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Shifts in attributes along agriculture-forest transitions of two streams in central Ohio, USA

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ABSTRACT

Riparian forests are strongly linked to stream ecosystems, and the creation and/or conservation of riparian forests can mitigate the influence of agriculture on streams. Although riparian forest buffers are commonly advocated as best management practices, the extent of forest necessary to effectively mitigate upstream agricultural effects on streams remains unresolved. To determine how soon agricultural streams exhibit detectable effects after entering forest fragments, we surveyed sixteen sites distributed across two 2nd-order headwater streams in agricultural landscapes of central Ohio that exhibit abrupt transitions as they flow from upstream agricultural land up to 1 km into downstream forest fragments. Along these transitions we measured leaf-colonizing benthic macroinvertebrate assemblages, leaf-litter breakdown, and physicochemical habitat. Our results indicated that forest fragments can rapidly alter physicochemical and biological attributes of agricultural streams. At both study streams, daily maximum temperature declined within the first 200 m of entering forest fragments. Changes in water quality were more variable, but there was evidence of a strong decline in NO_3–N along an agriculture-forest transition. There was also evidence of a decline in fine sediment with distance into the forest at one stream. Aquatic macroinvertebrate assemblages exhibited strong changes in composition ranging from the forest edge up to 324 m into forest fragments. Taxa that declined after entering forests were generally more tolerant of anthropogenic disturbance and/or those that rely on in-stream primary productivity (i.e., scrapers) whereas most of the taxa that increased after entering forests were relatively sensitive to disturbance and rely on allochthonous organic matter inputs from the forest (i.e., shredders). Collectively, the rapid changes in biological and physicochemical attributes that we observed suggest that even relatively small forest fragments may be able to markedly influence impaired streams and that conservation and restoration of small, discontinuous forest fragments may be important for maintaining stream ecosystem integrity in agricultural landscapes.

1. Introduction

Land-use and land-cover change has resulted in the widespread replacement of natural ecosystems with intensive agricultural and urban land uses (Foley et al., 2005). As streams and rivers are located at catchment low-points, they integrate land-use activities across catchments and thus are particularly vulnerable to anthropogenic disturbance. In the US, it has been estimated that over 40% of the nations' streams are in poor condition (US EPA, 2006), and a major driver of this impairment is agricultural land use. Agricultural practices (e.g., crop and livestock production) have a variety of effects on streams including increased erosion and deposition of fine sediment, nutrient enrichment (i.e., nitrogen (N) and phosphorus (P)), and disturbances to the riparian area (Quinn, 2000; Allan, 2004). Agriculture is the dominant land use in the Midwestern US (Lubowski et al., 2006), and agricultural effects on streams and rivers in the Midwest have been implicated as drivers of water-quality problems in downstream receiving waterbodies including Lake Erie (Myers et al., 2000) and extending to the Gulf of Mexico (Mitsch et al., 2001).

In an effort to minimize the effects of agricultural land use on aquatic systems, forested riparian buffers are often advocated as effective best management practices (Lowrance et al., 1997; Sweeney et al., 2004). Riparian forest buffers have been shown to decrease sediment inputs (Zaimes et al., 2004; Wynn and Mostaghimi, 2006), and reduce concentrations of N (Lowrance

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et al., 1984; Osborne and Kovacic, 1993) and P (Cooper and Gilliam, 1987; Borin et al., 2005) through bank stabilization, nutrient uptake, and settling of sediment-bound nutrients. Riparian forests also regulate stream temperatures, provide food resources and habitat for aquatic biota (Gregory et al., 1991; Naiman and Decamps, 1997), and can strongly influence stream ecosystem processes such as the breakdown of leaf litter (e.g., Paul et al., 2006). Although numerous studies have described the influence of riparian buffer characteristics (e.g., width and composition) on the relative capacity of buffers to ameliorate agricultural effects on streams (Osborne and Kovacic, 1993; Broadmeadow and Nisbet, 2004), studies addressing the extent of forested buffer necessary to mitigate upstream agricultural effects are rare.

In pastoral catchments of New Zealand, Storey and Cowley (1997) and Scarsbrook and Halliday (1999) observed that in small headwater streams (both 2nd-order, ranging from a maximum width of 0.6 m (Storey and Cowley) to ∼1.8 m (Scarsbrook and Halliday)), reaches in forest fragments downstream of agricultural land attained reference conditions for a variety of attributes within the first several hundred meters of entering a forest. The distance at which streams began to recover was contingent on the attribute considered and the responses were not always consistent between studies. For example, both Storey and Cowley (1997) and Scarsbrook and Halliday (1999) found evidence for aquatic macroinvertebate recovery after entering forests, whereas only Storey and Cowley found evidence for an appreciable influence of forests on NO_3–N. In larger streams of New Zealand (3rd-order, up to 5.4 m wide), the influence of forest fragments on agricultural stream attributes was largely undetectable (Harding et al., 2006). Whereas the effects of forest fragments on agricultural streams have also been observed in South America (Suga and Tanaka, 2013) and Africa (Chakona et al., 2009), information on how agricultural streams respond after entering forests in the US is largely lacking (but see Houghton et al., 2011). Therefore, a general understanding of the influence of forest fragments on agricultural streams and the distance at which stream conditions can be expected to recover remains elusive.

In the current study, we explored the potential of forest fragments to mitigate land-use effects on streams draining agricultural landscapes in the US Midwest. To this end, we established longitudinal transects along agriculture-to-forest transitions in two central Ohio headwater streams (Fig. 1). Along these transitions we measured a variety of stream attributes that are often used as indicators of land-use effects including: physical habitat, stream temperature, nutrient concentrations (N and P), leaf-colonizing aquatic macroinvertebrate assemblages, and leaf-litter breakdown. Based on previous studies of forested and agricultural stream reaches (Quinn et al., 1997; Storey and Cowley, 1997; Scarsbrook and Halliday, 1999), we expected that as agricultural streams transition into forests they become wider, have coarser surficial sediment, have lower temperature and nutrient concentrations, and are increasingly dominated by macroinvertebrate assemblages characterized by taxa sensitive to disturbance (e.g., EPT taxa and shredders). We also expected there to be a shift in leaf breakdown, however, the expected direction of land-use effects on breakdown was uncertain as evidence to date is equivocal (for decreases: Sponseller and Benfield, 2001; for increases: Paul et al., 2006). Our results provide initial evidence of the potential for forest fragments to mitigate agricultural influences on streams in midwestern US agricultural landscapes.

2. Methods

2.1. Study area

We sampled eight sites within each of two study streams, Fox Creek and Wilkin Run in the Sugar Creek and Mohican River watersheds, respectively (Fig. 1). The study streams are located in the headwaters of the Ohio River basin and the Low Lime Drift Plain ecoregion in central Ohio (Omernik and Griffith, 2013), and represented appropriate model systems for our study as common features of these catchments include a dominance of agricultural land use with small fragments of forest scattered across the landscape. Both Fox Creek and Wilkin Run are 2nd-order headwater streams, and at the site furthest into the forest they drain 740 and 700 ha, respectively. At Wilkin Run the dominant local land use upstream of the forest is pasture where cattle have direct access to the stream; tree cover is very sparse and is limited to scattered woody vegetation along the banks of the stream, and a two-lane road separates agricultural land from the downstream forest. The forest fragment is over 20 ha in area and the most

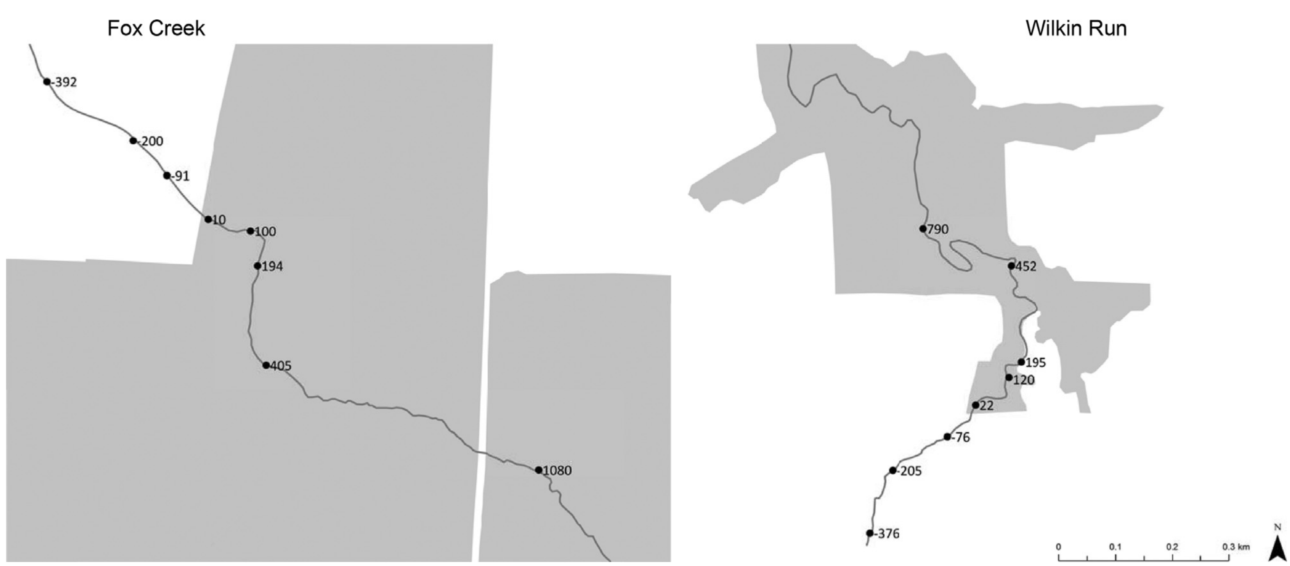

Fig. 1. Illustrations of sampling design at Fox Creek (left) and Wilkin Run (right). Grey shading corresponds to forest fragments (woody and herbaceous vegetation, and other natural areas); white areas are predominantly agricultural land (active or retired), but also correspond to residential areas and roads. The numbers correspond to the distance from the forest edge (m) with negative numbers signifying upstream of the forest (agriculture) and positive numbers indicating the forest interior. See methods for more details.