Top-down Regulation of Algal Blooms: Pathogens as a Potential Whole Lake Biological Control Measure?

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Student Corner

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Background

Phytoplankton are responsible for over half of Earth's primary production and thereby play an important role in the cycling of carbon and nutrients in both marine and freshwater ecosystems. Traditionally, grazing has been seen as the most important phytoplankton mortality factor. Although already observed and documented some decades ago (Van Donk and Ringelberg 1983), it is only recently that parasites are being generally acknowledged for having a share in plankton mortality as well. Parasitism is the most common lifestyle on earth, but only in recent times there has been a call for the inclusion of these infectious disease agents in food web research and models (Lafferty et al. 2008). For phytoplankton, the most common pathogens are fungal parasites (chytrids) and viruses, which can infect up to 90 percent of the total host community, and are the most common biological agents in both freshwater and marine ecosystems. In the field, chytrids and viruses can reach densities between 1 and 10 billion counts per litre. Here, I will focus on the potential role of chytrids, a common fungal parasite in phytoplankton communities, in controlling algal blooms.

The Role of Chytrids in the Food Web

Hilda Canter-Lund, one of the pioneers in plankton research, frequently encountered planktonic diatoms infected by chytrids when performing algal counts. Actually, most of the planktonic diatoms she came upon were found to be infected by these host-specific parasitic fungi. This indicates that most species potentially have a parasite able to infect them. Chytrids have been shown to be highly infective and extremely virulent. The free-swimming zoospores are the main dispersive agent of the fungus (Van Donk and Ringelberg 1983), which actively searches for new hosts using chemical cues released by the phytoplankton. Once a host is found and infected, a sessile stage (sporangium, Figure 1) is formed in which new zoospores are produced. Chytrid infections in most cases kill their hosts. Thereby they can control host populations, delay timing and size of the phytoplankton bloom, and lead to an altered seasonal species succession (Van Donk and Ringelberg 1983; Frenken et al. 2016). Research has shown that fungal zoospores are an excellent food source for *Daphnia*, and upon zooplankton grazing, fungal infections can be significantly decreased. When large celled phytoplankton species are infected by chytrid parasites (Figure 2), nutrients within host cells are transferred to zooplankton via the fungal zoospores (Kagami et al. 2007).

Global Warming and Eutrophication

In the scope of global warming and eutrophication, available evidence indicates that ecological changes are expected to amplify infectious diseases. Earlier studies have outlined the existence of a disease-free window of cold water in winter that creates an opportunity for phytoplankton to build up a bloom when chytrid development is still inhibited by the low lake water temperatures (<3˚C). During cold conditions, not only is

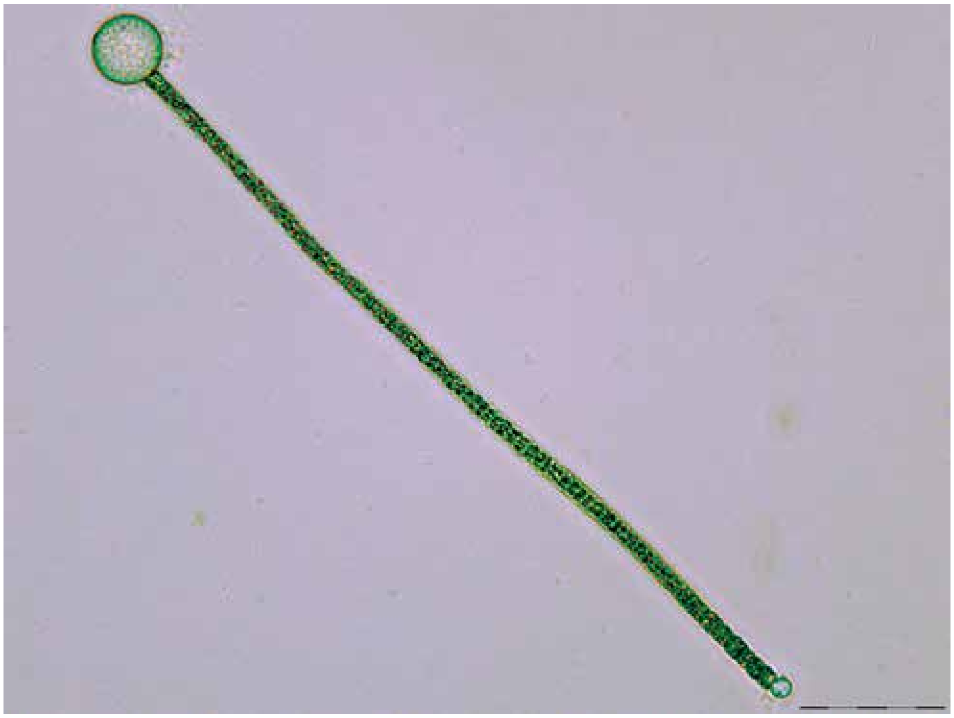

Figure 1. Example of a chytrid infection, with sporangia at both ends of a filament of Planktothrix rubescens *(scale bar length equals 50 µm).*

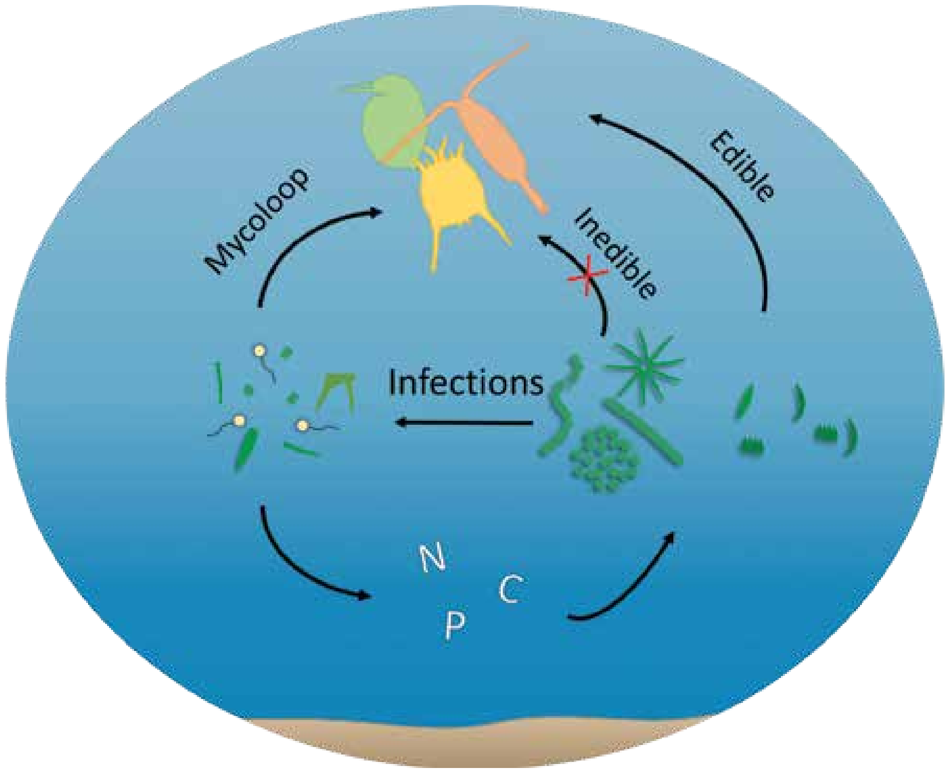

Figure 2. The mycoloop: grazing by higher trophic levels on fungal zoospores liberated after infection of large celled phytoplankton species.

chtyrid development time increased, also its expected lifetime is reduced. Due to global warming, the periods in which water temperatures remain low will be less frequent, decreasing the window of opportunity for uninfected growth (Ibelings et al. 2011). Additionally, warming is known to accelerate fungal parasite infections, which have been shown to terminate algal blooms (Frenken et al. 2016).

Regarding cultural eutrophication, usually the ratio between nutrients in catchment runoff is unbalanced. This ultimately forces phytoplankton growth into a limitation by nitrogen or phosphorus. These changes in the availability of nutrients will lead to a change in the nutritional quality of phytoplankton, and can change the availability of nutrients to the chytrids as well. Because chytrids are very susceptible to phosphorus limitation (Bruning 1991), nutrient-limited environments might impede chytrid proliferation. Overall, we can expect that top-down pressure by parasites is expected to increase in the future as a result of global warming and eutrophication.

Biological Control

The goal of biological control is to reduce or mitigate pests. In the case of algal blooms, the goal is to eliminate large-scale blooms using natural enemies of the target species. Because chytrids are very efficient at reducing host populations, they could represent a novel way to mitigate harmful and/or noxious algal blooms. However, practical applications may be hampered for several reasons. One reason can be host specificity of the chytrids. Chytrids can be highly host- (or genotype-) specific. Because most blooms consist of a mixture of genotypes from the same host or of different species, the efficiency of using chytrids in this scenario might be limited. Yet, some chytrids have a very broad host range. Thus, when the amount of host genotypes in a bloom are limited or chytrids with a broad spectrum are used for infection, applying chytrids might be a feasible biological treatment to control algal blooms. In lakes with high densities of zooplankton, the potential for using chytrids as a biological control might be limited, because zooplankton could graze away the fungal zoospores of the parasite. Therefore, in lakes with high densities of planktivorous fish, the potential for using chytrids as a biological control measure might be highest, because zooplankton populations can be controlled by the presence of fish.

Besides chytrids, viruses and pathogenic bacteria also might have a potential to be used as biological control measures to mitigate blooms. But, managers will need to find efficient ways to produce large amounts of pathogens first to enable the application of pathogen treatments on a whole lake basis. The amount of experiments testing the possibility to use pathogens of phytoplankton to control blooms is currently limited to laboratory studies and a large-scale mesocosm experiment. In my research, I focus on how eutrophication affects the infection mechanisms of chytrids, and test if their success rate changes during different nutrient loading scenarios. This might help us to predict the presence and behaviour of chytrids in the future, when nutrient loading of aquatic systems will change. Also, experiments are currently being performed where zooplankton are exposed to either healthy or infected cultures of phytoplankton, from which we can conclude the indirect effect of chytrid infections on the reproduction and population growth of zooplankton.

A Large-scale Mesocosm Case Study on the Termination of Algal Blooms by Pathogens

In 2007, a Chinese research group, Central China Normal University*, isolated pathogenic bacteria (Actinomycetes) that produces chemical compounds that are able to kill the notorious bloom-forming blue-green algae *Microcystis*. These pathogens were cultured in a relatively large-scale (~10,000 Litre) fermentation tank, where after they were dried and applied as a powder to a 1,000 m^3 enclosure in lake Dian-Chi, famous for its noxious *Microcystis* blooms. The bloom was ended three days after the single-dose treatment (Figure 3). This shows that it may be possible to use pathogens to control cyanobacterial blooms.

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Figure 3. Enclosures in lake Dian-Chi, China. On the left, a control enclosure, and on the right, an enclosure to which the pathogen was added.

Synthesis

To our knowledge, chytrids have never been used as a biological control measure. Before applying these pathogens to natural systems, much more research is needed to fully understand their infection mechanisms and how these interact with other trophic levels in aquatic systems. Experiments that investigate effects of pathogens usually focus on the host-parasite interaction, and not on the effects on the rest of the ecosystem and other organisms therein. Although we expect that the upcoming role of pathogens in controlling algal blooms will intensify, the practical applicability with our current knowledge is still limited.

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Thijs Frenken is a Ph.D. candidate at the Netherlands Institute of Ecology (NIOO-KNAW), with Dr. Dedmer B. Van de Waal and Prof. Dr. Ellen Van Donk as advisors. His research focuses mainly on the role of pathogens in structuring phytoplankton communities. His key interest is how bottom-up (nutrients) and top-down (zooplankton grazing) processes can affect phytoplankton diseases (chytrids and viruses) and their epidemics.

Next Issue – Spring 2017 *LakeLine*

The theme of our spring 2017 issue will be "PAH Sources to Lakes". Polycyclic aromatic hydrocarbons are a group of chemicals created by heating or burning material that contains carbon. The many sources of PAHs to the environment include asphalt, tire particles, used motor oil, and especially coal-tar-based sealcoat. PAHs are an environmental concern because many cause cancer, mutations, birth defects, or death in fish, wildlife, and invertebrates.