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Vertical sediment migrations of dominant midge species in subtropical lakes with implications for bioassessment

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ABSTRACT

Propsilocerus akamusi (Diptera: Chironomidae) is a dominant species in numerous eutrophic lakes and they could burrow into deep sediments (> 30 cm) during summer months. However, common-used grab samplers are efficient in collecting surface-dwelling species (< 20 cm), thus vertical migrations of dominant species may interfere bioassessment. Here, we monthly investigated the vertical sediment positioning of *P. akamusi* larvae and its influence on bioassessment. Our results indicated that, from late-April to October, most individuals aestivated at the sediment below 30 cm depth which maybe an adaptation to the thermal stress. As to other periods, the larvae were generally found in the depth of 10–30 cm. Moreover, Peterson grab samples collected only 0% and 12.6% of total *P. akamusi* individuals in summer and late-autumn, respectively, resulting in serious underestimation of the actual pollution status. This implied that vertical movements of dominant macroinvertebrates should be taken into account when designing of bioassessment protocols. For *P. akamusi*, Core-sampling for calibration were strongly encouraged, and the low-temperature period for Grab-sampling is also proposed.

1. Introduction

Macroinvertebrates are good indicators of environmental status and have been widely used for ecological quality evaluation of surface waters (Luoto, 2011; Birk et al., 2012; Poikane et al., 2016; Carew et al., 2018). In fact, indicator metrics based on macroinvertebrates are influenced not only by anthropogenic stressors, but also by sampling methods and effort, and temporal-spatial variations of the communities (Tolonen and Hämäläinen, 2010; Keizer-Vlek et al., 2012; Cai et al., 2017). For example, common grab samplers are efficient in collecting macroinvertebrates inhabiting the surface layer of sediment (< 20 cm). However, some species tend to perform seasonal vertical migrations between surface and deeper sediment layers (McLachlan and Cantrell, 1976; Iwakuma and Yasuno, 1983; Narita, 2006), which may bias the results of bioassessment based on surface sediment samples.

Non-biting midges (Chironomidae) are the most widely distributed and the most abundant group of insects in freshwater environment (Armitage et al., 1995; Pinder, 2003). Since Chironomidae are practical and efficient indicators of changes with anthropogenic or natural origin, chironomid-based metrics are often the most important ones in lakes bioassessment (Rabeni and Wang, 2001; Jyväsjärvi et al., 2009; Raunio et al., 2011; Odume et al., 2016). *Propsilocerus akamusi* (formerly *Tokunagayusurika akamusi*) is a large chironomid midge species (body length 10–17 mm), which is one of the most prevalent species in Asian subtropical and temperate freshwaters (Fig. 8 and Table S2). Several studies have shown that *P. akamusi* is a cold stenotherm species (Sasa, 1978; Butler, 1982; Gong et al., 2008; Wang et al., 2017). This species has relatively long life cycle (one or two years) (Gong et al., 2008), which is common for the species distributed in low temperate regions (Butler, 1982). In Chinese lakes, *P. akamusi* grow very fast during coldest months of winter, and their body length increase from few millimeters to about 15 mm in just two months under temperatures of 5–8 °C. *P. akamusi* commonly dominate benthic communities in many eutrophic lakes (Yamagish and Fukuhara, 1971; Iwakuma, 1987; Gong et al., 2008; Fig. 8, Table S2). This species is known to emerge and oviposit in enormous numbers during a short period in late-autumn, causing a serious nuisance to people residing near the lakes (Tabaru et al., 1987; Hirabayashi et al., 1998). Former studies have been found that the larvae of *P. akamusi* dwelled in deep sediment (> 30 cm) during summer months, resulting in the disappearance of species in grab samples (Yamagish and Fukuhara, 1971, Fig. 8). Hence, these considerable vertical migrations may adversely affect

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representativeness and accuracy of bioassessment results based on the macroinvertebrates samples collected by grab samplers. This may be the case especially in the lakes dominated by *P. akamusi*. Hence, details about population dynamics and behavior of the larvae of this species and its influence on bioassessment need to be examined.

To our knowledge, very few studies have focused on the vertical positioning and migrations of *P. akamusi* or other species of Chironomidae midges in the sediments (Yamagish and Fukuhara, 1971; Iwakuma, 1987). Furthermore, the influences of these migrations on the bioassessment are still speculative. We studied population dynamics of *P. akamusi* at high temporal resolution in two subtropical eutrophic shallow lakes. Our objective was, first, to examine the vertical distribution patterns and seasonal dynamics of *P. akamusi* in stratum covering upper one meter of the sediment and quantify if vertical movements of *P. akamusi* are affecting the performance of macroinvertebrate metrics used in the bioassessment. As *P. akamusi* larvae generally disappear from surface sediments during hot summer months (e.g. Iwakuma, 1987), we expected to meet seasonally triggered vertical movements (migrations) of the species between surface and deeper sediment layers. Second, we aimed to evaluate the potential factors triggering possible vertical migration behavior of *P. akamusi* and to give some proposals how to avoid negative effects of the vertical movements on the performance of bioassessment metrics. We expected that ignoring the population dynamics and vertical migration behavior of *P. akamusi* may overrate water quality. Therefore, the results of our study may provide important information for the development of macroinvertebrate-based bioassessment approaches in freshwater lake ecosystems.

2. Methods

2.1. Study area

Lakes Xuanwu (32°04′ N, 118°47′ E) and Donghu (30°34′ N, 114°25′ E) are located in the middle and lower reaches of Yangtze River region, which is one of the most highly developed and densely populated areas in China. The surface area of Lake Xuanwu is 3.68 km^2 with a mean depth of 1.14 m (Mei et al., 2010). Lake Donghu is larger with the surface area of 32 km^2 and a mean depth of 2.21 m (Gong and Xie, 2001). The lakes are located in the subtropical monsoon climate region, with the long-time average annual air temperature of about 15 °C, and the maximum temperatures are about 40 °C in July or August (Liu et al., 2014). Rapid urbanization over the past three decades and increased external nutrient inputs have resulted in serious eutrophication and pollution in both lakes, which have also suffered serious algal blooms (Xie and Xie, 2002; Yao et al., 2010).

2.2. Sample collection

One site was chosen in each lake to elaborate vertical migrations and seasonal dynamics of *P. akamusi* (Fig. 1). The larvae were collected monthly from October 2015 to September 2016 using a sediment core sampler with ten replicates (diameter: 90 mm). Besides, two additional samplings were implemented in November 2015, during emergence period of *P. akamusi*, in Lake Xuanwu. Sediment cores with 100 cm depth were collected at each sampling site of both lakes. The cores were divided into 10 cm layers and pre-sieved *in situ* through 250 μm mesh size sieve for subsequent analysis. In the laboratory, *P. akamusi* larvae were sorted on a white tray, after this the larvae were counted and dried to constant weight at 60 °C to determine dry weight (electronic balance: Sartorius BS-124 readability, 0.1 mg).

The bottom water temperature was measured monthly along with core sediment sampling using the YSI 6600 V2 multi-sensor sonde. An additional device was used to measure temperature profile in sediment from June 2016 to August 2016 in Lake Xuanwu. This device was composed of temperature probe, connecting wire and displayer. The probe was tied to the metal bar and inserted into sediment *in situ*, the temperature data were transmitted from the probe to displayer.

In July and November 2016, we also collected three replicates of surface sediment samples (< 20 cm) with Peterson grab to compare the performance of macroinvertebrate metrics based on surface samples with the metrics based on upper one meter of sediment collected with core sampler. This sampling method comparison was conducted at the intensive temporal monitoring site of Lake Xuanwu. By these means, we aimed to qualify the influence of vertical migrations of *P. akamusi* on the performance of bioassessment metrics. Macroinvertebrates distributed in surface sediment were collected in July 2016 and November 2016 in Lake Xuanwu at 21 sites (Fig. 2). The surface sediment samples were collected using a 0.025 m^2 Peterson grab, with three grabs comprising a sample. The materials collected were pre-sieved *in situ* using a 250 μm mesh size sieve to remove fine sediment and were taken to the laboratory immediately. In the laboratory, the samples were sorted on a white tray and the macroinvertebrates preserved in 75% ethanol solution. Specimens were identified to lowest taxonomic level possible using available taxonomic guides and keys (Liu et al., 1979; Morse et al., 1994; Tang, 2006; Wang and Wang, 2011) and counted.

2.3. Data analysis

We examined vertical and temporal variations in *P. akamusi* abundance based on density (ind.m^{-2}) and biomass (dry weight, g.m^{-2}) data. Moreover, Morisita's index (MI) was adapted to elucidate the vertical dispersion patterns of *P. akamusi* (Thackeray et al., 2006). And this index was calculated as follows:

$$MI = n \times (\sum (x_i)^2 - \sum x_i)/(\sum (x_i)^2 - \sum x_i)$$

Where x_i is the abundance of *P. akamusi* in each sediment layer, and n is the number of the total sediment layers (n = 10). This index is greater than 1 for an aggregated distribution, equal to 1 for a random distribution, and less than 1 for a uniform distribution (Thackeray et al., 2006). In addition, the mean residence depth (MRD) was used to quantify the average depth of vertical distribution for the larvae (Bezerra-Neto and Pinto-Coelho, 2007), calculated as follows:

$$MRD = \sum (x_i \times d_i)/(\sum x_i)$$

Where x_i is the abundance of *P. akamusi* in each sediment layer, and n is the number of the total sediment layers (n = 10), and d_i is the depth of ith sample. For testing the significance of vertical distribution between different sampling date, two sample Kolmogorov-Smirnov nonparametric test statistic (K-S test) were used for testing the null hypothesis of equal depth distributions between the two dates (Bezerra-Neto and Pinto-Coelho, 2007).

In our study, two types of comparisons were used to quantify the influence of *P. akamusi* population dynamics on bioassessment. As reported in previous study (Hirabayashi et al., 2003), *P. akamusi* larvae can be collected by grabs during low-temperature period (late-autumn or winter), whereas the larvae are generally not found in grab samples during summer. Thus, to determine whether the appearance of *P. akamusi* in grab samples has a significant influence on the bioassessment results, we compared commonly-used macroinvertebrate metrics between two periods: "Summer" and "Late-autumn" using Mann-Whitney *U* test.

Since *P. akamusi* was expected to perform vertical migrations, we examined if the influences of these vertical migrations on the bioassessment metrics could be diminished by the selection of sampling method. In this sampling method comparison, we compared commonly used macroinvertebrate metrics derived from the surface sediment samples (< 20 cm) collected with Peterson grab and from the core samples integrating upper 100 cm of the sediment. Differences in macroinvertebrate metric values obtained by different sampling methods were tested using *t* test or Mann-Whitney *U* test depending on