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Factors supporting harmful macroalgal blooms in flowing waters: A 2-year study in the Lower Ain River, France

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ABSTRACT

A two-year study was conducted to explore summer development of macroalgae and their total phosphorus and nitrogen content at three stations in a broad and clear French carbonate river. Water discharge, temperature and insolation, each with a different time lag, as well as substrates and nutrients were examined in order to explain macroalgal biomass variability. Twenty-four macroalgae genera were recorded with *Spirogyra, Cladophora, Vaucheria* and *Oedogonium* as abundant. Through redundancy analysis the macroalgal community composition exhibited significant differences, between the sampling sites and also from one year to the next. Water discharge (time-lag = 5 days) and temperature (time-lag = 20 days) both significantly explained macroalgal biomass variability, highlighting differences in the time lag of the macroalgal community's ecological response to environmental changes. Spatial segregation was observed within the wide riverbed due to habitat variability, allowing co-occurrence in the development of ecologically different taxa within each sampling site. The high nitrate concentrations as compared with the particular low phosphorus concentrations led to especially high DIN/SRP ratios (248 ± 103, $n = 18$). The N/P ratios in algal tissues were high (25 ± 16, $n = 26$) and indicated P-limitation. The differences in DIN/SRP and N/P ratios suggest additional nutrient sources than open water such as groundwater inputs.

1. Introduction

Among the ecological assessments of river system health in current environmental policy, benthic macroalgal blooms as a cause of environmental degradation remain poorly understood (Scanlan et al., 2007). Intrinsic properties in the development of these organisms (i.e. high spatial and temporal variability) imply difficulties in estimating the extent of their environmental pressure. Furthermore, contrary to other primary producers such as diatoms and their related normalized sampling protocol (e.g. Trophic Diatom Index), several sampling issues are inherent to the study of macroalgae due to their highly patchy distribution which differs among taxa (Aleya, 1991; Haury et al., 2006).

The Lower Ain River (France) suffered intensive grayling (*Thymallus thymallus*, L. 1758) mortality in the summer of 1998 and 2003 (Charles et al., 2006), as well as in 2008, with the possible implication of harmful macroalgal blooms. Due to its great width (i.e. ca. 70 m width), this clear carbonate river was thought to potentially shelter various co-existing macroalgae, further transcribed in a succession of summer macroalgae blooms that had to be studied if we were to understand their putative hazards for fish health and, more generally, for the river-ecosystem health. A two-year study was thus undertaken to depict the composition and structure of the summer macroalgal blooms in the Lower Ain using a sampling protocol based on macroalgal cartography and biomass estimations. Secondly, the influence of environmental constraints (i.e. temperature, nutrient discharge and insolation) on the macroalgae blooms was tested using different realistic time lags within which the macroalgae community could respond. This approach was thought to be ecologically meaningful for a better management of these threats. For instance, because water circulation in the Lower Ain is regulated by dam activity, water regulation is expected to impact the relationships between macroalgae and natural seasonal variability and thus be of potential use in controlling macroalgae blooms (Lapointe and Bedford, 2007). Finally, the possible limits to considering the trophic status of flowing water (according to the Water Frame Work Directive, 2000) as a reliable descriptor of the nutrient constraint limiting macroalgae blooms is discussed in the light of the comparison between nutrient content in flowing water and in macroalgal tissues.

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2. Materials and methods

2.1. Study area

The Ain River is a large tributary of the Rhône about 200 km long, its continuum interrupted by five dams along its course. The study area was located downstream from the last dam (Allement Dam), extending to the confluence with the Rhône (Fig. 1). This part of the river is commonly called the Lower Ain River and is 53 km long. The main characteristics of the study area are reported in Table 1. The catchment area is weakly urbanized and dominated by intensive agricultural activities mainly maize monoculture. The geology is composed of quaternary glacial to glacio-fluvial deposits of a calcareous nature. The area's climate is continental, characterized by warm summers and harsh winters. The mean annual precipitation is ~1118 mm yr^{-1}. Autumn is the rainiest season, and both spring and summer usually present low precipitation. Three secondary dams are implanted in the upper part of the study area. Though rather small (i.e. elevation max. ~3 m), they can nevertheless influence the natural discharge variability of the river.

2.2. Sampling sites

In April 2008, the morphological facies of the 53 km of the Lower Ain were determined according to Malavoi and Souchon (2002) by means of GPS waypoints recorded on a canoe expedition. Habitats called "riffles", (i.e. habitat found in any section of the river) were selected (following the advice of experienced river fishermen) for their capacity to support large harmful macroalgal blooms. The first 12 km were characterized mainly by a deep lentic habitat (i.e. 75%) due to the presence of secondary dams, riffles being the second facies present (i.e. 25%). In contrast, in the 40 km downstream from the secondary dams, riffles were dominant (i.e. 75%) and pools secondary. In order to compare changes in the macroalgae community along the longitudinal gradient, data were collected at three sampling sites, each over 50 m in length. Sites were located downriver from the outlet of Allement Dam at 1.8 km for S1, 13.8 km for S2 and 36.8 km for S3 (Fig. 1).

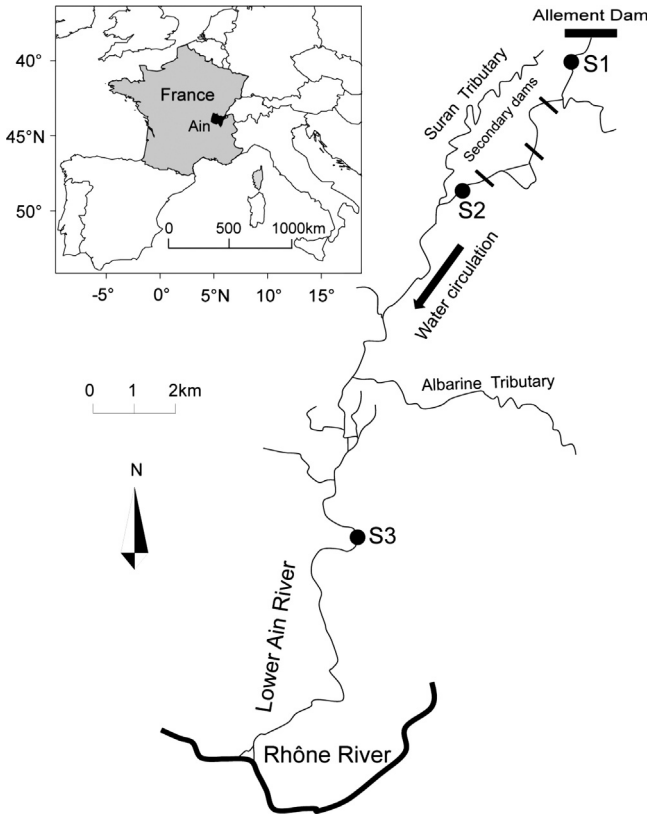

Fig. 1. Geographic position of the Lower Ain River (France). Black circles indicate sampling sites.

Table 1
Main characteristics of the study area.

River characteristics	Values
Length (km)	53
Catchment area (km^2)	3765
Average slope ($m\,km^{-1}$)	3
Average interannual flow ($m^3\,s^{-1}$)	106
Mean annual temperature (°C)	11.3
Mean width (m)	70
Conductivity ($\mu S\,cm^{-1}$)	350

2.3. Sampling procedure

Due to the high variability in macroalgae spatial development within sampling sites, and because identification in the field was not possible for some genera, a stratified protocol was developed using algal recovery intensity (%) according to the guide from the Macrophyte Biological Index for Rivers (AFNOR NF T90-395, 2003) that did not take into account the genus-specific spatial distribution. This protocol allows segregation of non-overlapping strata of homogenous algal recovery (Fig. 2). A cartography was produced to illustrate the spatial distribution of macroalgae blooms (Fig. 2); in each stratum three samples were haphazardly collected using a Sürber sampler (i.e. 1/20 m^2). Numerous samples were therefore found to vary according to the complexity of macroalgae development, usually ranging from 12 to 30 samples. Any non-algal materials (e.g. invertebrates, sand) were removed from samples using fine forceps. Samples were then systematically exposed to 20 turns of a salad spinner to remove water prior to being wet-weighed. Macroalgae in the study area did not strongly differ in their structural tissues limiting inter-genera variation in their wet mass/dry mass ratios. Indeed, prior tests showed that these ratios were steady between genera (ANOVAs, $p > 0.5$, $n = 24$, mean = 0.19 ± 0.05, unpublished data) in agreement with previous studies on macroalgae (e.g. Ramus and Venable, 1987). Wet mass was therefore considered as a robust proxy to describe macroalgal standing stock. The proportion of each genus within samples was determined in the laboratory using binoculars. The genera-specific biomass in each stratum was obtained by dividing the proportion of a genus by the total biomass of each sample within a given stratum. The cartography used to define sampling design was computed and the mean biomass of each taxon for a given study site was then obtained by summing the taxa-specific biomass in each strata weighted against

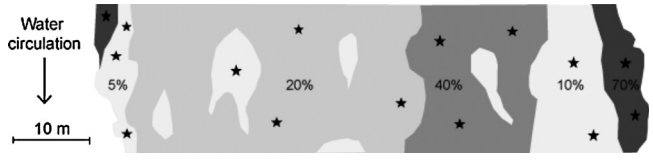

Fig. 2. Example of macroalgae map produced from the field. The different macroalgae strata are distinguished according to macroalgae recovery (%) with no consideration of the taxonomic differences as all the genera could not be visually identified in the field. The biomass of each genus was estimated from its relative proportion within samples in each stratum after laboratory determination. The color of the stratum becomes progressively darker as macroalgal recovery increases. Recovery strata were divided by classes of 10% of recovery. In each strata, three samples (black stars) were haphazardly collected.