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INTRODUCTION

The eutrophication of many freshwater ecosystems due to human activities frequently results in recurrent cyanobacterial blooms (O'Neil et al., 2012). These blooms disrupt the functioning of aquatic ecosystems and their uses, particularly because many species are likely to produce cyanotoxins (Paerl et al., 2016). It has long been known that the control of nutrients provides a sustainable solution to prevent and/or restore ecosystems from eutrophication and therefore from cyanobacterial blooms (Heisler et al., 2008). However, this requires reduced nutrient inputs, which are often complex and expensive to achieve, and the effects may take time to become visible. For these reasons, many managers have invested in short-term remedial solutions that rapidly reduce cyanobacterial concentrations.

The use of short-term solutions (STS) is primarily based on the application of chemical products such as copper sulfate ($CuSO_4$) and hydrogen peroxide (H_2O_2) or on the use of ultrasonic devices. The application of these STS has generated considerable debate within the community of scientists working on cyanobacteria. In France for example, the scientific community has largely agreed not to recommend STS. However, there is still considerable debate internationally, and this issue generated intensive discussion during a special session on the use of STS at the International Toxic Algae Conference held in Nantes, France in 2018. The aim of this opinion paper is to provide further context to why some scientists are concerned about the increasing use of STS.

HOW TO LIVE WITH CYANOBACTERIA?

Human exposure to cyanotoxins occurs mainly via ingestion of contaminated water. To limit the exposure, monitoring of cyanobacteria and their toxins has been implemented in many developed countries (**Figure 1**). This monitoring informs users of potential risks and can lead to the exclusion of some activities during bloom periods.

When cyanobacterial blooms occur that are potentially dangerous to human health, three kinds of actions can be implemented (i.e., Paerl, 2018). First, if the goal is to maintain different uses despite the recurrent proliferation of cyanobacteria, STS that rapidly reduce cyanobacterial biomass, can be used. To our knowledge, these STS are mostly used in developed countries to
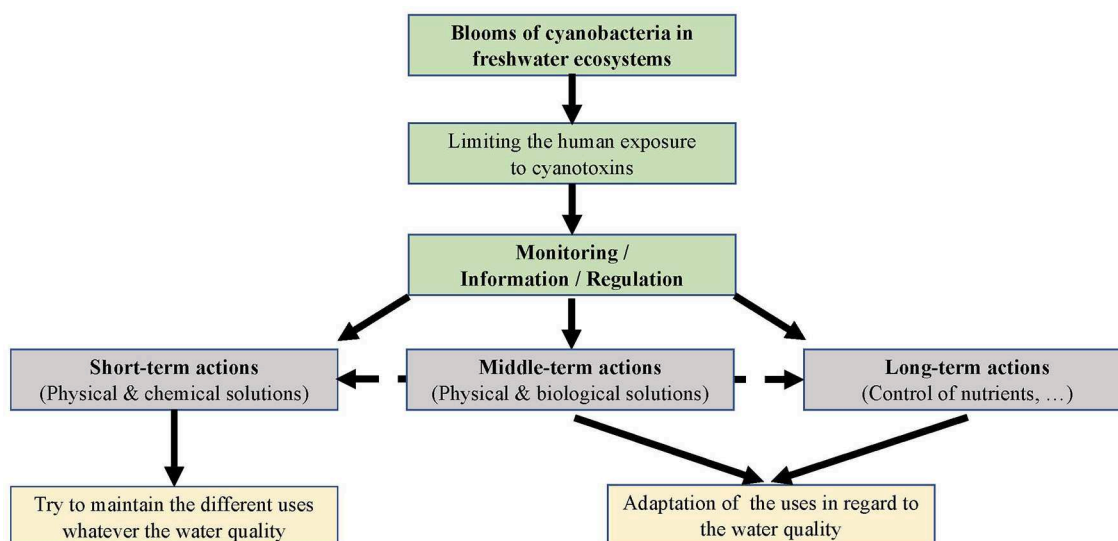
FIGURE 1 | Management scheme for cyanobacterial blooms.

maintain recreational activities in water bodies. Second, various middle-term solutions such as mixing of the water column, the use of compounds that absorb or precipitate phosphorus, or biomanipulation of trophic networks, can be used to limit the development of cyanobacteria. Third, long-term solutions based on the control of nutrient inputs can be implemented that reduce eutrophication and thereby moderate problematic cyanobacterial blooms. These two last strategies require water managers to modify water use by the public while the solutions take effect. For example, temporary swimming closures, or long-term changes in recreational activities, or finding alternative drinking water supplies may be required. It has been recommended that the two first strategies are used in combination with the sustainable protection and/or restoration of freshwater ecosystems (Ibelings et al., 2016).

From a legal perspective in Europe, it appears that the use of chemical products or ultrasound treatments in water bodies do not require specific authorization and there is little or no regulation of their application in natural environments. In the case of $CuSO_4$ and H_2O_2, these two products are classed as Type 2 biocides and algaecides by the European Chemical Agency (see https://echa.europa.eu/fr/information-on-chemicals/biocidal-products), but their use in natural environments is not clearly defined. This regulation mainly concerns the use of H_2O_2 in swimming pools or other closed basins, and recommendations have been made to limit discharges into natural environments. The European regulation n°528/2012 on the biocidal use of copper sulfate [https://circabc.europa.eu/sd/a/b3b0f644-6e3b-4ac4-8c5f-2bba6e5cf9c6/Copper%20sulphate%20(assessment %20report%20as%20%20finalised%20on%2027.09.13).pdf] only concerns the industrial use of this product and recommends limited discharges into natural environments. Finally, we were not able to find any administrative authorization related to the use of ultrasound devices in freshwater ecosystems in Europe.

IS IT POSSIBLE TO ASSESS THE REAL IMPACT OF SHORT-TERM REMEDIAL SOLUTIONS ON ECOSYSTEMS?

We have identified several potential problems in the assessment of the impact of STS on ecosystem biodiversity and functioning:

- Some of these impact studies have been performed by research teams who were involved in the development of these products and/or have financial links with private companies involved in their development and/or implementation. As it has been already described in medical research, such situations can generate potential conflicts of interest (Bekelman et al., 2003; Resnik, 2007).

- We are concerned about the difficulties in assessing the impact of STS on freshwater ecosystems by using laboratory experiments. These experiments focus on a limited number of target organisms compared to the biodiversity present in natural freshwater ecosystems. It is well-known that susceptibility to a substance varies significantly between species, even if they belong to the same class (Ma et al., 2002, 2006). Additionally, the target species chosen for these tests are not always those that are the most likely to be affected by the treatment. For example, there are no data on the impact of H_2O_2 on the bacterial communities in aquatic ecosystems despite the well-known bactericide activity of this product (Colobert et al., 1962). Bacteria play a key role in aquatic nutrient cycles (Azam et al., 1983), therefore enhancing knowledge on the effect of H_2O_2 on bacterial communities should be a priority.

- Extrapolating, data obtained from laboratory or mesocosm experiments to natural environments is difficult because aquatic organisms are subject to much greater stresses in their

natural environment. This has marked consequences on their responses to an additional stress (Heugens et al., 2001).

These concerns highlight the difficulties of carrying out an *a priori* assessment of the potential impacts of STS on biodiversity and freshwater ecosystem functioning. They are similar to those already widely acknowledged for the assessment of the environmental impacts of pesticides (see, for example, Forbes et al., 2008). To overcome these limitations and difficulties, long-term monitoring of ecosystems where the solutions have been applied should be systematically implemented (Vijver et al., 2017). Such monitoring programs are the most robust way to detect the long-term effects of these treatments, especially if they lead to disturbances that do not affect the main uses of water bodies. However, when looking at the current situation in France, most of the ecosystems where these solutions have been applied are not subject to any long-term ecological monitoring. For example, of the 35,000–500,000 water bodies (surface >0.01 hect) identified in France (Bartout and Touchard, 2013), only 435 are monitored for their ecological status under the Framework Water Directive.

ENSURING SUITABLE PRACTICES IN THE APPLICATION IN THE FIELD OF SHORT-TERM SOLUTIONS

We have identified several difficulties in the field application of STS. The first concerns the estimation of optimal doses to be applied to prevent or reduce the development of cyanobacterial blooms while limiting the adverse effects on non-target organisms. In respect to ultrasound, Lürling et al. (2016) noted that significant differences occurred between the protocols applied in the laboratory and those implemented in the field according to the characteristics of the ecosystems and the equipment used. While it is relatively straight forward to define the optimal chemical doses during laboratory experiments, it is much more difficult to do so in natural environments. Doses depend on the ecosystem characteristics (its morphometry for example) and environmental variables that may interfere with treatment efficacy. Barrington et al. (2013) and Drábková et al. (2007) have shown that the optimal dose for H_2O_2 depends on the volume of the water body, the phytoplankton biomass, the type of cyanobacteria (for example, the size of the colonies) and the UV radiation/light intensity. As a result, the recommendations in terms of effective doses vary considerably in the literature, from 2 to 20 mg. L^{-1} (Matthijs et al., 2012; Lürling and Tolman, 2014; Kansole and Lin, 2017). These findings emphasize that prior to chemical application a detailed knowledge of each ecosystem is needed.

Finally, at least in France, the application in the field of STS is not subject to any control, which may result in practice that are unsafe or lead to ecosystem health decline. For example, it is recommended that application of $CuSO_4$ is avoided during cyanobacterial blooms to prevent the release of free toxins into the water. However, in many cases this recommendation is not followed (see for example, Bourke et al., 1983; Jancula and Marsalek, 2011, and a report produced by the French Water Agency describes numerous cases of inappropriate use of $CuSO_4$: http://documentation.pole-zhi.org/doc_num.php?explnum_id=344).

IS THE USE OF SHORT-TERM SOLUTIONS COMPATIBLE WITH THE IMPLEMENTATION OF LONG-TERM ACTIONS AIMED AT REDUCING NUTRIENT LOAD IN AQUATIC ECOSYSTEMS?

STS are considered by some researchers and managers of water bodies as a complementary option to long-term actions for the control of nutrient inputs. However, there is often competition between the use of STS and the implementation of long-term actions. STS constitute a lucrative and growing market for many companies that attempt to convince managers of freshwater ecosystems that the use of these solutions will lead to rapid results. Consequently, many water managers prefer to invest in STS instead of implementing long term actions aimed at reducing nutrient inputs.

STS are presented as less expensive than long-term solutions but their cost is frequently underestimated because they must be repeated several times during the summer season and for many years [for example see Olivier (2018) for the Brittany region]. Moreover, poor efficiency means that water managers frequently test multiple STS with little consideration for the cumulative effects on ecosystems. For example in a waterbody located near Paris, the following actions have been applied successively in the past 15 years: lime, $CuSO_4$, installation of aerators, barley straw boots, addition of bacteria, installation of nets to protect one beach and construction of a wall to protect another beach. Consequently, in the context of limited budgets, especially when the management of water bodies belongs to small municipalities, these STS clearly compete with long-term actions for funding and resources.

CONCLUSIONS

Because of (i) the many uncertainties about the long-term environmental impacts of STS application on biodiversity and ecosystem functioning and (ii) the costs of these STS and consequently the financial competition between these solutions and the measures that reduce the eutrophication, we encourage scientists and managers of freshwater ecosystems negatively impacted by cyanobacterial blooms to consider a more cautious approach when recommending the application of STS, particularly when they aim to maintain non-essential uses such as recreational activities.

To better understand the reasons for the failures of the strategies implemented to combat eutrophication and to allow for the emergence of new paradigms that lead to the improvement the management of aquatic ecosystems, we believe that it is necessary to better implement transdisciplinary research approaches using sociologists, ecologist and economists as well as managers and users of these ecosystems, as it has been done for other issues (i.e., Lang et al., 2012). In this context, we will work

for example on the development of a territorial management approach for a set of water bodies where their uses and the actions implemented for their protection/restoration will be defined by cooperative approaches according to (i) the water quality and ecological health of these ecosystems and (ii) the users and managers expectations (Project GESTERR funded by the Britany Region and the Water agency Loire-Bretagne that will start in January 2020).

Finally, the issue of cyanobacterial blooms management has mainly concerned developed countries and some developing countries like China and Brazil. However, human population growth and associated activities means that an increasing number of developing countries, in particular on the African continent, will face increasing problems with cyanobacterial blooms. In these countries where numerous people have a limited access to treated water, the sustainable management of water bodies is a crucial issue and the uncontrolled use of STS might have dramatic consequences on human and environmental health.

AUTHOR CONTRIBUTIONS

J-FH and CQ have written the paper together.

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