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Benthic diatoms and phytoplankton to assess nutrients in a large lake: Complementarity of their use in Lake Geneva (France–Switzerland)

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Lakes can be monitored using different bioindicators, among which phytoplankton and benthic diatoms. We compared these two indicators in Lake Geneva for nutrient assessment. Bimonthly samplings were carried out during one year in the euphotic layer of a pelagic site. In the same time four littoral sites were sampled at 40–50 cm depth. Species compositions and abundances of both bioindicators were analyzed following European standards. Water physico-chemical composition was analyzed at the same time. Seasonal succession of benthic diatom guilds was observed. The dynamics of benthic diatom communities were better correlated to the pelagic chemistry than to the local littoral chemistry. We also observed that in the sampling sites frequently exposed to winds and waves, benthic diatoms showed lower correlations to physico-chemical dynamics, because of an increase of pioneer diatoms abundance adapted to turbulent environment, such sites must be avoided for lake monitoring. Finally, biotic indices calculated with benthic diatoms in wind protected sites showed higher correlations with pelagic nutrient concentration (PO_4^{3-}) than indices calculated with phytoplankton. This unexpected situation can be explained by differences of temporal variability of chemical and biological compartments. Littoral chemistry changed faster than pelagic chemistry because of rains, diffuse flow from watershed and rivers flowing in the littoral zone whereas pelagic chemistry has a much smoother evolution because it is situated 10 km from the coast. But phytoplankton showed a high temporal variability because of wind influence, which explained the low correlation with the smooth evolution of pelagic chemistry. On the other hand, benthic diatoms from sites protected from the dominant wind, showed a lower temporal variability and were more in synchrony with the smooth evolution of pelagic chemistry.

Even if we show that diatom seem to be promising indicator of nutrient level of the lake, we also underline the complementarity of using both indicators: benthic diatom and phytoplankton. Each of them brings different information about temporal variability of the lake and about the functioning of different habitats. Comparing these two bioindicators only on the basis of nutrient correlation ability would be an over-simplification whom managers must be warned.

1. Introduction

Microalgae are powerful ecological indicators for freshwater ecosystems. Phytoplankton is worldwide used since a long time as bioindicator in lakes. Phytoplankton species succession during seasons (e.g. Sommer et al., 1986) and nutrient levels (e.g. Brettum, 1989) are well-known for large alpine-lakes. In a recent review, it was shown that lake phytoplankton studies outnumber lake periphyton studies by an order of magnitude (Cantonati and Lowe, 2014). Lake Geneva is an excellent representative of this situation, since numerous papers have been published about phytoplankton (e.g. Anneville and Leboulanger, 2001; Anneville et al., 2002; Rimet et al., 2009a; Kaiblinger et al., 2009) and only a few papers about benthic micro-algae (Rossier and Cosandey, 1972; Larras et al., 2014). In rivers, the situation is much different, since benthic diatoms are the most commonly used micro-algal ecological indicator for several decades (e.g. Butcher, 1947; Fjerdingstad, 1950; Kelly and Whitton, 1995). It has been shown that diatoms indicate a number of anthropomorphic pressures such as eutrophication, acidification, land use and toxic pollution (Rimet, 2012). They are now routinely used in Europe after the Water Framework Directive, WFD (European Commission, 2000) required member states to assess the ecological status of their rivers using diatoms.

Even if the choice of an ecological indicator for a particular environment is often based on tradition, other objective criteria such as its abundance and biodiversity are essential in its

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selection. This influenced the decision to choose diatoms for rivers quality assessment, since this is often the most common algal class in terms of biomass and it has a huge diversity (Stevenson, 1998). The same rational was carried out for lake and phytoplankton where it plays a key role in lake ecosystems (Wetzel, 2001). Nevertheless, recent studies showed that lake periphyton can display important biomass changes when nutrients level decrease (Althouse et al., 2014; Vadeboncoeur et al., 2001) and modifying their species composition (King et al., 2000). Moreover, it was shown that diatoms could be good surrogates for periphyton lake assessment (Kelly et al., 2008) and some authors proposed guidelines for their sampling (King et al., 2006). Several authors applied river diatom indices to assess lake pollution, which showed good results (Blanco et al., 2004; Bolla et al., 2010; Cellamare et al., 2012). Other authors showed that indices recently developed and adapted for littoral diatoms in lakes seemed to be more efficient for providing a more realistic ecological assessment (Bennion et al., 2014; Stenger-Kovacs et al., 2007; Marchetto et al., 2013; Marchetto, 2013). But this is debated; Kahlert and Gottschalk (2014) stated that river indices work very well in lakes, probably because similar mechanisms are steering benthic diatom communities in lakes and rivers.

On a regulation point of view, the WFD requires both phytoplankton and periphyton data be collected to assess lake quality. But from a lake manager's point of view, applying periphyton and phytoplankton to assess the ecological quality of a lake sounds redundant; they are both micro-algae, with short generation times. Nevertheless, they are not expected to respond equally to the same environmental factors. Phytoplankton should respond faster to environmental changes, since its drifts freely in the horizontal/vertical water currents of lakes and could sink rapidly in aphotic layers (Crossetti et al., 2013). On the other hand, periphyton do not drift due to its sessile life form, and therefore should integrate the environmental changes on a longer time scale. Only a few studies have compared periphyton and phytoplankton in lakes (e.g. Cellamare et al., 2012; Crossetti et al., 2013) and reported contrasting results.

The objective of this study is to compare littoral benthic diatoms to phytoplankton in a biomonitoring framework for a large deep lake, Lake Geneva. This lake is monitored by sampling above the deepest point bi-monthly (or monthly during winter) in the framework of a long-term ecosystem research SOERE OLA (Système d'Observation et d'Expérimentation au long terme pour la Recherche en Environnement – Observatoire des LAcs alpins – http://www6.dijon.inra.fr/thonon/L-observatoire-OLA). The trophic level of the lake is evaluated by means of a phytoplankton index adapted for large alpine lakes (Wolfram and Dokulil, 2007) and by means of phosphorus concentration (PO_4^{3-}). Even if littoral diatom sampling recommendations have been proposed to sample only one site per lake (King et al., 2006), given that Lake Geneva is a large lake, a heterogeneity of diatom communities will be expected. Therefore, several sampling sites were sampled monthly (or bi-monthly) during one year.

The following hypotheses were addressed:

(1) We were expecting that seasonal dynamics of littoral benthic diatoms in lake Geneva would occur even if they are generally poorly described (King et al., 2005; Cantonati and Lowe, 2014). We were also expecting that they would be principally controlled by nutrients concentrations.
(2) Since lake Geneva is a large lake, we were expecting that littoral benthic diatoms would be heterogeneous and this would be partly explained by the action of waves in wind exposed sites since it is a parameter already identified as a determinant to explain micro-algae composition in shallow habitats of lakes (Cantonati and Lowe, 2014).
(3) Because of their sessile habit, we were expecting that littoral benthic diatom communities of wind protected sites to have a lower temporal variability than pelagic phytoplankton. We were expecting this lower temporal variability of diatoms to be a benefit to be more in synchrony with the smooth nutrient changes occurring in the pelagic zone.

Finally, some biotic indices based on benthic diatoms and phytoplankton will be calculated and their correlations with nutrients concentrations (PO_4^{3-}) of the pelagic zone will be compared. Then we will discuss the complementarity of these two bioindicators for lake monitoring.

2. Materials and methods

2.1. Study site

Lake Geneva is 72.3 km long and 13.8 km wide. It has a maximum depth of 310 m and an average depth of 152 m. Its surface area measures 582 km^2 and has a volume of 89 km. The mean retention time of the water is 11.4 years (Druart and Balvay, 2007). It is a monomictic meso-oligotrophic lake. Pelagic phytoplankton samples were taken from the middle of the lake – SHL2 sampling site – (Fig. 1), over the greatest depth of water (coord. CH: 534.700/144.950). Littoral diatoms were sampled at the four sites (Fig. 1). The north-east wind was the dominant wind in the lake (Fig. 1) and this is the case every year. Appendix A gives a precise description of the littoral sampling sites.

2.2. Sampling and laboratory procedures

Littoral benthic diatoms were sampled at four littoral sites according to guidance protocols (King et al., 2006). Collections were conducted from 4 April 2012 to 3 April 2013. Each site was sampled twice a month from April 2012 to June 2012, then once a month from July 2012 to April 2013. The dominant substrate in this deep lake was stones, unlike in shallow lakes where macrophytes are abundant (Blanco et al., 2004; Stenger-Kovacs et al., 2007). Therefore, five stones were collected at 40–50 cm depth. For all sampling the water was transparent and the stones could be easily seen and collected (the water was not turbid). Their upper surface was scraped using a tooth brush. The biofilms were collected and fixed with 70% ethanol. The biofilms were treated according to the European standard EN 13946 (Afnor, 2003) using hot H_2O_2 and Naphrax was used to mount permanent slides. Four hundred frustules were counted and determined to species level according to EN 14407 (Afnor, 2004) using classical European floras (e.g. Krammer and Lange-Bertalot, 1986, 1988, 1991a,b; Krammer, 2001, 2000, 2002, 2003 etc.).

Diatom ecological guilds abundance in the samples was defined using (Rimet and Bouchez, 2012). Their seasonal dynamic was calculated. The interest to use such metrics was to get rapid information about biofilm structure and usually strengthens relationships with certain parameters (e.g. nutrients or turbulence, as shown in Berthon et al., 2011 or Passy and Larson, 2011).

Pelagic samples were carried out at SHL2 site from 26 April 2012 to 29 April 2013, collections were conducted twice a month from May to November 2012 and from March to April 2013; the other months were sampled once. Phytoplankton was sampled at SHL2 site using an integrated sampler (INRA-patent 1974), as it is usually done for the long-term monitoring of the lake (e.g. Druart and Rimet, 2008). Phytoplankton samples were collected from the 0–20-m layer and fixed with Lugol's. The laboratory procedure