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Agricultural management and flooding shape habitats for non-native earthworms in southern Quebec, Canada

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ABSTRACT

Agricultural intensification leading to the cultivation of unmanaged field margins along rivers and streams is expected to impact soil biodiversity. Earthworm communities are typically smaller with fewer species in agricultural soils, but the effect of agriculture on earthworms could be mitigated by the more favorable soil moisture regime in riparian areas, as well as planting perennial grasses or keeping forest fragments as permanently vegetated buffers. The objective of this study was to compare earthworm community composition under contrasting land use (agricultural vs. riparian forest) ~5 m and ~30 m away from the Pike River in southern Quebec, Canada. Furthermore, we evaluated how earthworm communities were affected by management intensity, flooding, soil and vegetation patterns within these land uses. We established 4 transects at 3 sites along the Pike River representing 4 land uses (agricultural field, agricultural buffer, riparian forest fragment, upland forest fragment). Along each transect, earthworm populations and soil properties were evaluated at 5 discrete points on 4 occasions from fall 2009 to spring 2011. Vegetation cover and plant species richness were measured, and management and flooding intensity were documented through farmer surveys. Earthworm abundance and diversity were highest in a riparian forest transect (460 individuals m^{-2}, 9 species) and agricultural buffer (325 individuals m^{-2}, 10 species), and lowest in the agricultural fields with annual crop rotations and agrochemical inputs, which also had the lowest plant diversity. Redundancy analysis revealed that differences in earthworm species compositions across the study area were linked to site-specific management and flooding, represented by differences in soil moisture, vegetation diversity, and soil nutrient concentrations (dissolved organic carbon in soil solution, mineral nitrogen, extractable phosphorus). Generalized linear mixed modeling also showed that less intensively managed agricultural buffers and forest fragments with regular flooding supported higher earthworm diversity. We recommend further research on soil functions affected by earthworms in riparian areas because these non-native earthworms could affect the conservation value of unmanaged agricultural buffers and forest fragments in southern Quebec, Canada.

1. Introduction

The once forested landscape of southern Quebec, Canada, is now highly fragmented and predominantly under agricultural production. Within this landscape, riparian buffer strips and forest fragments are important since they conserve and protect surface watercourses from agricultural run-off. Such riparian areas have greater biodiversity and an array of habitats compared to adjacent agricultural fields, as well as variable nutrient fluxes due to periodic flooding events (Naiman and Decamps, 2007). Greater plant diversity is expected to support more non-native earthworm species with different feeding habits due to a larger amount and variety of plant-derived substrates in the soil (Lee, 1985). For example, throughout forest sites in an agricultural landscape in Georgia, USA, earthworm abundance was positively correlated ($r = 0.91$) with soil organic carbon and plant residue inputs (Hendrix et al., 1992). Therefore, agricultural intensification that maximizes cultivated areas and minimizes forested riparian strips may reduce earthworm habitat, abundance and diversity.

Intense agricultural practices, like tillage, are often associated with lower earthworm abundance and species richness due to physical injuries (e.g., cutting) causing earthworm mortality (Kladivko, 2001), or indirectly by modifying soil temperature, moisture and surface litter supply (Peigne et al., 2009; Dominguez

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et al., 2010). Large anecic earthworms such as *Lumbricus terrestris* and *Aporrectodea longa* are impacted adversely by tillage because they feed primarily on surface litter and have more permanent burrows than smaller endogeic species such as *Aporrectodea turgida*. Consequently, a shift toward\ conservation tillage systems, for example, led to more anecic species relative to other species (Chan, 2001). Likewise, lumbricid earthworm communities were larger and more diverse in long-term pastures containing a mixture of grasses and legumes than in monocultures of annual grain crops (Fraser et al., 1996). We predict, therefore, that the untilled, permanently vegetated forest fragments comprise habitats that are conducive to different earthworm species than surrounding agricultural fields, and thus increase the β-diversity of non-native earthworm communities across agricultural landscapes.

While soil disturbance and food supply are important for earthworm demographics, their populations and communities are also vulnerable to the interactive effects of land use and soil moisture dynamics. The mechanisms responsible for such interactive effects may depend on certain earthworm species' ability to survive in soil with differing moisture conditions, which in turn may be controlled by vegetation characteristics. Likewise, Zorn et al. (2005) found that in a temperate floodplain, earthworm density was highest in the riparian areas with larger herbaceous vegetation than in areas with short grass vegetation. Larger, herbaceous vegetation might improve the habitat value because of both soil protection and improved food supply. It is thus expected that habitats with abundant vegetation that are more susceptible to flooding and residual high soil moisture will have larger and more diverse earthworm species composition than habitats further away from the river that less susceptible to flooding. Understanding how land use and associated environmental factors affect the spatial distribution and composition of earthworm communities is important to predict the contribution of non-native earthworms to processes such as litter decomposition and nutrient turnover; (Bohlen et al., 2004a,b; Eisenhauer et al., 2007; Lubbers et al., 2013) across diverse habitats. This is particularly true for Quebec, where their range is expected to grow, in part by using streams for dispersal (Costello et al., 2011), and they may therefore significantly influence ecosystem processes in riparian areas (Costello and Lamberti, 2008, 2009).

In this study, we focused on the banks of the Pike River, near the town of Bedford, Quebec (Canada). This 67 km long waterway transports high nutrient loads from the surrounding farmlands into the Missisquoi Bay of Lake Champlain (Smeltzer et al., 2012). This setting thus presents a eutrophic river in a mosaic of agricultural fields, forest fragments and unmanaged riparian buffer strips. Our objectives were to (1) compare earthworm community composition between riparian habitat types in agricultural and forested land use systems, at different distances from the Pike River, and (2) evaluate whether soil or vegetation gradients were determinants of earthworm community composition.

2. Materials and methods

2.1. Site description

Earthworms and their habitats were studied in 3 sites along the Pike River in southern Quebec, Canada (45°08′N, 73°03′W), from fall 2009 to spring 2011. According to the recent 29 year average (1981–2010), the mean daily temperature is 6.4 °C, mean highest temperature is 11.6 °C, lowest mean temperature is 1.2 °C, the mean precipitation is 1132 mm, July is the month with the mean highest temperatures, and January is the month with the mean lowest temperatures (http://climate.weather.gc.ca/climate_normals/results_1981_2010_e.html?stnID=5358&autofwd=1, last accessed on 26.04.2015). Soils at sites 1 and 3 were Suffield clay loam soils (brown podzolic group) with textures ranging from clay loam to silt loam. At site 2, the soil was a Ste. Rosalie clay loam (dark grey Gleysolic group). The topography was gently undulating across sites, such that sites were 0–2 m above the river level.

2.2. Experimental design

Earthworm communities were characterized in 4 habitats at each of the 3 sites. These were (i) uncultivated herbaceous buffer

Table 1
Dominant vegetation (>15% relative abundance of total vegetation) in 3 sites along the Pike River, Quebec, Canada, as affected by land use and distance to the river. The management intensity index (on a scale from 0 to 6 where 0 is the least intensity and 6 is the greatest intensity) is reported for each site.

Habitat	Dominant understory vegetation and trees	Herbicide	Fertilizer	Tillage	Traffic	Total intensity
Site 1						
Ag-5 m	*Bromus inermis, Dactylis glomerata, Echinoclea crusgali, Phalaris arundinacea, Ambrosia artemisefolia, Hydrophyllum virginianum, Physalis heterophylla, Solidago rugosa, Solidago canadensis, Solidago gigantean, Anthicus sylvestris*	0	0	0	0	0
Ag-30 m	*Zea mays* L. and *Glycine max* L. rotation	1	2	1	2	6
For-5 m	*Acer negundo, Ulmus americana, Laportea canadensis, Dactylis glomerata, Eupatorium maculatum, Crataegus* sp., *Pilea pumila, Geum* sp., *Matteuccia struthioptensis, Brassicacaeae* sp.	0	0	0	1	1
For-30 m	*Prunus virginiania, Pinus strobus, Lysimachia nummularia, Bromus inermis, Dirca palustris, Geum* sp., *Acer negundo*	0	0	0	1	1
Site 2						
Ag-5 m	*Bromus inermis, Dactylis glomerata, Echinoclea crusgali, Phalaris arundinacea, Caprifoliaceae* sp., *Cornus sericea, Acer negundo, Prunus virginiana, Lysimachia nummularia, Vitis riparia, Toxirodendron radicoms, Prunus coratona, Quercus rubra, Tilia americana*	0	0	0	0	0
Ag-30 m	Hay forage	0	0	0	2	2
For-5 m	*Tovara virginiana, Lysimachia nummularia, Prunus virginiana, Acer saccharum, Bromus inermis, Dactylis glomerata, Echinoclea crusgali, Phalaris arundinacea, Solidago rugosa, Solidago gigantum, Acer negundo*	0	0	0	1	1
For-30 m	*Impatiens capensis, Tovara virginiana, Lysimachia nummularia, Laportea, Onoclea sensibilus, Prunus serotina, Acer negundo, Fraxinus pensylvanica, Crataegus* sp.	0	0	0	1	1
Site 3						
Ag-5 m	*Phalaris arundinacea, Anemone canadense, Toxirodendron radicoms, Solidago rugosa, Tilia americana, Fraxinus pensylvanica*	0	0	0	0	0
Ag-30 m	*Triticum aestivum* L. and *Glycine max* L. rotation	1	2	0	2	5
For-5 m	*Mattucia strutheopris, Maianthemum canadense, Hemecopalis* sp., *Rubus allegheniensis*	0	0	0	1	1
For-30 m	*Prunus serotina, Acer saccharum, Fagus grandifolia, Abies balsamea, Smilacena trifoliata, Cornus alternifolia*	0	0	0	2	2