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Riparian forests mitigate harmful ecological effects of agricultural diffuse pollution in medium-sized streams

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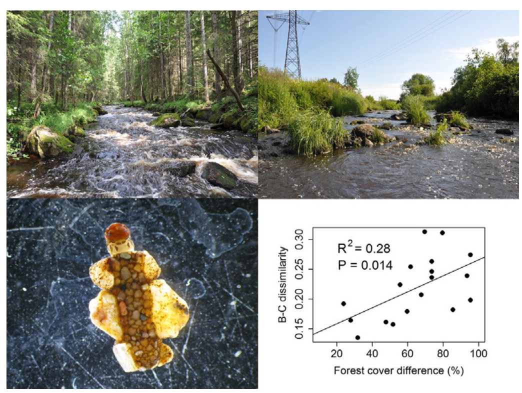
HIGHLIGHTS

- Streams and riparian forests are highly linked.
- Riparian forests can provide many ecological benefits to agricultural streams.
- Stream biota responded to riparian forests cover in the agricultural streams.
- Catchment-scale land use and pollution were the main drivers of stream communities.
- Forested riparian zones can enhance ecological recovery of agricultural streams.

GRAPHICAL ABSTRACT



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ABSTRACT

Agricultural pollution persists as a significant environmental problem for stream ecosystems. Uncultivated buffer zones or reforestation of riparian zones are advocated as a key management option that could compensate the harmful land use impacts. The effectiveness of riparian forests to protect ecological conditions of agricultural streams is yet inconclusive, particularly regarding the benefit of riparian buffers in streams suffering from uninterrupted agricultural diffuse pollution. We studied the effects of riparian land use on periphyton production and diatom, macrophyte and benthic macroinvertebrate communities in medium-sized agricultural streams by a) comparing 18 open field and forested agricultural stream reach pairs that only differed by the extent of riparian forest cover, and b) comparing the agricultural reaches to 15 near-natural streams. We found that periphyton abundance was higher in open reaches than in the forested reaches, but diatom community structure did not respond to the riparian forest cover. Macrophyte and macroinvertebrate communities were clearly affected by the riparian forest cover. Graminoids dominated in open reaches, whereas bryophytes were more abundant in forested reaches. Shredding invertebrates were more abundant in forested reaches compared to open reaches, but grazers did not differ between the reach types. Macrophyte trait composition and macroinvertebrate community difference between the reaches were positively related to the difference in riparian forest cover. The community structure of all three groups in the agricultural streams differed distinctly from the near-natural streams. However, only macrophyte communities in forested agricultural reaches showed resemblance to near-natural composition. Our results suggest that riparian forests provide ecological benefits that can partly compensate the impacts of agricultural diffuse pollution. However, community structure of forested agricultural reaches did not match the near-natural composition in any organism group indicating that catchment-scale management

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and mitigation of diffuse pollution need to be still advocated to achieve ecological goals in stream management and restoration.

1. Introduction

Agriculture has changed the landscapes worldwide with pervasive negative impacts to stream ecosystems (Harding et al., 1998; Allan, 2004; Greenwood et al., 2012). Agricultural streams and rivers tend to receive extra loads of organic pollution, nutrients, fine inorganic sediments and pesticides from multiple diffuse locations in the catchment, which together are the major causes for deteriorated ecological conditions in streams (Sponseller et al., 2001; Buck et al., 2004). The impacts of agriculture on species diversity, community structure and ecosystem functions are well documented (Tolkkinen et al., 2013; Rosemond et al., 2015; Turunen et al., 2016). However, mitigation of agricultural diffuse pollution has been proven to be a difficult task and despite of management effort and legislation, diffuse pollution continues to be a major problem in streams (Volk et al., 2009).

Typically, agricultural streams have lost their natural riparian vegetation, which can have profound effects on ecosystem structure and functions (Hawkins et al., 1983; Hladyz et al., 2011). Leaving or creating riparian buffer strips to protect streams from land use effects are indeed an increasingly highlighted and applied management tool to reduce nutrient loading and sediment erosion with variable effects on water quality and ecology (Jones et al., 1999; Kiffney et al., 2003; Broadmeadow and Nisbet, 2004). In addition, riparian forests reduce stream channel erosion and provide crucial habitat and important ecological corridors for species migration (Naiman et al., 1993). Intact riparian forests may not only protect streams from nutrient or sediment pollution but the shading can protect streams from warming and the effects of climate change (Sponseller et al., 2001; Kiffney et al., 2003; Johnson and Almlöf, 2016). However, the understanding of the importance and the effects of riparian land use on ecological condition in agricultural streams is still limited. Moreover, studies have mostly focused on small headwater streams and the effects of forested riparian zones in larger streams, that are the major management units in EU Water Framework Directive assessment and ecological status goals, are yet poorly understood (Feld et al., 2018).

Streams and riparian forests are highly intertwined by reciprocal energy subsidies in form of nutrients, detritus, terrestrial and aquatic insects and physical habitat interactions such as flooding and light conditions (Gregory et al., 1991; Nakano et al., 1999; Baxter et al., 2004; Warren et al., 2016). Riparian forests provide shade and organic matter to streams which reduce solar heating and influence ecosystem functions (Vannote et al., 1980; Studinski et al., 2012; Johnson and Almlöf, 2016). Shaded forest streams with abundant organic matter stocks tend to be metabolically more heterotrophic (i.e. stream productivity is mainly based on allochthonous organic matter) than open streams that receive abundant light and thus are more autotrophic (i.e. functioning is more based on primary production within the stream) (Vannote et al., 1980; Burrel et al., 2014). Leaf litter is a dominant basal resource in many stream food webs and detritus based ecosystem productivity is reflected in the community structure of stream biota (Cummins et al., 1989; Wallace et al., 1997; Wallace et al., 2015). Shredding invertebrates that consume leaf litter are typically abundant in forested stream reaches with abundant leaf litter stocks, whereas grazers often dominate open reaches that tend to have more instream algal biomass (Cummins et al., 1989; Death and Zimmermann, 2005). By providing shelter from solar heating and wind, presence of riparian forest can also have fitness consequences for terrestrial adult stages of aquatic insects (Collier and Smith, 2000; Remsburg et al., 2008; Carlson et al., 2016).

Several studies have attempted to quantify the effectiveness riparian buffers on water quality (Hickey and Doran, 2004; Liu et al., 2008; Bowler et al., 2012) or compared the relative influence of local and catchment scale land use (Sliva and Williams, 2001). In terms of ecological effects, some studies suggest that catchment scale land use and degradation is the major anthropogenic driver for stream biota and that local riparian land use has relatively little effect (Roth et al., 1996; Harding et al., 2006; Death and Collier, 2010; Wahl et al., 2013), while others report stronger relation between reach scale riparian land use and biological metrics than catchment land use (Storey and Cowley, 1997; Jones et al., 1999; Lammert and Allan, 1999). Despite of the often assumed benefits of forested riparian zones to streams, it is unclear whether catchment scale pressures and stressors (altered flow regime, sediment and nutrient pollution) restrict any benefits of local scale habitat factors to stream biota (Palmer et al., 2010; Bernhardt and Palmer, 2011). In certain cases buffer strips or small scale reforestation might have little effect on water quality if the majority of pollution is carried by drainage ditch network to receiving streams (Osborne and Kovacic, 1993; Walsh et al., 2007; Feld et al., 2018). For stream management, it is highly relevant to understand if riparian forests, as a management tool, have beneficial impacts on stream ecosystems despite the continuous stress from agricultural diffuse pollution or is the diffuse pollution a major stressor driving the community structure by overruling any effects of riparian forests.

In this study, we use within- and between stream comparisons of periphytic diatom, macrophyte and macroinvertebrate communities in boreal stream reaches draining agricultural catchments but with contrasting reach-scale forest cover, and a set of near-natural streams, to explore the influence of riparian land use on the mitigation of harmful impacts of agricultural catchment-level diffuse pollution. We did not expect the riparian forest to have effect on water quality because the reach types within a stream were close to each other and riparian forests do not occur extensively along stream corridors limiting their effectiveness. In addition, a large portion of agricultural pollution comes from drainage ditches, thus reducing the effectiveness of riparian forests in mitigating pollution. We specifically asked if, i) riparian forest has any influence on species and trait composition and periphyton production irrespective of diffuse pollution, or is diffuse pollution overruling the potential effects of riparian forests; ii) How the response varies between different organism groups; and iii) Does community composition in forested reaches resemble more that of natural streams than open reaches suggesting positive effect of riparian forest on ecological conditions of stream reach. Due to the rather low diffuse pollution level in these streams (Turunen et al., 2016) we expected that, i) the riparian forest would have an effect on periphyton abundance, community and trait composition of diatoms, macrophytes and macroinvertebrates. Especially, we expected ii) diatoms to have the weakest response to forest cover, whereas macrophytes and macroinvertebrates were expected to be more influenced by provision of shade and organic matter by riparian forest. We also anticipated that iii) riparian forest would result in a macroinvertebrate and macrophyte community structure to resemble composition of natural streams. Specifically we assumed that iv) forested reaches would be dominated by low growth profile diatoms adapted to low light conditions and high growth profile diatoms would dominate in open reaches (Lange et al., 2011). Periphyton production, graminoid plant and grazer abundance would be lower, but shredder abundance and bryophyte cover higher in forested stream reaches compared to open reaches.