Phytoplankton Species Variation Analysis in Lake Biwa by means of the Three-Ways Layout ANOVA

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Lake Biwa, the largest lake in Japan, has very important roles in several purposes such as water supply, fishery, recreation and aquatic biodiversity protection, and understanding of its flora is quite valuable for its utilization and conservation. However, there have been few studies that quantitatively analyse the phytoplankton data with intention of their variation considerations. The purpose of this study was to propose a quantitative evaluation procedure for spatial and temporal variation of each species in the Lake, with three indicators of phytoplankton species and some statistical methods.

The data used in this study were derived from bi-monthly phytoplankton observations during a 30-year (1979-2008) period at both Site S (South basin) and Site N (North basin) by Lake Biwa Environmental Research Institute (LBERI). LBERI recorded the phytoplankton data basically with cells/mL for each species, and its value can be converted to volume (μm^3/mL) by cell volume (μm^3/cell). Finally, three indicators of Occurrence (%, the probability of appearance for a species in a given group), Cell counts (cells/mL), and Biovolume (μm^3/mL) were evaluated for all of the species observed in the lake.

A total of 295 phytoplankton species were detected, belonging to 10 taxa groups. This study found brown flagellum taxon were most dominant indicated by 98.5% occurrences. Green algae group had the largest biovolume and was most abundant during the observation period. Blue green (cyanobacteria) taxa were detected in the highest number (average 3.6 x 10^7 cells/mL). In terms of species composition, *Cryptomonas* sp. (brown flagellum taxon) was the most frequently detected species, although its volume was ranked at the fourth in all of the species. *Staurastrum dorsidentiferum* var. ornatum (green algae group) showed the largest Biovolume of 9.7 x 10^5 μm^3/mL, and the third highest Occurrences of 60.3 %. **Table 1** summarizes some important phytoplankton species.

Although we can compare abundance differences among phytoplankton species as shown in Table 1, each species varied highly by season, years and sites. **Figure 1** shows some of typical species, which had obvious differences in seasons, years or sites. Most of algal species had their favourite seasons; such as spring for *Fragilaria crotonensis,* summer for *Aphanothece clathrata* and autumn for *S. dorsidentiferum and Aulacoseira granulate.* Yearly analysis indicates increasing trend for *Cyclotella* spp. and decreasing one for *Aulacoseira niponica* and *Pediastrum biwae*. South and north basins are connected each other, but the concentrations of each species were sometimes more than doubled or less than halved either basin.

Since many factors were affecting variation of each species concentration, the following model equation was introduced to explain effects of their factors:

$$X_{k,i,l} = Xo + a_k + b_i + c_l + (ab)_{k,i} + (bc)_{i,l} + (ac)_{k,l} + e_{k,i,l}$$

Where $X_{k,i,l}$ *i*s a common logarithmic value of a target species concentration (cells/mL or μm^3/mL) at site *k* at month *i* in the year *l*. *Xo* is the level, a_k, b_i, c_l are main effects of sites, seasons and years, respectively while $(ab)_{k,i}$, $(bc)_{i,l}$, and $(ac)_{k,l}$

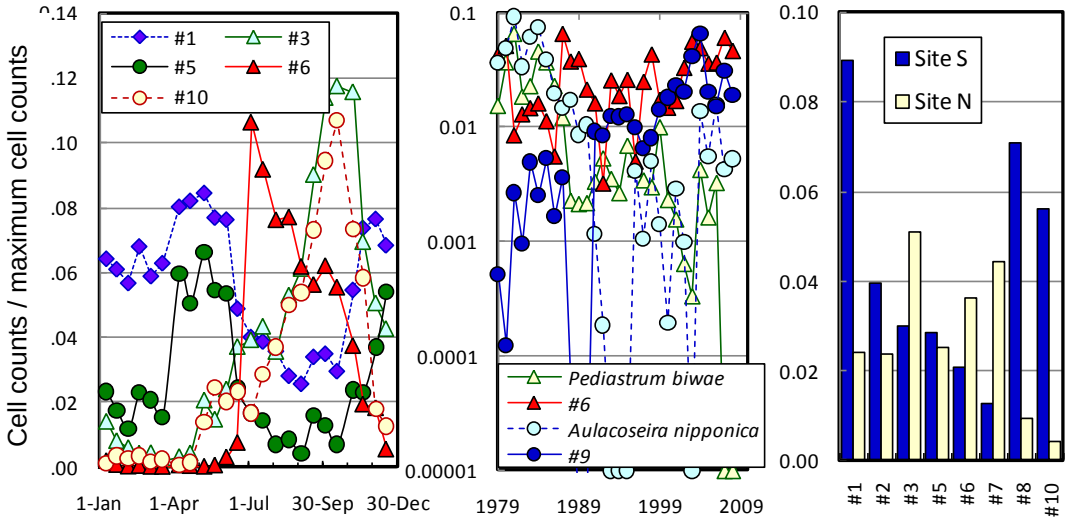
are their interaction effects, and $e_{k,i,l}$ is the remaining part (residual) that cannot be explained these effects.

Since the data of phytoplankton were observed systematically with the arrangement of 2 sites × 24 times (bimonthly) × 30 years, ANOVA (analysis of variance) for three-ways layout can be used to evaluate main and interaction effects. These effects were quantitatively evaluated with their contribution proportions for the whole variance. In cases of top 30 species in occurrence, these effects explained 24 – 87 % of their total variances. The highest contribution of main effects was 27 % (*Nitzschia* spp.) for sites, 54 % (*Aphanothece clathrata*) for months, and 75 % (*Rhodomonas* spp.) for years. Interaction effects were not negligible, and were highest at 11 % (*Cyclotella glomerata*) for site × month, 34 % (*Closterium aciculare* var. subpronum) for month * year, and 7% (*Aulacoseira nipponica*) for site × year. These results indicated that the three-ways layout ANOVA is the powerful tool to describe the complicated variation patterns for several phytoplankton species.

Table 1 Main phytoplankton species in Lake Biwa during 1979 - 2008

#	Taxa	Phytoplankton species	*Occurrence*	*Cell count*	*Biovolume*
			%	cells/mL	$10^3\mu m^3$/mL
1	Brown flagellate	*Cryptomonas* spp.	90.8	91(19)	155(4)
2		*Rhodomonas* spp.	64.7	222(9)	38(15)
3	Green algae	*Staurastrum dorsidentiferum*	60.3	30(29)	968(1)
4		*Closterium aciculare*	58.8	22(36)	200(3)
5	D	*Fragilaria crotonensis*	44.1	96(16)	72(9)
6	BG	*Aphanothece clathrata*	42.6	21,391(1)	21(20)
7	Diatom (D)	*Stephanodiscus pseudosuzukii*	41.3	32(28)	15(27)
8		*Nitzschia* spp.	40.3	10(54)	3.0(64)
9		*Cyclotella* spp.	38.5	25(31)	5.0(51)
10		*Aulacoseira granulata*	38.4	101(15)	152(5)

#: Ranking in Occurrence, () shows ranks of the indicator, BG: blue green algae



(a) Seasonal variation (b) yearly trend (c) comparison of sites

Fig. 1 Effects of seasons, years and sites for some species

(#1 - #10 mean species shown in Table 1)