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Ammonium treatments to suppress toxic blooms of *Prymnesium parvum* in a subtropical lake of semi-arid climate: Results from *in situ* mesocosm experiments

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ABSTRACT

Prymnesium parvum is a haptophyte alga that forms toxic, fish-killing blooms in a variety of brackish coastal and inland waters. Its abundance and toxicity are suppressed by ammonium additions in laboratory cultures and aquaculture ponds. In a cove of a large reservoir (Lake Granbury, Texas, USA) with recurring, seasonal blooms of *P. parvum*, ammonium additions were tested in mesocosm enclosures for their ability to suppress blooms and their effects on non-target planktonic organisms. One experiment occurred prior to the peak abundance of a *P. parvum* bloom in the cove, and one encompassed the peak abundance and decline of the bloom. During 21-day experiments, weekly doses raised ammonium concentrations by either 10 or 40 μM. The added ammonium accumulated in experimental mesocosms, with little uptake by biota or other losses. Effects of ammonium additions generally increased over the course of the experiments. The higher ammonium dose suppressed the abundance and toxicity of *P. parvum*. The biomass of non-haptophyte algae was stimulated by ammonium additions, while positive, negative and neutral effects on zooplankton taxa were observed. Low ammonium additions insufficient to control *P. parvum* exacerbated its harmful effects. Our results indicate a potential for mitigating blooms of *P. parvum* with sufficient additions of ammonium to coves of larger lakes. However, factors excluded from mesocosms, such as dilution of ammonium by water exchange and sediment ammonium uptake, could reduce the effectiveness of such additions, and they would entail a risk of eutrophication from the added nitrogen.

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1. Introduction

There is growing appreciation for the potential degradation of water resources by harmful algal blooms (Heisler et al., 2008; Hallegraeff, 2010). Disruption of ecosystem function through toxicity to fish and other wildlife is one such impact (Sunda et al., 2006), and is especially associated with *Prymnesium parvum* (Carter), a unicellular haptophyte responsible for fish kills in aquaculture (Reich and Aschner, 1947; Barkoh et al., 2010), coastal waters (Otterstrøm and Steemann Nielsen, 1940; Johnsen et al., 2010), and inland waters (Holdway et al., 1978; Southard et al., 2010). The direct and indirect costs of fish-killing blooms of *P. parvum* have been substantial and motivate a search for control measures to prevent incipient blooms or mitigate ongoing ones.

One of the oldest control measures is the addition of ammonium salts (Reich and Aschner, 1947). *Prymnesium parvum* appears to be especially sensitive to free ammonia formed by deprotonation of ammonium (Barkoh et al., 2003; Grover et al., 2007), permitting the identification of ammonium doses sufficient to control *P. parvum* blooms while sparing non-target species, especially in aquaculture applications (Barkoh et al., 2004, 2010). For the small, enclosed water bodies often used aquaculture, ammonium dosing can be regarded as a proven treatment for *P. parvum* blooms. Treatments remain at an exploratory stage for larger water bodies, such as the multipurpose reservoirs constructed in much of the south central US, where *P. parvum* blooms have recently become common (Southard et al., 2010; Roelke et al., 2011). Focusing treatments on the marginal coves of such lakes offers the potential to create refuges for fish where *P. parvum* blooms are locally suppressed.

An advantage of treating selected coves in a larger lake system is the possibility to apply treatments that are too expensive or potentially harmful at the larger, whole-lake scale. For example, flushing with water free of *P. parvum* can remove or dilute bloom populations, and provide nutrient enrichment that suppresses toxic activity (Roelke et al., 2010; Schwierzke-Wade et al., 2011). Infeasible or prohibitively expensive water volumes might be needed to clear an entire reservoir, but might be achievable at cove scale (Hayden et al., 2012). Reduction of pH below 7 reduces the toxicity of *P. parvum* to fish (Shilo and Aschner, 1953; Valenti et al., 2010). While adjusting the pH of an entire lake could be expensive and entail ecological risks, treatment of smaller coves could be feasible (Prosser et al., 2012). Likewise, adding sufficient amounts of ammonium to an entire lake to suppress toxic blooms of *P. parvum* would require substantial nitrogen loading and potentially exacerbate eutrophication and oxygen depletion. The study reported here was designed to assess whether smaller, cove-scale treatment with ammonium doses could be of use in controlling blooms of *P. parvum*. Such treatments were applied to *in situ* mesocosm enclosures containing populations of *P. parvum* at different stages of bloom development. Efficacy of treatment is not a primary issue, since many prior studies indicate the potential for ammonium doses to control *P. parvum* (Reich and Aschner, 1947; Barkoh et al., 2003, 2004, 2010). Rather, the goal was to address the timing of such doses, comparing pre-bloom and bloom decline stages, and the potential for immediate effects on non-target organisms and community structure. Additionally, ammonium doses were compared to two other treatments that were tested simultaneously, hydraulic flushing (Hayden et al., 2012) and pH reduction (Prosser et al., 2012).

2. Methods

2.1. Study site

This study was conducted in Lake Granbury (32.40° N, 97.76° W, construction completed in 1969), an impoundment on the Brazos River (Texas, USA). This elongated lake follows the submerged river channel, with a volume of 189 × 10^6 m^3, surface area of 34 km^2, and mean depth of ~5 m and watershed area of 41,732 km^2. Lake Granbury has experienced recurrent fish-killing blooms of *P. parvum* since the winter of 2000–2001 (Roelke et al., 2011).

2.2. Experimental design

Mesocosms were deployed in a cove of Lake Granbury, on the northeastern shore about 2/3 of the way from the headwaters to the dam (Hayden et al., 2012). Enclosures were cylindrical plastic bags (1 m diameter, 2 m deep), open to the air and closed at the bottom, with rigid supports and flotation collars. Mixing within bags on daily time scales was anticipated based on prior experience verified by *in situ* depth profiles of water quality parameters (Roelke et al., 2007). In each experiment, 36 enclosures were deployed on rafts of 18 each. Twelve of these enclosures were allocated as controls receiving no treatment, six were allocated to treatments testing additions of NH_4 to suppress *P. parvum*, and the remaining 18 enclosures were allocated testing other means of suppressing *P. parvum* (hydraulic flushing: Hayden et al., 2012; pH reduction: Prosser et al., 2012). All treatments were allocated randomly to enclosures.

Two experiments were conducted. Based on observations of *P. parvum* blooms in Texas reservoirs (Southard et al., 2010; Roelke et al., 2011), the first was timed to coincide with the pre-bloom stage and the second with bloom decline. Each experiment lasted 21 days: the first began on February 23, 2010; and the second on March 31, 2010. Conditions in cove water nearby the enclosure array were monitored weekly throughout the times that these experiments were conducted (Hayden et al., 2012).

Ammonium pulses were added weekly at two levels, to triplicate enclosures for each level. The two pulse levels delivered were designed to raise NH_4 concentrations by 10 and 40 μM, levels used in previous laboratory experiments on suppression of *P. parvum* (Grover et al., 2007). The high dose lowered toxicity in laboratory cultures of *P. parvum*, while the low dose is within the range of natural variations in NH_4 concentration in surface waters of Texas reservoirs (Chrzanowski and Grover, 2005). Ammonium chloride (NH_4Cl) was used as the salt for NH_4 additions because chloride is the dominant anion in Lake Granbury, constituting about 40% of total dissolved salts (Wurbs and Lee, 2009). Thus the