Submitted as a Letter to *Science (October, 2014)*

Published online here:

http://comments.sciencemag.org/content/10.1126/science.346.6206.175-a

Cyanobacterial harmful algal bloom: *Legends of the fall … die hard*!

Stéphan JACQUET

INRA, UMR CARRTEL, 75 avenue de Corzent, 74203 Thonon-les-Bains, France

sjacquet@thonon.inra.fr

A general and accepted consensus is that cyanobacterial blooms may increase in distribution, duration and intensity with eutrophication and/or global temperature rise because warming can selectively promote cyanobacterial growth. In the last issue of *Science* (October 2014, vol 346, issue 6206), a first letter of Hans Pearl and colleagues reported that lake management should now consider more the importance of nitrogen supply and removal and no longer only the phosphorus control because of its historical limiting status. These authors explained indeed that some algal blooms have been observed in response to N supply only and that the "P only management paradigm should be amended to incorporate to N-driven eutrophication and HAB abundances". Mingzhi Qu and colleagues proposed in a second letter an alternative strategy they referred to as the proactive control of HAB, for the management of inhibition of algal growth during the spring period. Authors wrote they were enabled to prevent cyanobacterial blooms in a variety of eutrophicated lakes and reservoirs.

These two letters reminded me as much we are used to reading articles dealing with cyanobacterial blooms and all problems (and future/expected ones) associated to their increasing severity worldwide, while it is rarer to see examples of large ecosystem recovery. Thus, I would like to report here a case study, a story with a happy ending exemplified with Lake Bourget (the largest natural lake in France) restoration. During almost 20 years, the toxic and filamentous cyanobacteria *Planktothrix rubescens* developed and bloomed (representing between 20 and more than 50% of the algal biomass each year) in this ecosystem despite efforts to reduce phosphorus loading since the early 1980's. While phosphorus input to the lake was estimated to be more than 300 tons per year in the mid 70's, restoration (with the construction or modernization of sewage treatment plants but merely through the implementation of an underground gallery diverting all the treated water away from the lake) resulted in significant abatement of phosphorus concentration into the lake. From 1980 to 2014, at the monitoring reference station (situated at the deepest point of the lake and away from lake tributaries), phosphorus concentration decreased between more than 100 to near 10 µgP/L. It was during the 1996-2009 period that the bloom occurred and persisted (especially in summer and fall) while mesotrophic conditions characterized the lake (with average P concentrations varying typically between 20 and 50 µg/L).

By the end of 2009, however, during fall (a period opportune to *Planktothrix rubescens,* Feuillade 1994), a conjunction of events occurred so that the cyanobacterium disappeared. Interactions among nutrients, light availability, temperature and water column stability as well as zooplanktonic grazing could be identified as important in explaining bloom collapse as it is generally the case for cyanobacterial dynamics and blooming determinism (Huisman et al. 2005). From October 2009, and in contrast to the same period during previous years, phosphorus was nearly absent in the upper layers of Lake Bourget, PO_4 depletion reached deep layers (below 50 m) and was below the detection limit from the beginning of October 2009 to early January 2010. *P. rubescens* growth was thus limited by resources, and its biomass started to decrease. In conjunction to nutrient limitation, the cyanobacterium was limited by light since at the end of summer, early autumn, transparency was relatively low and the bottom of the euphotic zone largely above the biomass peak. By the end of 2009, high zooplanktonic biomass and low microcystin concentrations were recorded. A similar dynamic pattern was found between the cyanobacterium and all herbivorous zooplanktonic forms. Furthermore, we demonstrated experimentally that filament length, i.e. resistance to grazing, decreased as phosphorus availability decreased (Jacquet et al. 2014). All together, these observations suggested that zooplankton grazing pressure could have promoted bloom termination. A parallel study conducted in summer 2009 confirmed that *P. rubescens* was efficiently grazed by small zooplanktonic species (Perga *et al*., 2013). The biomass decreased until the end of autumn, so that during winter 2009/10, *P. rubescens* was observed just once and counted at 580 cells mL^{-1} at a depth of 30 m. In other words, only a small and isolated inoculum (which is important for enabling the cyanobacterial proliferation in summer, when the water column is stratified) was observed at the beginning of 2010. Moreover, full mixing of the water column occurred during winter 2010, enhancing dilution of the population throughout the water column, and preventing the subsequent increase in *P. rubescens* population*,* which probably later collapsed in response to both light limitation and vesicle damage due to hydrostatic pressure (Walsby et al. 1997). As a result, no filament was observed in winter and spring 2010, and since that time, the cyanobacterium never bloomed, a new phytoplankton assemblage arose, more typical of an oligotrophic ecosystem (e.g. with small diatoms, chrysophytes, cryptophytes, picocyanobacteria) and the mean annual biomass remained below 1500 µg L^{-1} when it could reach up to 5 mg L^{-1} before.

The cost of such a success has been estimated to 250 million euros, which is probably less than the money loss induced by *Planktothrix* blooms, in terms of ecosystem services provided (tourism and recreational activities, fisheries, drinking and irrigation water supplies). With an important policy effort *Planktothrix rubescens* disappeared. It die hard but it died! We are aware, however, that, if oligotrophication is not likely to favor pelagic harmful cyanobacterial bloom, the probably of such event occurrence is not null. Species such as *Microscystis* or *Anabaena*-like could indeed develop sporadically in the future, because some species can survive in sediments or form biofilms in littoral zones where they could respond efficiently to nutrient pulses noticeably associated to extreme events such as important rainfalls or physical disturbance such as stochastic lake level fluctuations (Callieri et al. 2014), some typical responses to climate change.

Callieri C, Bertoni R, Contesini M, Bertoni F. 2014. Lake level fluctuations boost toxic cyanobacterial oligotrophic blooms. *PlosOne* 9, 10, e109256.

Die hard (1994, John McTiernan)

Feuillade J. 1994. The cyanobacterium (blue-green alga) *Oscillatoria rubescens*. In Studies on Lake Nantua France. Stuttgart (DEU) : E. Schweizerbart'sche (Ergebnisse der Limnologie, 41), 77-93.

Huisman J, Matthijs HCP, Visser PM. 2005. Harmful Cyanobacteria Series. *Aquatic Ecology Series*, Vol. 3, XIII, 243 p.

Jacquet S, Kerimoglu O, Rimet F, Paolini G, AnnevilleO. 2014. Cyanobacterial bloom termination: The disappearance of *Planktothrix rubescens* from a large restored lake. *Freshwater Biology* doi:10.1111/fwb.12444.

Legends of the fall (1988, Edward Zwick)

Pearl HW, Gardner WS, McCarthy MJ, Peierls BJ, Wilhelm SW. 2014. Algal blooms: Noteworthy nitrogen. *Science* 346, 6206:175.

Perga ME, Domaizon I, Guillard J, Anneville O. 2013. Cyanobacterial blooms: trophic dead-ends or unexpected dietary bonus. *Oecologia* 172, 551-562.

Qu M, Lefebvre DD, Wang Y, Qu Y, Zhu D, Ren W. 2014. Algal blooms: Proactive strategy. *Science* 346, 6206:175-176.

Walsby AE, Hayes PK, Boje R, Stale LJ. 1997. The selective advantage of buoyancy provided by gas vesicles for *Planktothrix* cyanobacteria in the Baltic Sea. *New Phytologist* 136, 407-417.

Lake Bourget without toxic cyanobacteria oligo- or mesotrophic bloom!