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Evaluation of physico-chemical parameters regulating zooplankton community structure in the Geum River, Korea

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Abstract

The aim of the present study was to examine the dynamics of zooplankton community structure in the midstream of the Geum River, South Korea. The sampling was performed bi-monthly at five stations. During the study period, the most dominant taxa was Rotifera, comprising 73.3% of the total abundance, followed by Protozoa (17.3%), Cladocera (5.4%), and Copepoda (4.0%). The correlation coefficients between selected physico-chemical parameters and zooplankton abundance showed that the generation of zooplankton in the study area was highly correlated with water temperature (WT), chlorophyll *a* concentration, and pH values. As the river flows downstream (from GC and MC stations to SW, GW, and BW stations), zooplankton abundance was augmented, influenced by the levels of total phosphorus (TP), and total nitrogen (TN), while total organic carbon (TOC) decreased, and pH values increased. Furthermore, the values of WT, TN, TP, and TOC were higher and zooplankton abundance was lower at the GC station than at other stations. The results suggested that the dynamics of zooplankton community in the midstream of the Geum River was influenced not only by physico-chemical factors but also by the inflow from the upper streams.

Keywords: Relationship, Physico-chemical parameter, Abundance, Zooplankton community

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Introduction

Zooplanktons are a group of small-sized heterotrophic organisms living in aquatic environments. They are important members of the aquatic ecosystem because of their roles in transferring primary energy to secondary consumers and generation of various nutrients in the environment via feeding on photoautotrophic or other organisms (Steinberg and Condon, 2009). Because the size range of zooplankton is highly diverse (microzooplankton, <200 μm; mesozooplankton, 200 μm–2 mm; macrozooplankton, >2 mm), it is considered that the feeding properties of zooplankton vary and may significantly affect production and distribution of other organisms (Steinberg and Condon, 2009). In addition, they play important roles in the regulation of biological carbon cycling and phytoplankton structure dynamics (Vanni, 1987; El-Sherbiny *et al*., 2011; Abdulwahab and Rabee, 2015). Thus, the studies on seasonal dynamics of zooplankton community are important to examine properties of aquatic ecosystem. According to a number of studies, physico-chemical factors such as total phosphorus (TP), total nitrogen (TN), water temperature (WT), chemical oxygen demand, dissolved oxygen, and total dissolved solids are closely related to the occurrence of different taxa of zooplankton in different study areas (Hwang and Heath, 1997; Abdulwahab and Rabee, 2015). Hence, the presence of different zooplankton taxa can be used as bio-indicators of environmental pollution in water (El-Bassat and Taylor, 2007; Neto *et al*., 2014; Abdulwahab and Rabee, 2015). The Geum River is the third largest river in South Korea. Due to the year-round activities of agriculture, such as cultivation of crops in greenhouses near the river, its groundwater has been contaminated and highly eutrophic, with nitrate (NO_3), iron (Fe) and manganese (Mn) exceeding the Korean drinking water limits (Chae *et al*., 2004). Such conditions facilitate frequent and harmful algal blooms (HABs) along the Geum River during the summer season (Oh *et al*., 2007; Huy *et al*., 2013). Furthermore, since the implementation of the Four Major Rivers Restoration Project (FMRRP) was approached in South Korea, there have been growing concerns about problems in aquatic ecosystem due to harmful cyanobacterial bloom (Lim *et al*., 2015). Therefore, the restoration of aquatic ecosystems has attracted increasing attention, and the Korean Ministry of Environment has investigated and assessed the health status of the aquatic ecosystems based on that of benthic diatoms, macro-invertebrates, fishes, and aquatic plants through the National Aquatic Ecological Monitoring Program (NAEMP) (Lee *et al*., 2011; Park and Hwang, 2016). Although many studies on the dynamics of various organisms under different physico-chemical conditions were performed along the Geum River (Yih *et al*., 2005; Lee *et al*., 2011; Shin, 2013), correlation between physico-chemical parameters and the dynamics of zooplankton community structure remains poorly understood. Therefore, this study investigated the effect of physico-chemical parameters on the dynamics of zooplankton community structure at five stations located in the midstream of the Geum River from January 2014 to December 2015. The information about zooplankton community structure will provide comprehensive understanding of the effect of HABs generation and its relationship with other organisms, the dynamics of aquatic ecosystems, the patterns of carbon cycling, and the estimation of predator community.

Materials and methods

Study site

The Geum River extends for about 396 km over 9,810 km^2 of basin area, and it flows into the Yellow Sea (Park *et al.*, 2007; Suzuki *et al.*, 2010). As shown in Fig. 1, the study was performed at five stations in the midstream: Gap-Cheon (GC; N127°24′09.11″ E36°27′07.44″), Miho-Cheon (MC; N127°19′15.83″ E36°31′19.44″), Sejong weir (SW; N127°15′47.87″ E36°28′06.42″), Gongju weir (GW; N127°08′27.58″ E36°27′24.28″), and Beakjae weir (BW; N127°00′40.16″ E36°22′54.78″). The streams from GC and MC flow into SW, and the water body from SW flows into GW and BW. The study was conducted for two years from January 2014 to December 2015.

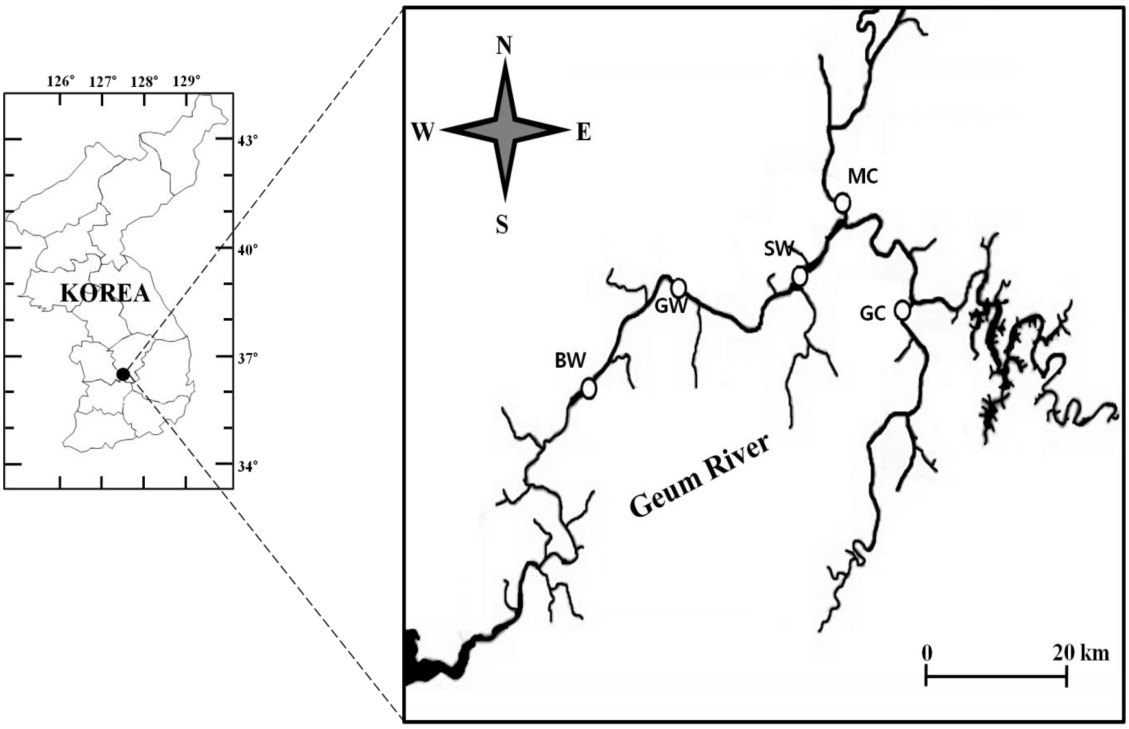

Figure 1: Map of the study site located in the midstream of the Geum River, Republic of Korea.

Data analysis

The sampling was performed twice every month without replicates as follows. At each sampling site, 50 L of freshwater, collected using a sterilized 5 L beaker, was filtered through a plankton net (60 µm mesh size) and immediately fixed with freshly prepared formalin solution (4%, v/v). Subsequently, the enumeration and identification of zooplankton species were performed simultaneously in a Sedgewick Rafter counting chamber with a dimension of 80×50×2 mm (Marienfield-Superior, Lauda-Königshofen, Germany) under a Leica DM IL LED inverted microscope (Leica Microsystems, Wetzlar, Germany) following the proposed standard methods by APHA (2012).

The physico-chemical data, namely WT, pH, TP, TOC, TN, and chlorophyll *a*, were obtained from the Water Information System (open access), which is operated by the Korean Ministry of Environment (Water Information System, 2014–2015). The dominance index (λ) and diversity index (H') were calculated by the following equations (Shannon and Weaver, 1949; Simpson, 1949).

$$\lambda=\Sigma\{(N_i^2-N)/(N(N-1))\} \quad (1)$$

$$H'=-\Sigma P_i \log_{10} P_i, \quad (2)$$

where N is the total number of individuals of species, N_i is the number of species i, and P_i is the ratio of N_i/N.

Statistical analysis

Statistical analysis was performed with SPSS statistics program (ver 22.0 for Windows; IBM Corp., Armonk, NY, USA). The relationship between physico-chemical parameters and zooplankton abundance was determined by calculating the Pearson correlation coefficient (r), and Canonical correspondence analysis (CCA) was performed using PC-ORD Multivariate Analysis of Ecological Data program (version 6, MJM software, USA), and values at $p<0.05$ are considered significant differences.

Results

Changes of physico-chemical parameters

The average WT, pH, TP, TOC, TN, and chlorophyll *a* at the MH, GC, SW, GW, and BW stations for the two study years (2014 and 2015) are presented in Fig. 2. The highest average WT was measured at the GC station in both 2014 and 2015 (18.8 °C and 18.1 °C, respectively), and similar values were measured at other stations (Fig. 2A). The maximum average pH was registered at the GW station in 2014 (pH 8.14) and the BW station in 2015 (pH 8.13), and the minimum value was recorded at the GC station in both years (pH 7.53 and pH 7.51, respectively) (Fig. 2B). The maximum average levels of TP, TOC, and TN were found at the GC station in both years, whereas the minimum levels of TP, TOC, and TN were detected at the BW, GW, and BW station, respectively (Fig. 2C–E). In both years, the maximum average concentration of chlorophyll *a* was found at MC (46.1 mg m^{-3} in 2014 and 72.0 mg m^{-3} in 2015), and the minimum values were measured at the GC station (16.3 mg m^{-3} in 2014 and 22.1 mg m^{-3} in 2015) (Fig. 2F). The average pH increased in a downstream direction (from GC and MC to SW, BW, and GW), whereas the average TP, TOC, and TN concentrations decreased in the same direction.

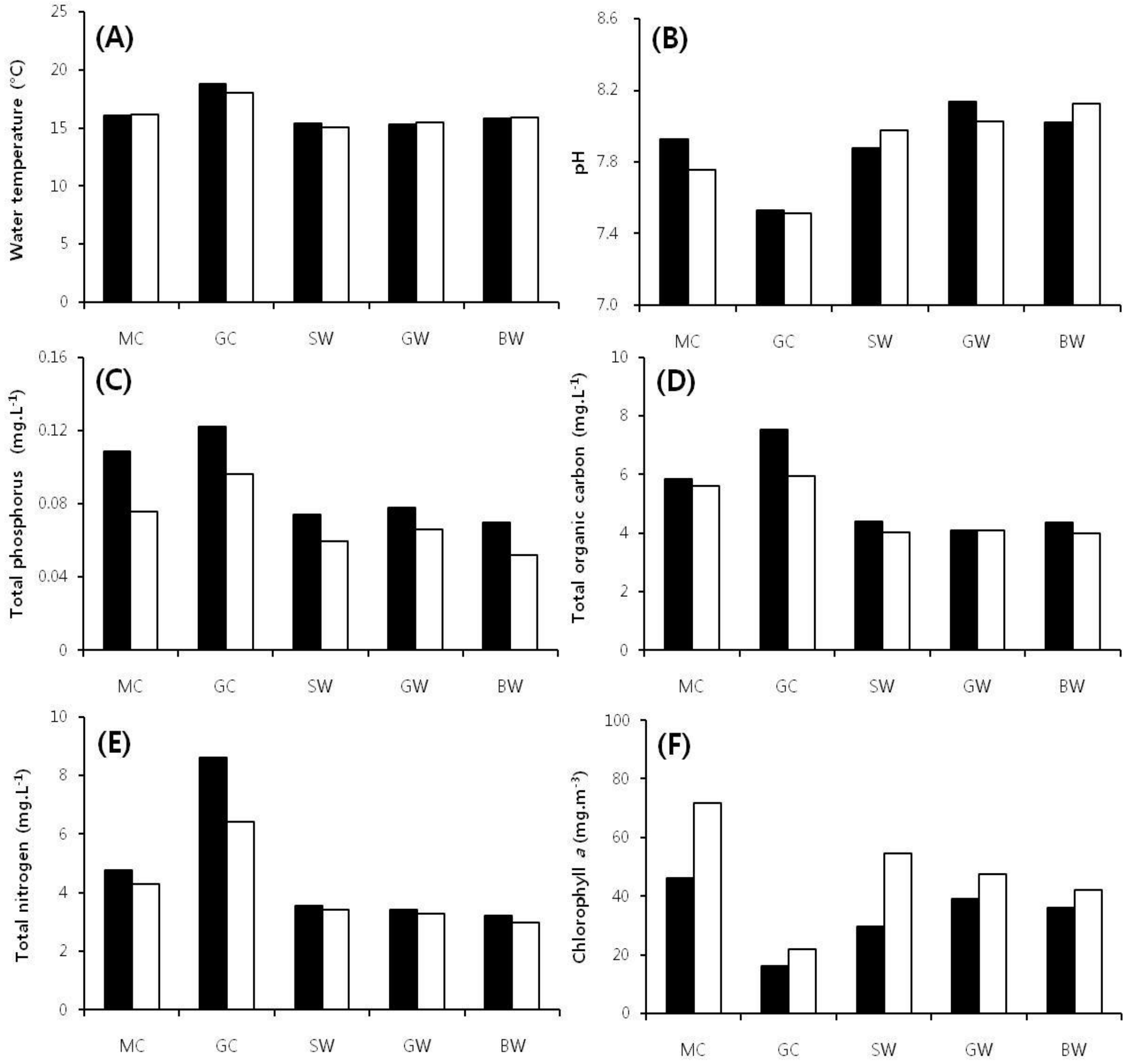

Figure 2: The average values of water temperature, pH, total phosphorus (TP), total organic carbon (TOC), total nitrogen (TN), and chlorophyll *a* concentration at the Miho-Cheon (MC), Gap-Cheon (GC), Sejong weir (SW), Gongju weir (GW), and Baekjae weir (BW) stations from 2014 (black bar) to 2015 (white bar).

Zooplankton abundance and species composition

During the two years of study, a total of 93 species were identified: 20 species of Protozoa (21.5%), 53 species of Rotifera (57.0%), 9 species of Cladocera (9.0%), and 11 species of Copepoda (11.8%). Among the Rotifera, *Cephalodella* sp., *Notommata* sp., *Synchaeta* spp., *Polyarthra* spp., *Trichocerca* spp., *Asplanchna* spp., *Brachionus* spp., *Keratella* spp., *Kellicottia* sp., *Platyias* sp., *Anuraeopsis* sp., *Notholca* sp., *Colurella* sp., *Lecane* spp., *Dipleuchlanis* sp., *Euchlanis* spp., *Monostyla* spp., *Lepadella* spp., *Trichotria* sp., *Filinia* spp., *Hexarthra* sp., *Pompholyx* sp., *Ploesoma* sp., *Ascomorpha* sp., *Philodina* sp., and *Brachionus calyciflorus* were frequently observed during most of the study period; among the Protozoa, *Kellicottia bostoniensis, Arcella intermedia*, *Arcella vulgaris,* and *Epistylis plicatilis* were dominant in

February, November, and December in 2014, and February, March, October, and December in 2015 (Table 1). Monthly changes in zooplankton abundance at each station fluctuated largely along with the number of species or zooplankton taxa (Fig. 3).

Table 1: Monthly changes in dominant species and their contribution to the total number of zooplankton species in the midstream of the Geum River, Korea, from 2014 to 2015.

Year	Month	Dominant species	%
2014	Jan	*Kellicottia bostoniensis* (Rotifera)	28.8
	Feb	*Arcella intermedia* (Protozoa)	13.7
	Mar	*Brachionus rubens* (Rotifera)	23.6
	Apr	*Brachionus calyciflorus* (Rotifera)	27.9
	May	*Keratella cochlearis* (Rotifera)	21.9
	Jun	*Brachionus calyciflorus* (Rotifera)	32.6
	Jul	*Brachionus calyciflorus* (Rotifera)	25.1
	Aug	*Brachionus quadridentatus* (Rotifera)	26.2
	Sep	*Brachionus calyciflorus* (Rotifera)	22.3
	Oct	*Brachionus calyciflorus* (Rotifera)	27.9
	Nov	*Arcella vulgaris* (Protozoa)	24.6
	Dec	*Arcella vulgaris* (Protozoa)	20.1
2015	Jan	*Synchaeta oblonga* (Rotifera)	25.7
	Feb	*Arcella vulgaris* (Protozoa)	20.1
	Mar	*Arcella vulgaris* (Protozoa)	23.4
	Apr	*Synchaeta oblonga* (Rotifera)	26.4
	May	*Brachionus calyciflorus* (Rotifera)	40.2
	Jun	*Brachionus calyciflorus* (Rotifera)	27.5
	Jul	*Brachionus calyciflorus* (Rotifera)	21.5
	Aug	*Polyarthra vulgaris* (Rotifera)	14.5
	Sep	*Polyarthra vulgaris* (Rotifera)	19.8
	Oct	*Epistylis plicatilis* (Protozoa)	45.5
	Nov	*Brachionus calyciflorus* (Rotifera)	22.9
	Dec	*Arcella vulgaris* (Protozoa)	25.8

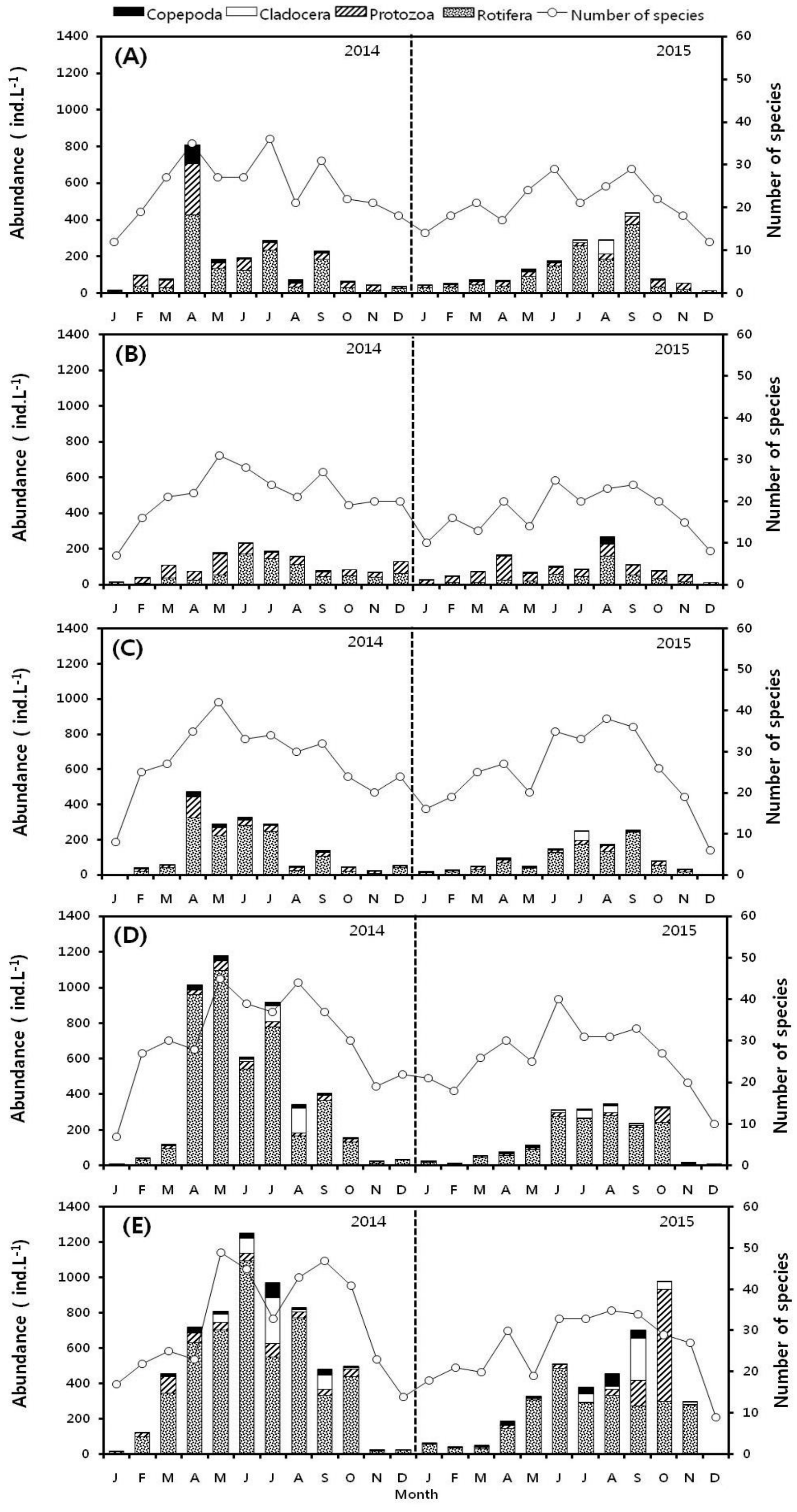

Figure 3: Monthly changes in zooplankton abundance and number of species in Miho-Cheon (A), Gap-Cheon (B), Sejong weir (C), Gongju weir (D), and Baekjae weir (E) from January 2014 to December 2015.

At the MC station, a total of 66 and 57 species were identified in 2014 and 2015, respectively. The maximum number of zooplankton species was collected in July 2014, and the minimum number of species was registered in January 2014 and December 2015. Moreover, the maximum zooplankton abundance was observed in April 2014, and the minimum abundance was detected in December 2015. During the study period, the overall zooplankton abundance and number of species were high from April to September in both years with Rotifera being the most dominant group (Fig. 3A). At the GC station, a total of 61 and 56 species were identified in 2014 and 2015, respectively. The highest number of zooplankton species was found in March 2014, and the minimum number in January 2014. Also, the maximum zooplankton abundance was detected in August 2015, and the minimum abundance was registered in December 2015 (Fig. 3B). At SW, 74 and 71 species were identified in 2014 and 2015 respectively. The maximum and the minimum number of zooplankton species was observed in May 2014 and December 2015, respectively. The highest zooplankton abundance was calculated for April 2014, and the lowest abundance was estimated for January 2014 (Fig. 3C). At GW, a total of 75 and 67 species were identified in 2014 and 2015, respectively. The highest number of zooplankton species was found in May 2014, and the minimum number of species was detected in January 2014. Also, the maximum zooplankton abundance was observed in May 2014 and the minimum abundance was present in January 2014 (Fig. 3D). At BW, 79 and 67 species were identified in 2014 and 2015, respectively. The highest and the lowest number of zooplankton species were detected in May 2014 and December 2015, respectively. The maximum zooplankton abundance was present in June 2014, and the minimum abundance was detected in December 2015 (Fig. 3E).

Correlation between physico-chemical parameters and zooplankton abundance

To investigate the effects of physico-chemical parameters on zooplankton production and composition, Pearson's correlation coefficients were calculated between zooplankton abundance and physico-chemical parameters pH, TN, TP, TOC, WT, and chlorophyll *a* concentration. As shown in Table 2, the pH, WT, and chlorophyll *a* concentration were significantly and positively correlated (p<0.01, r=0.598, r=0.684, and r=0.590, respectively) and the TN was significantly negatively correlated (p<0.01, r=-0.540) with the total zooplankton abundance. While the pH level was positively correlated with all the zooplankton taxa, the TN was negatively correlated with all the taxa except the Protozoa (Table 2). The TP and TOC were somewhat correlated with the abundance of Protozoa (p<0.01, r=0.452 and r=0.411, respectively) compared to other taxa. The Rotifera was highly correlated with the physico-chemical parameters pH, TN, WT, and chlorophyll *a* concentration (p<0.01, r=0.606, r=-0.527, r=0.672, and r=0.594, respectively). The Cladocera was weakly correlated with TN (p<0.01, *r*=-0.409) and WT (p<0.01, r=0.485) and Copepoda were weakly correlated with pH (p<0.01, r=0.441) and WT (p<0.01, r=0.422), and highly correlated with TN (p<0.01, r=-0.504) as compared to other physico-chemical parameters.

Table 2: Correlation coefficients between the number of different zooplankton species and environmental variables, pH, total nitrogen (TN), total phosphorus (TP), total organic carbon (TOC), water temperature (WT), and chlorophyll *a* (CA) content, for two years of the study period (January 2014–December 2015, *n* = 120).

Variable	pH	TN	TP	TOC	WT.	CA
Total abundance	0.598**	-0.540**	0.134	0.131	0.684**	0.590**
Protozoa	0.107	0.121	0.452**	0.411**	0.471**	0.231*
Rotifera	0.606**	-0.527**	0.128	0.138	0.672**	0.594**
Cladocera	0.285**	-0.409**	0.154	-0.041	0.485**	0.388**
Copepoda	0.441**	-0.504**	0.025	-0.031	0.422**	0.310**

*for p<0.05, **for p<0.01

As shown Fig. 4, the result of CCA analysis showed that the sampling sites were influenced by variables of environmental factors. The axis 1 was positively correlated with WT, chlorophyll *a* and pH while negatively correlated with NH_3-N, TN, DTN, NO_3-N and conductivity. The GC (group A) and MC (group B) stations were in the negative direction showing influence of nitrogen based compounds along with high conductivity. However, the SW, GW and BW stations (group C) showed diverse influences by environmental parameters.

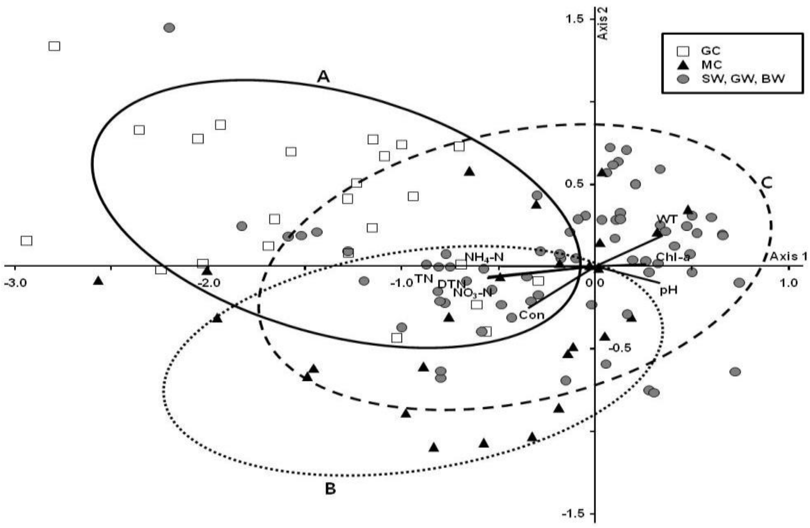

Figure 4: Ordination bioplots of study sites and environmental variables including nitrate (NO_3-N), ammonia nitrogen (NH_4-N), dissolved total nitrogen (DTN), total nitrogen (TN), dissolved total phosphorus (DTP), total phosphorus (TP), conductivity (Con), dissolved oxygen (DO), chlorophyll *a* (Chl-*a*), water temperature (WT), total organic carbon (TOC), chemical oxygen demand (COD) and biochemical oxygen demand (BOD) in the midstream of the Geum River from 2014 to 2015.

As shown Fig. 5, the axis 1 was positively correlated with biochemical oxygen demand (BOD), chlorophyll *a* and pH, but negatively correlated with NH_4-N, NO_3-N, conductivity, TOC, DTP, TP and chemical oxygen demand (COD). The axis 2 was positively correlated with DO and pH, but negatively correlated other factors. In the result, the most dominant Rotifera species including *B. calyciflorus*, *S. oblonga*, *P. vulgaris*, *K. cochlearis*, *B. quadridentatus* and *B. rubens* were in the positive direction of axis 1 suggesting possible influences by WT, chlorophyll *a*, pH and BOD. On the other hand, dominant Protozoa species including *A. vulgaris* and *A. intermedia* were in the negative direction suggesting correlation with NH_4-N, NO_3-N, conductivity, TOC, DTP, TP, DTN, TN and COD, and these results showed similar patterns with results of Pearson correlation coefficient (r) (Table 2).

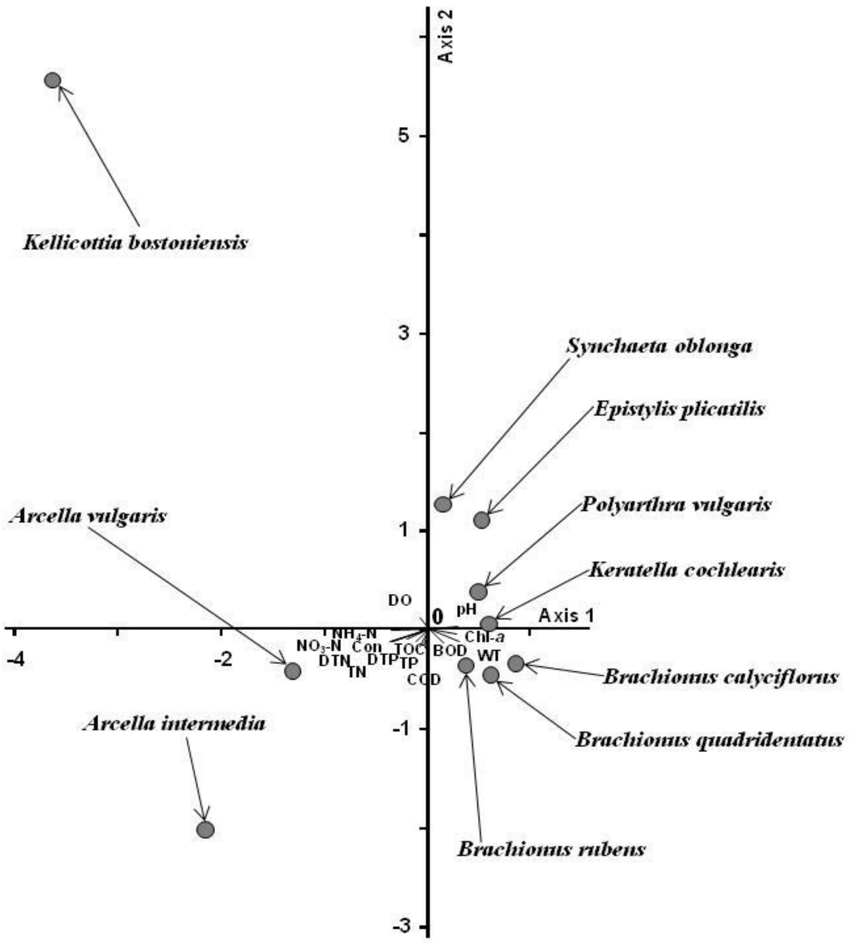

Figure 5: Ordination bioplots of dominant species of zooplankton and environmental variables including nitrate (NO_3-N), ammonia nitrogen (NH_4-N), dissolved total nitrogen (DTN), total nitrogen (TN), dissolved total phosphorus (DTP), total phosphorus (TP), conduvtivity (Con), dissolved oxygen (DO), chlorophyll *a* (Chl-*a*), water temperature (WT), total organic carbon (TOC), chemical oxygen demand (COD) and biochemical oxygen demand (BOD) in the midstream of the Geum River from 2014 to 2015.

Changes of major physico-chemical parameters and zooplankton abundance

Because the pH, chlorophyll *a* concentration, and WT were highly correlated with the total zooplankton abundance, changes in those parameters and fluctuation in the total zooplankton abundance were examined on a monthly basis during the two experimental years. As shown in Fig. 6, the WT increased from January to July and decreased from July to December in 2014, and increased from January to August and decreased from August to December in 2015. WT ranged from 2.87 to 28.15°C; the highest WT was measured at the GC station throughout the study period, but similar values were measured at other stations (Fig. 6A). The chlorophyll *a* concentration ranged from 3.5 mg m^{-3} to 189.6 mg m^{-3}, and the monthly changes in the concentration showed a similar pattern to that observed for WT. During the study period, high concentrations of chlorophyll *a* at each station coincided with high WT; the highest levels were measured at MC, and the lowest at GC (Fig. 6B). The pH ranged between 7.1 and 9.0, with low pH value was measured at the GC station during most of the study period (except values from August to December in 2014, and August and December in 2015) (Fig. 6C). Zooplankton abundance was high from April to October in both years; the highest abundance was observed at the BW station (maximum abundance was seen in June 2014) and the lowest at the GC station during the study period. Overall, zooplankton abundance increased in the downstream direction (GC, MC→SW→GW→BW) along the Geum River and showed a similar pattern in monthly changes to that of pH (Fig. 6D).

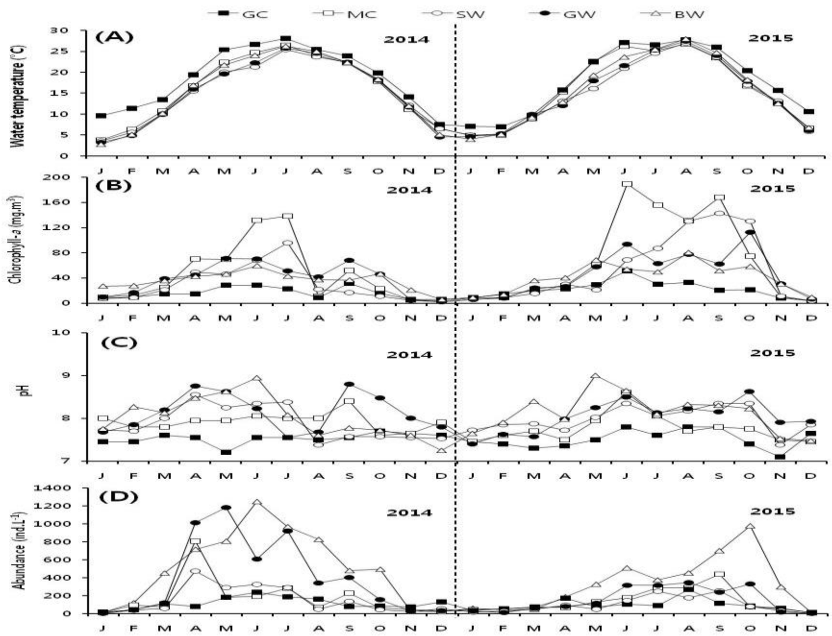

Figure 6: Monthly changes in water temperature, pH, chlorophyll *a* concentration, and zooplankton abundance in the midstream of the Geum River from January 2014 to December 2015.

Changes of the diversity index, dominance index, and the number of species.

To evaluate the dynamics of zooplankton community structure and health conditions, changes in the diversity and dominance indices were determined for the study period. As shown in Fig. 7A, the monthly changes in the two indices showed different patterns in 2014 and 2015. In August 2014, the diversity index was low and the dominance index was high, whereas the reverse pattern was observed in August 2015, the diversity index was high and the dominance index was low. In 2015, the maximum diversity index (2.98) and minimum dominance index (0.25) along with 48 species of zooplankton were observed in August, whereas the minimum diversity index (2.12) and maximum dominance index (0.62) and 52 species of zooplankton were found for October. As compared by region (Fig. 7B), the highest dominance index was seen at GC station with a minimum diversity index, and dominance index showed increasing pattern in the downstream direction (MC→SW→GW→BW) with decreasing values of diversity index without GC station.

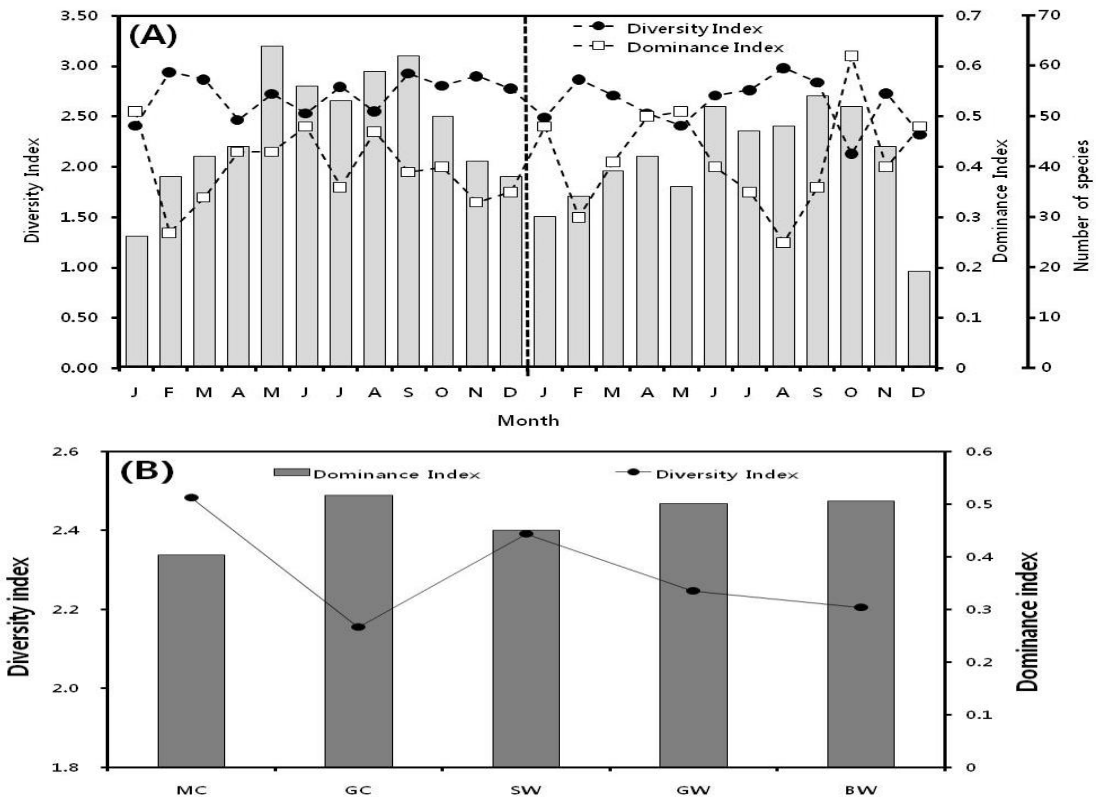

Figure 7: Monthly changes in diversity index, dominance index, and the number of zooplankton species in the midstream of the Geum River from 2014 to 2015.

Discussion

A total of 93 zooplankton species were identified in the study area, belonging to Rotifera and the species *K. bostoniensis*, *B. rubens*, *B.calyciflorus*, *K. cochlearis*, *B. quadridentatus*, *S. oblonga*, and *P. vulgaris* were the dominant group and species during the study period. The zooplankton community consists of Rotifera (75.3%), Protozoa (14.3%), Cladocera (6.4%), and Copepoda (4.0%). In a previous study on zooplankton community structure performed in the Geum River estuary in 2001, Cladocera, with *B. longirostris* and *Daphnia galeata*, was the dominant taxon in the upstream side and marine Copepoda, with *Acartia omorii* and *Paracalanus crassirostris*, was the dominant taxon in the downstream side of the Geum River estuary (Kim *et al*., 2002). The compositional differences between the previous and the present study may be derived from the differences in sampling sites. However, Nakdong River, one of the four major rivers in Korea, showed a similar composition in the zooplankton community. The main channel of the Nakdong River contains 83 species of zooplankton, comprising 60 species of Rotifera, 14 species of Cladocera, and 9 species of Copepoda; *Brachionus* spp., *Keratella* spp., and *Polyarthra* spp. from Rotifera were the most dominant (Kim *et al*., 2001). Furthermore, Rotifera was the dominant group with a similar composition in other major rivers in other countries, the Rhine River (Netherlands), Meuse River (Belgium), and Seine River (France) (De Ruyter and Steveninck *et al*., 1992; Billen *et al*., 1994; Viroux, 1997; Iloba and Ruejoma, 2014). Therefore, the dominance of Rotifera is a ubiquitous phenomenon in rivers and lakes. The dominance of Rotifera is highly related to chlorophyll *a* concentration and water residence time because this zooplankton taxon is generally regulated by the abundance of food resources such as phytoplankton and bacteria, both of which have a relatively short generation time and smaller body size compared to those in other zooplankton groups (Walz, 1995; Kim and Joo, 2000). The dominance of Rotifera is also related to changes in WT, pH, and nutrient concentrations (Paulose and Maheshwari, 2007). The high nutrient concentration and eutrophication accompanied with low chlorophyll *a* concentration at GC have been reported previously by Lee *et al*. (2006). Similarly, in the present study, the maximum average values of TP, TOC, and TN, along with the minimum average levels of pH and chlorophyll *a*, were observed at the GC, indicating the eutrophication of the water at the GC station. It is considered that the high nutrient concentrations are due to direct inflow of nutrients from discharge waters released from the Daejeon Sewage Treatment Plant located at the GC station, although this hypothesis needs further testing. The MC station showed the second highest values of TP, TOC, and TN concentrations, and the second lowest values of pH. A previous study reported that the high nutrient contents at the MC station was the result of the discharge of contaminated water from tributaries, including those from Seoknamcheon, in which high concentrations of nutrients originates from the discharge from the Cheongju sewage treatment plant (Kim *et al*., 2014). Furthermore, the physico-chemical parameters were similar among the SW, GW, and BW stations, whereas the values of TP, TOC, and TN were lower at these stations compared to those at the GC station (Fig. 2). Because the stream from GC and MH flows into SW and then into GW and BW, both of which are located downstream on the Geum River, it is considered that the high concentration of TP, TOC, and TN at GC and MH were gradually diluted by the water inflow at the upper stations. Moreover, the chlorophyll *a* concentration gradually increased from the GC towards other stations, suggesting the generation of photoautotrophic organisms containing chlorophyll *a* as a major photosynthetic pigment.

The growth of photoautotrophic organisms at the MC may be augmented by simultaneous effects of abundant nutrients and optimal pH levels. Also, the possible reason of pH distributions in each station may be derived from different chlorophyll *a* levels, because photosynthesis by photoautotrophic organisms affects pH levels in common freshwater environments (Tucker and D'Abramo, 2008). During the daylight, photoautotrophic organisms remove carbon dioxide suggesting the increase of pH levels while respiration decreases pH level via carbon dioxide generation (Tucker and D'Abramo, 2008).

The total zooplankton abundance was highly related to the levels of pH, TN, WT, and chlorophyll *a* according to the Pearson correlation coefficients (Table 2). Furthermore, Rotifera, which was the most abundant taxon, was significantly correlated with physico-chemical parameters.

Previous studies have reported a high correlation between the zooplankton generation and the variations in pH, WT, and chlorophyll *a* concentration (Kim *et al*., 2001; Rajashekhar *et al*., 2010; An *et al*., 2012; Iloba and Ruejoma, 2014). Furthermore, a laboratory study on the relationship between different pH levels and survival of *B.calyciflorus*, a major dominant species in the present study (Table 1), reported that its survival decreased as the pH changed in the order 9.5>8.5>7.5>10.5 and the net reproductive rate of amictic and mictic eggs increased with an increase in pH from 7.5 to 8.5 (Mitchell and Joubert, 1986). Another study reported that the rate of embryonic development of the Rotifera species *B. calyciflorus* exhibited a positive correlation with temperature in the range of 15°C–35°C (Galkovskaja, 1987). In the present study, the high monthly abundance and number of zooplankton species from April to October in both years in most of the stations was due to high abundance of Rotifera in WT range of 15°C–28°C (Figs. 3 and 6A). The abundance of Rotifera was significantly correlated with chlorophyll *a* concentration in the Nakdong River because Rotifera rely on photoautotrophic organisms as food resources (Kim *et al*., 2001). Taken together, we can conclude that the sensitivity of Rotifera to the variations in pH, WT, and chlorophyll *a* concentrations determines the zooplankton abundance in the Geum River. The dominance of Rotifera indicates conditions in the aquatic environment. The high density of Rotifera is frequently associated with high clarity of water (low turbulence) and high phytoplankton populations (Williams, 1996). Thus, it is suggested that the dominance of Rotifera in this study showed clarity at each station in the midstream of Geum River.

Concerning the Protozoa, their generation was relatively highly correlated with TP and TOC concentration as indicated by the Pearson's correlation coefficient (Table 2); thus, their abundance was relatively higher at the GC and MC stations than at the SW, GW, and BW stations (data not shown). Protozoa have been considered one of the useful bio-indicators of effluents from activated sludge plants and biologically treated wastewaters because they are the major predators of bacteria and organic carbon sources in activated sludge (Ratsak *et al*., 1994; Salvado *et al*., 1995; Martin-Cereceda *et al*., 2002). Additionally, previous studies reported that Protozoa effectively enhances mineralization of phosphorus and affects phosphorus cycling via uptake of organic materials in aquatic environment (Barsdate *et al*., 1974; Ratsak *et al*., 1994). Thus, the high correlation between TOC and Protozoa in this study was likely due to the presence of bacteria or organic carbon sources. Furthermore, high TOC concentrations at the GC and MC stations explain the higher Protozoa abundance at those stations (Figs. 2, 3A and 3B).

The pH, WT, chlorophyll *a* concentration, and zooplankton abundance at all the stations increased between April and October in both years, and the overall zooplankton abundance was higher in 2014 than in 2015. This difference in zooplankton abundance between 2014 and 2015 may be derived from the difference in precipitation and generation of toxic substances by Cyanophyceae. In a previous study, increased rainfall significantly increased loading of chemicals such as organic carbon and silica, which in turn have facilitated flourishing of zooplankton (Weyhenmeyer *et al*., 2004). Furthermore, toxic substances from Cyanophyceae directly influence fertility, growth, and feeding properties of zooplankton (Dumont, 1977; Lampert, 1987; Sampaio *et al*., 2002). According to Han *et al*. (2016), the phytoplankton standing crop of Cyanophyceae, Bacillariophyceae, and Chlorophyceae was high in 2015 as compared to that in 2014, whereas the total precipitation at the same station on the Geum River was higher in 2014 than in 2015. These results suggested that the flourishing of Cyanophyceae and the difference in precipitation in the study area may affect the annual difference in zooplankton abundance. Also, as suggested by Han *et al*. (2016), the inflow of GC and MC stations may influence zooplankton community and distributions of environmental parameters. As exhibited in Figs. 2F and 4, chlorophyll *a* content gradually decreased in the downstream directions, and obvious classifications of inflow stream and reservoirs were observed (group A, B and C). These results suggested that the inflow of nutrientsrich GC and MC influenced toward SW, GW and BW in the downstream direction, and group C was closely related to environmental parameters.

Shannon Weaver diversity index and Simpson's dominance index, two indices widely implemented in community ecology, were used to evaluate ecological properties of the zooplankton community in the Geum River. The two indices showed the opposite tendency during the study period (Fig. 7A). Thus, the average diversity index was 2.72 and 2.62 and the dominance index was 0.40 and 0.42 in 2014 and 2015, respectively. A previous study conducted at the same stations reported that high levels of phytoplankton standing crops in 2015 compared to those in 2014 were due to various physico-chemical parameters (Han *et al*., 2016). Han *et al*. (2016) suggested that the low phytoplankton standing crops in 2014 may be due to grazing by highly abundant zooplankton. Furthermore, the abundant food resources in 2014 may have affected the fluctuations in the number of zooplankton species, resulting in relatively high diversity index and low dominance index. Additionally, the differences of physico-chemical factors including WT, pH, TP, TOC and TN in different stations also may affect both diversity and dominance indexes as exhibited in Fig. 7B. These results indicated that the water body of the upper stream in Geum River affects diversity and dominance in other stations in the downstream direction (MC→SW→GW→BW).

In the present study, the monthly dynamics of the zooplankton community structure in the midstream of the Geum River was investigated. The results showed that Rotifera was the dominant taxon, and pH, WT, and chlorophyll *a* concentration were the physico-chemical parameters that affected the temporal variations of zooplankton abundance. Furthermore, the zooplankton abundance in different stations increased in the downstream direction along with the decrease in nutrients, WT, and chlorophyll *a* concentration. The results suggest that Rotifera and Protozoa, as major zooplankton groups whose distribution is affected by various physico-chemical parameters, may play important roles in carbon linkage and nutrient production in biological systems in the midstream of the Geum River.

The variations of zooplankton community structure indicate changes in environmental factors, and their effect on fluctuations in other aquatic organism communities. Because only few studies about zooplankton community were performed in this area, this study will provide important information for the comprehensive understanding of dynamics of aquatic ecosystem in the Geum River.

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