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Assessing temporal and spatial variation in sensitivity of communities of periphyton sampled from agroecosystem to, and ability to recover from, atrazine exposure

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ABSTRACT

Lotic systems in agriculturally intensive watersheds can experience short-term pulsed exposures of pesticides as a result of runoff associated with rainfall events following field applications. Of special interest are herbicides that could potentially impair communities of primary producers, such as those associated with periphyton. Therefore, this study examined agroecosystem-derived lotic periphyton to assess (1) variation in community sensitivity to, and ability to recover from, acute (48 h) exposure to the photosystem II (PSII)-inhibiting herbicide atrazine across sites and time, and (2) attempt to determine the variables (e.g., community structure, hydrology, water quality measures) that were predictive for observed differences in sensitivity and recovery. Periphyton were sampled from six streams in the Midwestern U.S. on four different dates in 2012 (April to August). Field-derived periphyton were exposed in the laboratory to concentrations of atrazine ranging from 10 to 320 μg/L for 48 h, followed by untreated media for evaluation of recovery for 48 h. Effective quantum yield of PSII was measured after 24 h and 48 h exposure and 24 h and 48 h after replacement of media. Inhibition of PSII EC50 values ranged from 53 to $>$320 μg/L. The majority of periphyton samples (16 out of 22) exposed to atrazine up to 320 μg/L recovered completely by 48 h after replacement of media. Percent inhibition of effective quantum yield of PSII in periphyton (6 of 22 samples) exposed to 320 μg/L atrazine that were significantly lower than controls after 48 h ranged from 2% to 24%. No distinct spatial or temporal trends in sensitivity and recovery potential were observed over the course of the study. Conditional inference forest analysis and variation partitioning were used to investigate potential associations between periphyton sensitivity to and ability to recover from exposure to atrazine. Although certain environmental variables (i.e., proximity of high flow/velocity events and dissolved solutes) were significantly associated with sensitivity to atrazine, recovery was not significantly associated with any variables, which is predicted by the rapid reversible binding at PSII. Consistent and rapid recovery of effective quantum yield of PSII across sites and sampling dates indicates that acute exposure to atrazine is unlikely to adversely affect function of these communities in their current state in intensive agroecosystems.

1. Introduction

Herbicides are used in agriculture to control weed species for the purpose of increasing yield and quality of crops. Depending on the physical-chemical properties of the herbicide and environmental factors including hydrology, topography, and climate, herbicides can potentially move into adjacent surface waters through processes such as run-off or spray drift. The herbicide atrazine (2-chloro-4-(ethylamino)-6-(isopropylamino)-s-triazine) is predominantly used in pre- and post-emergence control of weeds during cultivation of corn, sorghum, and sugarcane in the United States (USEPA, 2011). A moderate solubility in water (~33 mg/L at 22 °C), relatively low affinity for soil organic matter, and persistence in soil on the order of months creates the potential

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for atrazine to be transported from the field of application to neighboring water bodies via runoff following rainfall events (Giddings et al., 2005; Solomon et al., 1996). In lotic systems of agriculturally intensive watersheds that are vulnerable to runoff, exposure of aquatic organisms to atrazine is typically acute and pulsed, as a result of run-off during rainfall events or irrigation after application of atrazine (Andrus et al., 2013; Giddings et al., 2005; Solomon et al., 1996; Stoeckel et al., 2012; Thurman et al., 1992). Based on daily or near-daily monitoring of atrazine from small (23–104 km^2) Midwestern US watersheds (where atrazine is commonly used and representing the upper 20th centile of potential runoff vulnerability in the USA) the median duration of peaks greater than 15 μg/L is 2 d and the 90th centile duration 7 d (Andrus et al., 2013; Brain et al., 2012).

Atrazine inhibits photosynthesis by competing with the electron carrier molecule, plastoquinone, for the binding site on photosystem II (PSII), which results in disruption of electron transport (Forney and Davis, 1981). Due to this mechanism of action, algae and macrophytes are the taxonomic groups most sensitive to atrazine in aquatic environments. Since the nature of interaction between atrazine and quinone-b binding site is non-covalent, competitive, and fully reversible, electron flow, and consequently photosynthesis, can resume upon cessation of exposure (Jensen et al., 1977; Shimabukuro et al., 1970; Van Oorschot, 1965). When characterizing the effects of atrazine on primary producers, this reversibility combined with the pulsed nature of exposure requires consideration of not only sensitivity to acute exposure, but also the potential for subsequent recovery (Brain et al., 2012; Vallotton et al., 2008).

Historically, characterizing the potential risks of herbicides to aquatic ecosystems has been based upon standard single-species toxicity tests with a specific set of laboratory-cultured species under continuous exposure. This approach requires extrapolation to assess potential effects on communities in the field. Consequently, the use of periphyton to directly investigate effects of herbicides on communities of primary producers has increased in order to reduce extrapolation uncertainty (Laviale et al., 2011; Navarro et al., 2002; Porsbring et al., 2007; Sabater et al., 2007; Schmitt-Jansen and Altenburger, 2008). Periphyton is composed of bacteria, diatoms, cyanobacteria, and/or green algae that colonize submerged substrates in aquatic systems (Azim et al., 2005). The presence of these species in water bodies receiving agriculture runoff renders periphyton susceptible to effects from potential exposure to herbicides. Investigating the effects of herbicide exposure on periphyton is also ecologically relevant as they represent the functional foundation of aquatic food webs, influence the flux of dissolved and particulate matter, and affect habitat structure through stabilization of substrata (Dodds, 2003; Vadeboncoeur and Steinman, 2002). Field-derived periphyton are an effective tool for monitoring water quality, as the assemblage of species present in the community is sensitive to changes in the biological, chemical, and physical characteristics of the colonized site (Morin et al., 2010; Pesce et al., 2011).

A number of studies have used field-collected periphyton to examine effects of acute exposure to photosynthetic-inhibiting herbicides, as well as environmental factors that can modulate sensitivity to herbicide exposure (Guasch et al., 1998, 1997; Guasch and Sabater, 1998; Navarro et al., 2002; Pesce et al., 2010a; Tlili et al., 2011, 2008). Guasch et al. (1998) attempted to identify environmental variables related to variation in sensitivity to acute exposure of periphyton sampled in undisturbed and polluted lotic systems to atrazine. Pesce et al. (2010a) investigated whether sensitivity of field-collected periphyton to acute exposure to diuron (an inhibitor of PSII) was influenced by various environmental factors (i.e., temperature, pH, conductivity, nutrients, and concentration of diuron) using chlorophyll a, proportion of cyanobacteria, and effective quantum yield of PSII as responses. These studies demonstrated that environmental factors could influence the taxonomic composition of periphyton, and therefore influence community sensitivity to herbicide exposure.

Few studies have investigated whether the ability of periphyton to recover from acute exposure may vary with environmental factors. Schneider et al. (1995) simulated 24-h pulsed exposure of periphyton to a triazine herbicide hexazinone in outdoor experimental stream channels. Morin et al. (2010) relocated periphyton that had colonized artificial substrate at stream sites exposed to pesticide runoff to sites upstream that were not exposed. Both studies observed considerable recovery in periphyton once exposure ceased. Only two studies have specifically characterized the ability of periphyton to recover from acute exposure to atrazine (Laviale et al., 2011; Prosser et al., 2013). Laviale et al. (2011) observed significant recovery when monitoring maximal and effective quantum yield of PSII of field-collected periphyton during 7-h exposure to isoprotorun or atrazine and 36 h after periphyton were removed to herbicide-free water. However, none of these studies have investigated whether the ability of periphyton to recover from acute atrazine exposure varies across sites with varying environmental conditions or over the course of the corn growing season and encompassing the spring-summer algal bloom in regions where atrazine is intensively used (April to August). If field-derived periphyton are going to be used in assessing the effect of exposure to herbicides, it is important to characterize how sensitivity and ability to recover from exposure may change with environmental conditions at the site and over the growing season.

The objective of the present study was to characterize the variability in sensitivity of periphyton to, and ability to recover from, exposure to atrazine over time and across agricultural sites with historically differing atrazine exposure. The current study focused on periphyton within an agroecosystem as these communities are annually exposed to atrazine, therefore it is important to understand their sensitivity to exposure and ability to recover. Previous studies suggest that prior herbicide exposure could influence the sensitivity of periphyton to subsequent exposures (Gustavson and Wangberg, 1995; Knauer et al., 2010; Pesce et al., 2010a). Therefore, it is expected that the sensitivity of field-collected periphyton to exposure of atrazine will be related to historical exposure. However, little variation in the potential for periphyton to recover from exposure to atrazine is expected across sites due to the reversible binding of atrazine to the quinone-b binding site on PSII. The study also attempted to identify associations between sensitivity and potential for recovery of periphyton acutely exposed to atrazine and measured environmental and taxonomic parameters. Periphyton was sampled at six sites in the Midwestern United States at four different time points (April to August) for in vitro evaluation of sensitivity and potential to recover from acute atrazine exposure. Data on water chemistry, hydrologic, climatic, and taxonomic composition were also collected from the six sites over the same time period (Andrus et al., 2015). Overall, this study aimed to provide insight into characterizing the potential risks of atrazine to primary producers and the role that environmental factors may play in modulating the effect of exposure to atrazine on periphyton.

2. Methods

2.1. Site selection and sampling schedule

A periphytometer with eighteen tiles was deployed at each of six locations across the Midwestern United States [Missouri (Long Branch-MO-05, Honey Creek-MO-07N), Iowa (Lick Creek-IA-03),