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Spatial and temporal variation of algal assemblages in six Midwest agricultural streams having varying levels of atrazine and other physicochemical attributes

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HIGHLIGHTS

- We monitored algal communities at 6 Midwest streams receiving atrazine in 2011 and 2012.
- Partitioning of CCA models of algal community by environment assessed the influence of specific variables.
- Overall, water chemistry and hydroclimate variables were most influential to community.
- Time since ≥ 30 μg/L atrazine pulse was more influential than other atrazine variables.
- Results are consistent with transitory community effects only at concentrations above 30 μg/L.

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ABSTRACT

Potential effects of pesticides on stream algae occur alongside complex environmental influences; in situ studies examining these effects together are few, and have not typically controlled for collinearity of variables. We monitored the dynamics of periphyton, phytoplankton, and environmental factors including atrazine, and other water chemistry variables at 6 agricultural streams in the Midwest US from spring to summer of 2011 and 2012, and used variation partitioning of community models to determine the community inertia that is explained uniquely and/or jointly by atrazine and other environmental factors or groups of factors. Periphyton and phytoplankton assemblages were significantly structured by year, day of year, and site, and exhibited dynamic synchrony both between site–years and between periphyton and phytoplankton in the same site–year. The majority of inertia in the models (55.4% for periphyton, 68.4% for phytoplankton) was unexplained. The explained inertia in the models was predominantly shared (confounded) between variables and variable groups (13.3, 30.9%); the magnitude of inertia that was explained uniquely by variable groups (15.1, 18.3%) was of the order hydroclimate > chemistry > geography > atrazine for periphyton, and chemistry > hydroclimate > geography > atrazine for phytoplankton. The variables most influential to the assemblage structure included flow and velocity variables, and time since pulses above certain thresholds of nitrate + nitrite, total phosphorus, total suspended solids, and atrazine. Time since a ≥ 30 μg/L atrazine pulse uniquely explained more inertia than time since pulses ≥ 10 μg/L or daily or historic atrazine concentrations; this result is consistent with studies concluding that the effects of atrazine on algae typically only occur at ≥ 30 μg/L and are recovered from.

1. Introduction

The structure of algal communities in streams is affected by multiple factors. Temporally- and spatially-varying environmental parameters such as nutrient composition, pH, light intensity, salinity, wind shear, hydrology, general climate, and anthropogenic stressors can influence

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the composition of periphyton and phytoplankton in stream systems (Biggs, 1996; Schelske et al., 1995; Pan et al., 1999; Leira and Sabater, 2005; Julius and Theriot, 2010; Black et al., 2011). These effects occur at varying scales and include regional synchronicity, seasonality, historical influence, and interactions between factors (Pan et al., 1999; Leira and Sabater, 2005; Black et al., 2011; Allan, 2004; Soininen et al., 2004; Kent et al., 2007; Urrea and Sabater, 2009); it can be difficult to separate any individual impacts of each contributing variable.

Farming practices have the potential to influence agro-ecosystems via several mechanisms which include changing the composition and concentration of sediment, addition of nutrients (fertilizers), and use of agricultural chemicals (Kroeze and Seitzinger, 1998; Malmqvist and Rundle, 2002; Foley et al., 2005). A number of these inputs are highly dynamic and can be linked to precipitation events, resulting in periodic pulses of inputs to streams adjacent to agricultural areas (Schultz, 2001; Ferenczi et al., 2002; Spalding and Snow, 1989; Neumann et al., 2003; Debenest et al., 2009; Rabiet et al., 2010); of these, herbicides have been shown in some cases to affect primary production or species composition of primary producers (e.g., (Guasch et al., 1998; Relyea, 2005; Debenest et al., 2009; Fairchild, 2011)).

Atrazine is an herbicide used primarily to control broadleaf weeds in corn and sorghum via reversible inhibition of photosystem-II, and exhibits pulsed stream input behavior coincident with use and precipitation timing and intensity due to its solubility in water (Hamilton et al., 2011; Guasch et al., 1998; Giddings et al., 2005). Atrazine is used both as a pre-emergent and early post-emergent herbicide and has been used in numerous countries since the 1960s (Lakshminarayana et al., 1992; Solomon et al., 1996). Typical atrazine pulse concentrations in surface waters draining agricultural watersheds where atrazine is used range between 0.1 and 30 μg/L, with values most often reported to be below 10 μg/L; atrazine concentrations above 100 μg/L are infrequently reported (Waldron, 1974; Richard et al., 1975; Huber, 1993; Solomon et al., 1996). Atrazine inputs to small Midwestern streams generally occur in short pulses. Based on data (>150 site–year of samples collected at daily or near daily frequency) from monitored sites in Midwest US watersheds representing the upper 20th centile of atrazine concentrations, the median duration of atrazine concentrations greater than 15 μg/L is 2 days (P. Hendley, Syngenta Crop Protection, Greensboro, NC, USA, personal communication; derived from data shown in (United States Environmental Protection Agency, 2011)).

Numerous studies have been conducted on the effects of atrazine on freshwater periphyton and phytoplankton, both on individual species and on algal communities in micro- or mesocosms. These studies have generally concluded that significant effects on primary producers typically only begin to occur with prolonged atrazine concentrations >30 μg/L and that subsequent to any disturbances algal populations recover (Gruessner and Watzin, 1996; Nyström et al., 2000; Baxter et al., 2011; Huber, 1993; Solomon et al., 1996; Giddings, 2012). However, mesocosm studies testing atrazine concentrations > 50 μg/L for extended periods have shown decreased activity, abundance, or diversity, or shifts in algal community structure (Kosinski and Merkle, 1984; Hamala and Kollig, 1985; Larsen et al., 1986; Krieger et al., 1988; Hamilton et al., 1988; Hamilton and Mitchell, 1997; Nyström et al., 2000; Guasch et al., 2007).

Much research has been conducted using freshwater pond (lentic) micro- or mesocosms (e.g., Larsen et al., 1986; Hoagland et al., 1993; Berard et al., 1999),flowing (lotic) mesocosms (e.g., Lynch et al., 1985; Gruessner and Watzin, 1996; Nyström et al., 2000; Muñoz et al., 2001), or on natural lotic communities (Jurgensen and Hoagland, 1990; Lakshminarayana et al., 1992; Guasch et al., 1998; Dorigo et al., 2004; Laviale et al., 2011). However, to our knowledge, this initiative is the only such study to examine in situ the effects of atrazine on periphyton and phytoplankton dynamically throughout the growing season in several Midwestern agricultural stream areas where atrazine use is among the highest (Solomon et al., 1996; Andrus et al., 2013). Concurrent evaluation of native algal community structure in real time with environmental parameters enables hypothesis testing concerning the relative contribution of measured variables to biological trends under natural environmental conditions of evaluated agro-ecosystems.

The study reported here is an extension to the Syngenta Atrazine Ecological Monitoring Program ("AEMP"; (Prenger et al., 2009; USEPA, 2007a, 2007b, 2009a, 2009b, 2010, 2011, 2012), a program required by EPA to assess atrazine residues in small headwater streams in runoff from vulnerable watersheds (USEPA, 2007a)). The collection of AEMP watersheds as a whole was selected in part based on similar size and agricultural use; for the current study, six watersheds within the AEMP group were chosen from four different Midwestern states and differing historic atrazine concentrations. Periphyton and phytoplankton samples, along with coincident water chemistry, hydrology, climate, and geographical factors were collected from each watershed for 16 weeks, spring to summer periods in 2011 (three watersheds) and 2012 (all six watersheds).

The objectives of this study were to evaluate the following:

1) Structure and dynamics of phytoplankton and periphyton communities
2) Diversity and variation in algal communities between sites and within sites
3) Extent of association between community metrics and variation in measured and unmeasured environmental metrics

The tested null hypothesis was that there would be no association between environmental metrics and algal community structure and dynamics; the alternative hypothesis was that there would be.

2. Materials and methods

2.1. Study design

The structure and dynamics of periphyton and phytoplankton communities were characterized weekly in situ at 6 agricultural streams sites (three in 2011 and three additional sites in 2012) in the Midwestern US over the course of the summer growing season (i.e. May through August in 2011 and April through July in 2012). The Atrazine Ecological Monitoring Program contains multiple watersheds that differ substantially in terms of land area and topography. For the purposes of this study, watersheds of similar size and site characteristics but with a range of historical atrazine concentrations were selected to enable comparison along an atrazine gradient. A variety of environmental parameters related to hydrology, geography, and water chemistry, including atrazine concentrations were measured concurrently. Statistical approaches including Canonical Correspondence Analyses (CCAs) and variation partitioning of community models were used to evaluate potential associations between biological trends and environmental metrics. Exploratory and preliminary results from the first year of the study have been published (Andrus, et al., 2013); here, the combined results from both study years are reported. To address the challenges of separating the effects of co-varying natural and anthropogenic gradients and of differing temporal patterns and scales of influence, several strategies were employed. First, to more accurately describe the effects of intermittent pulses or chronic impacts of a particular parameter, a number of derived variables were incorporated into the analysis, including site averages and maxima and variables describing the time elapsed since an event of a particular threshold. Second, we used a variance partitioning methodology to assess the impact of individual environmental variables and variable groups on the composition of each algal community while controlling for coincident variables and variable groups. We chose as our ordination methodology a direct (CCA) rather than an indirect (CA or Nonmetric Mutidimensional Scaling) comparison because it allows for a more quantitative assessment of the impacts of each factor, and for more straightforward testing of significance.