobacteria (*Merismopedia* sp. and *Anabaena* sp). Although, nutrient concentrations appeared to be favorable for increased phytoplankton population in the Day River. The increase of phytoplankton abundance of Chlorophyceae and Cyanobacteria during the rainy period could be due to combination of high light intensity, warm temperature climatic regime, and high inputs of nutrients and sediments. These abovementioned conditions probably promoted the cyanobacteria and gave green algae a comparative advantage over the other phytoplankton in the Day River system (Sekadende et al. 2005; Duong et al. 2012).

Zooplankton community

During the studied period, a total of 53 taxa were recognized through the analysis of 44 samples from 11 studied sites in dry and rainy seasons. Zooplankton from the Day River was comprised of three main groups including Copepoda, Cladocera, and Rotatoria. All of the zooplankton genera observed in the present study were planktonic. The relative abundance of zooplankton composition was dominated by the Copepoda (reached 48% of the total zooplankton community) then followed by Cladocera (reached 31% of the total zooplankton community) and Rotatoria (reached 19% of the total zooplankton community) (Fig. 5). Another group of zooplankton formed only 2% of the total zooplankton community including *Ostracoda*, *Mollusca*, *Chironomidae*, and *Hemiptera*. The dominance of Copepoda observed in the present study was generally in line with other reports by Fetahia et al. (2011) for tropical waters of Ethiopia, by Tackx et al. (2004), in the Scheldt estuary in Belgium in which copepods and several Cladocera abundant in the freshwater and lower brackish water transect of the estuaries. Regarding species composition, Copepoda was the most diversed (21 species)

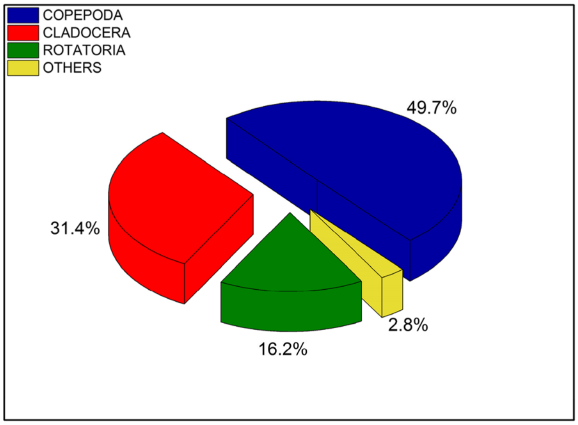

Fig. 5 Proportion of different zooplankton groups in the Day River during the study period from January to December 2015

followed by *Cladocera* (16 species), *Rotatoria* (9 species), and other group (7 species) (data not show). Among the zooplankton organisms identified in the Day River, the following zooplankton species were prominent: *Mesocyclops* spp., *Thermocyclops hyalinus* (Copepoda); *Bosmina longirostris*, *Diaphanosoma sari*, *Moina dubia*, *Moinodaphnia macleayi* (Cladocera), *Asplanchna sieboldi*, *Brachionus calyciflorus*, *Brachionus falcatus* (Rotatoria) (Table 5). Most of them are cosmopolitan and planktonic taxa. These species recorded in the present study were common in other water bodies and rivers in North Vietnam (Phan and Nguyen 2013; Dang and Ho 2001). The occurrence and dominance of species *Bosmina longirostris*, *Mesocyclops*, *Diaphanosoma*, and *Asplanchna* in the Day River have been known as indicators of the trophic status of water bodies and high level of organic pollution (Padmanabha and Belaghi 2008; Dirican et al. 2009; Li et al. 2016).

Table 5 Zooplankton groups and dominant species in the Day River during the year 2015

Zooplankton groups	Dominant species
Cladocera	*Bosmina longirostris*, *Diaphanosoma sari*, *Diaphanosoma excisum*, *Moina dubia*, *Ceriodaphnia rigaudi*, *Ilyocrypus halyi*
Copepoda	*Mongolodiaptomus birulai*, *M. botulifer*, *Phyllodiaptomus tunguidus*, *Mesocyclops woutersi*, *Mesocyclops* spp., *Thermocyclops hyalinus*, *Thermocyclops taihokuensis*
Rotatoria	*Asplanchna sieboldi*, *Brachionus calyciflorus*, *Brachionus falcatus*, *Filinia longiseta*, *Lecane ungulata*, *Rotaria rotaria*

The spatial distribution of zooplankton groups in the Day River during rainy and dry seasons is presented in Fig. 6. Based on numerical abundance, Copepoda was the most dominated zooplankton group in most of the studied sites and both during rainy and dry periods. There was no significant difference ($p > 0.05$) in the proportion of Cladocera between sites and seasons during the study period. The main difference in zooplankton community structure was observed for the Rotatoria group. Rotatoria abundance was higher in the rainy period than the dry season. Relative abundance of Rotatoria increased from sites D1 to D7.

As shown in Fig. 7, the overall zooplankton standing crop throughout the study period presented that the river was productive with higher zooplankton biomass in rainy season (137,836 individuals/m^3). Copepoda represented 55.6% (5324 individuals/m^3) of the total zooplankton community in the rainy season and 43% (5390 individuals/m^3) of the total zooplankton community in the dry season. However, Cladocera formed similar percentage, accounting 32% of the total count (in the rainy period) and 30% (in dry period) of the total count. Rotatoria contributed significant biomass about 25% of the total zooplankton community in rainy season compared to those in dry season (about 10% of the total zooplankton community). More nutrient sources from drainage basin entering the river during the rainy season may have contributed positively to high zooplankton productivity (Ikhuoriah et al. 2015). The increase of individual number of zooplankton community during wet period, especially rotifers, could be explained by their short life cycle, quick adaptation to environmental variations, and higher turnover rates (Neto et al. 2014).

Relations between plankton and physical and chemical factors

Relations between plankton communities and environmental factors are enhanced through the principal correspondence analysis (Fig. 8) and the Pearson correlation analysis (Table 3). Physical and chemical parameters (water temperature, DO, salinity, conductivity, TDS, pH, turbidity, NH_4-N, PO_4-P, TP, and TN) and biological parameters (Chl a, phytoplankton and zooplankton density, relative abundance of phytoplankton and zooplankton groups) were selected as independent variables for the PCA. The results indicate that nutrients (TP and

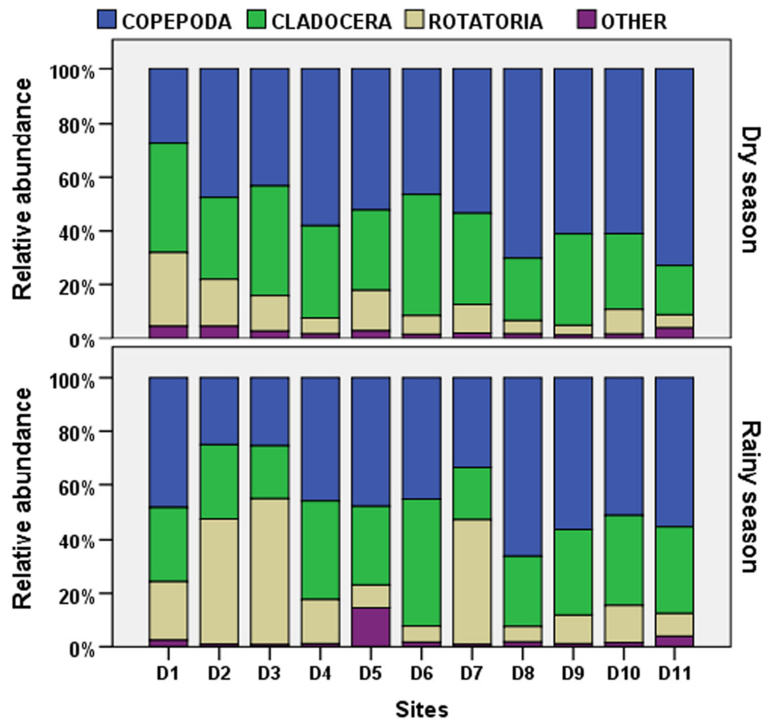

Fig. 6 Longitudinal zooplankton group proportions (% from abundance data) at 11 sites in the Day River during the rainy season (May to October) and in the dry season (November to April) 2015

TN), temperature, salinity, and conductivity are the variables that affected the variation and distribution of the plankton in the Day River. The first two axes of the PCA components accounted for 55% of the explained variability. Three groups of sites are clearly separated on the PCA plane. The upstream sites (D1 and D2) located on the lower right side of PCA where high relative abundance of Cyanobacteria, Chlorophyceae, Euglenophyceae, Xanthophyceae, and Cryptophyceae coincided with ammonia, phosphate, TP, and Chl a concentrations. The second group of sites located on the upper side of the PCA plane

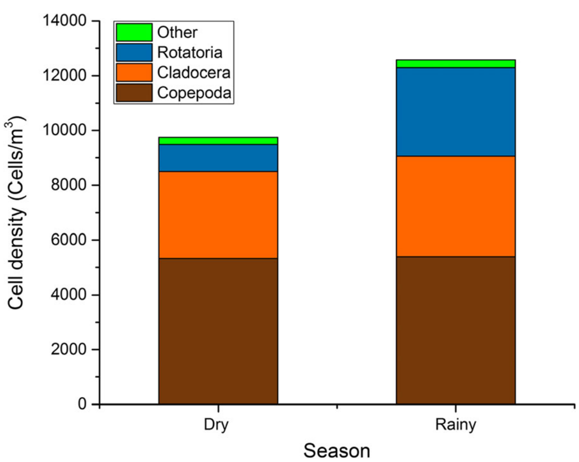

Fig. 7 Zooplankton density in the Day River during the rainy (May to October) and in the dry seasons (November to April) in 2015

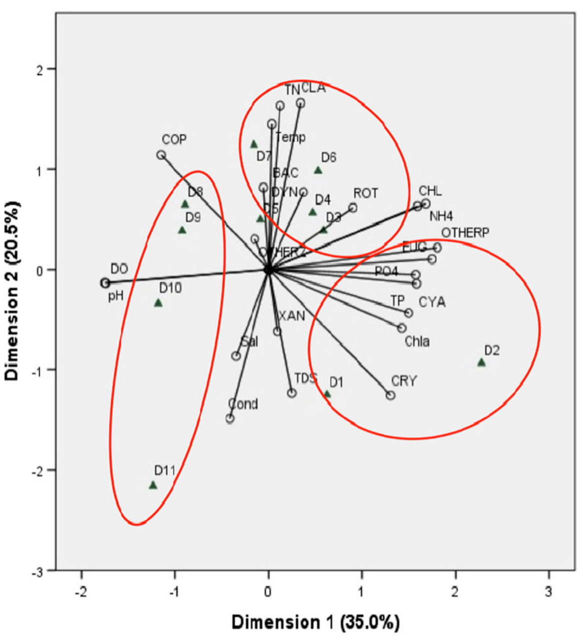

Fig. 8 Principal component analysis based on biotic and abiotic factors for 11 sampling sites during the period of January–December 2015 in Day River

(D3, D4, D5, D6, and D7 sites) where Cladocera, Rotatoria, Bacillariophyceae, and Dinophyceae constituted plankton communities of the middle course of the Day River related high level of TN. The downstream sites (D8, D9, D10, and D11) appear clearly separated and located on the right part of the PCA. These sites were represented high level of pH, dissolved oxygen, conductivity, salinity, TDS, and a high abundance of Copepoda. On the axis 1, there is an opposition between the downstream part under seawater influence and the upstream part under influence of human point source of organic pollution. Then, the positive part of axis 1 is driven by a high level of NH4 and PO4 loads, such as eutrophic area, as well. Crossing, the axis 2, is balanced between conductivity and TDS in the negative part to the TN and temp in the positive part. The results suggested that the influence of water quality on the structure of the plankton assemblages was greater in the upper part of the Day River.

In aquatic ecosystems, many factors including radiation, temperature, nutrient availability, physical transport processes, and grazing are known to control the biomass, distribution, and variation of plankton communities (Paerl and Huisman 2008; Lancelot and Muylaert 2011; Sailley et al. 2015). In the present study, an analysis of PCA and Pearson correlation revealed that plankton abundance appeared to be controlled by several environmental factors especially water temperature and nutrient sources (Table 3). Water temperature is one of the important environmental factors that plays a major role in plankton growth. Phytoplankton biomass (in term of Chl a and density), zooplankton density, and relative abundance of all dominant plankton groups in the Day River showed significant positive correlation with water temperature and total phosphorus (Table 3). Our results correspond to the observations of O'Farrel and Izaguirre (1994) and De-Domitrovic et al. (2014). These authors explained that temperature and suspended solid were responsible for the spatial and temporal changes of phytoplankton in the Uruguay and Paraguay river systems during their investigations. In other earlier studies conducted in estuary systems, water temperature and salinity were the main environmental gradients regulating variations in zooplankton species composition and abundance (Tackx et al. 2004; Marques et al. 2008). Thus, in our study, high temperature increased biomass of plankton and proportion of important groups (Cyanobacteria, Chlorophyceae, Euglenophyceae, Cladocera, and Rotatoria) in the Day River except Bacillariophyceae, Cladocera, and Copepoda. This result suggested that temperature was a more important factor for the growth of Cyanobacteria, Chlorophyceae, Euglenophyceae, Cladocera, and Rotatoria than diatom, Cladocera, and Copepoda in the Day River. Look at the important plankton communities, the biomass of Cyanobacteria, Chlorophyceae, Cladocera, and Rotatoria groups increased relatively in all studies sites during the summer and autumn months (rainy season). The Cyanobacteria and green algae, mainly represented by Chlorococcales, formed the major component of the phytoplankton community in summer. The increase in their abundance clearly appeared to be related to temperature increases; this phenomenon has been previously observed in several aquatic systems (Salmaso 2000; Suikkanen et al. 2013). The prevailing Chlorophyceae and cyanobacteria in the present study could be linked to their small forms, short life cycle, and greater nutrient storage capacity, which makes them better competitors than other plankton. It can be seen from PCA and Pearson correlation analyses that nutrients such as total phosphorus and total nitrogen were also important in regulating plankton communities within the Day River (Fig. 8 and Table 3). As known, nutrients factors seem to be important for some plankton groups in structuring their communities. Indeed, it has been found that P concentration promoted the growth of phytoplankton especially Cyanobacteria and green algae (Davis et al. 2009; Joung et al. 2011). The positive and significant relationship between TP and relative abundance of Cladocera and Rotatoria demonstrated that the biomass of these groups had strong dependence on total phosphorus concentrations. As pointed out by several earlier studies, factors such as temperature, phosphorus, and Chl a have controlled the dominance of Rotatoria species (Czerniawski and Domagala 2011).

In conclusion, the 1-year survey conducted on the Day River (in the Red River Delta) provided valuable information on the spatial and temporal variations in water quality and plankton communities. The results showed that the Day River was strongly influenced by untreated sewage from Hanoi metropolitan and water runoff from agriculture areas, presented by low dissolved oxygen, anoxic conditions, and high concentrations of nutrients. This river is a eutrophic ecosystem with the average values of total phosphorus concentration of 0.17 mg/L, total nitrogen concentration of 1.98 mg/L, and Chl a of 54 μg/L. Phytoplankton of the Day River were characterized by cosmopolitan and eutrophic species belonging to main groups such as Chlorophyceae, Bacillariophyceae, and Cyanobacteria. There was a distinct longitudinal dynamics of phytoplankton composition during the dry and rainy season. The phytoplankton exhibited higher densities in rainy season with increasing of green algae and Cyanobacteria. Zooplankton from the Day River was comprised of three main groups including Copepoda, Cladocera, and Rotatoria of which Copepoda was the most dominated zooplankton group in most of the studied sites and in both rainy and dry periods. The dominant zooplankton species also revealed the typical eutrophic conditions of the Day River. In the present study, nutrients and temperature were the main factors structuring plankton communities, their distribution, and growth in the Day River system.

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