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Responses of anurans to composition and configuration of agricultural landscapes

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ABSTRACT

It is imperative to identify farming systems that support biodiversity. Amphibians are the most threatened class of vertebrates globally and are particularly sensitive to the impacts of agricultural intensification. While it is known that areas of natural cover are important for amphibians in farmland, it is unknown whether cropped areas of the landscape can be structured in ways that benefit them. We examine relationships between anurans (frogs and toads) and farmland heterogeneity (structural complexity of cropped areas). We hypothesize that anurans benefit from higher compositional and configurational heterogeneity via increased prey resources and refuge habitat, and facilitation of movement. We measure compositional heterogeneity as crop diversity and configurational heterogeneity as mean field size in agricultural landscapes. We predicted that anuran richness and abundance are positively related to crop diversity and negatively related to mean field size. We surveyed 34 agricultural landscapes in eastern Ontario, Canada, representing gradients in farmland heterogeneity, for anuran richness and abundance. We used a multi-model inference approach to calculate and compare model-weighted mean coefficients to determine the direction and relative importance of landscape variables on anuran response variables. While species richness and abundance were most strongly related to the amount of forest in the landscapes, anuran abundance was also negatively related to mean field size (i.e. positive association with configurational heterogeneity). In addition, the presence of one species, American Toad, was positively associated with crop diversity. Our results suggest that conserving natural habitats such as forest is the most effective means of maintaining anuran diversity and abundance in agricultural landscapes, but that increasing the landscape configurational heterogeneity through reduction of crop field sizes can provide an additional strategy to enhance anuran abundance.

1. Introduction

Effects of agriculture on biodiversity are complex. Many species depend on farmland for habitat (Javorek and Grant, 2010), and traditional agricultural systems can support high levels of biodiversity and ecosystem services (Baudron and Giller, 2014; Stoate et al., 2009; Tscharntke et al., 2005; Wright et al., 2012). However, since the second half of the 20th century there has been a shift from diverse, low-intensity systems to industrial agriculture characterized by reliance on high inputs of synthetic chemicals and homogenization of the farm landscape to achieve high yields (Benton et al., 2003; Horrigan et al., 2002; Stoate et al., 2001; Thiere et al., 2009). These systems are associated with deterioration of soil, air, and water quality, and biodiversity declines across taxa (Benton et al., 2003; McLaughlin and Mineau, 1995; Stoate et al., 2001). Given that farmland has the potential to support biodiversity, and that the pressure to increase production will continue to intensify with increases in human population and economic growth, it is imperative that we identify farming systems that can support biodiversity while meeting agricultural demands.

It has been suggested that promoting landscape heterogeneity in agricultural systems may be critical for supporting biodiversity in farmland (Benton et al., 2003; Fahrig et al., 2011). Landscape heterogeneity increases with the number and evenness of different cover types in the landscape and with the complexity of their spatial patterning (Fahrig and Nuttle, 2005). One method to enhance landscape heterogeneity in agricultural landscapes is to increase the diversity and pattern complexity of the more natural

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cover types, such as wooded areas, wetlands, and various types of vegetated field margins (Fahrig et al., 2011). As these elements provide habitat for various taxa, biodiversity is often positively associated with the amount of more natural cover in agricultural landscapes (Le Féon et al., 2010; Pluess et al., 2010; Porej et al., 2004). Many studies examining biodiversity – agricultural heterogeneity relationships have focused on this component, such that landscape heterogeneity is considered highest in landscapes with the greatest areas of natural cover (Thies et al., 2003).

Another way to enhance landscape heterogeneity in agricultural systems is to increase the spatial heterogeneity of the cropped areas of farmland by increasing the diversity and pattern complexity of the arable cover types (Fahrig et al., 2011). Relationships between biodiversity and heterogeneity of the cropped area are currently not well understood. However, there is some evidence that increasing this component of farmland heterogeneity can benefit biodiversity (Fahrig et al., 2015; Lindsay et al., 2013; Mitchell et al., 2014; Novotný et al., 2015). This suggests a potential conservation strategy to support farmland biodiversity without taking land out of crop production.

Heterogeneity of the cropped area of the landscape can be increased either by diversifying the crop types grown (higher compositional heterogeneity) or by growing them in a more complex spatial pattern (higher configurational heterogeneity) (Fahrig et al., 2011). Landscapes with higher crop diversity can support higher levels of biodiversity (Lindsay et al., 2013; Novotný et al., 2015) because different crops can provide resources for different species (Le Féon et al., 2010; Novotný et al., 2015; Westphal et al., 2003). Fahrig et al. (2015) found consistent, positive relationships between farmland configurational heterogeneity (measured as lower mean crop field size) and diversity of birds, plants, and five different arthropod groups in agricultural landscapes. They hypothesized that species benefit from easy access to field boundary habitats in landscapes with small crop fields. Similarly, Mitchell et al. (2014) reported a decrease in arthropod diversity with increasing field widths in agricultural landscapes. Landscapes with high configurational heterogeneity may also facilitate animal movement, as field edges can be used as movement corridors by some species (Holzschuh et al., 2009; Joyce et al., 1999).

Amphibians are recognized as the most threatened class of vertebrates on the planet (Stuart et al., 2004), largely resulting from habitat loss due to agriculture (Gallant et al., 2007). Habitat degradation from agricultural activities further compromises amphibian populations. For example, agrichemical exposure can cause lethal and sub-lethal toxic effects such as endocrine disruption, immunosuppression, behaviour modification, and growth and developmental abnormalities (Bridges, 1999; Christin et al., 2013; Hayes et al., 2002; Howe et al., 2004; Mann et al., 2009; Relyea, 2005). Despite the negative effects of agriculture, some species have been found to be positively associated with high intensity crop cover (Koumaris and Fahrig, 2016). Habitats within farmland are regularly used by amphibians (Bishop et al., 1999; Christin et al., 2013; Gagné and Fahrig, 2007; Harding, 1997; Harris et al., 1998; Knutson et al., 2004; Koprivnikar et al., 2006; Koumaris and Fahrig, 2016; McDaniel et al., 2008; Ouellet et al., 1997), and in some areas are considered critical for the persistence of local populations (Bishop et al., 1999; Knutson et al., 2004). Many amphibian species use shallow farm wetlands such as ponds, drainage ditches, and flooded fields for breeding (Gagné and Fahrig, 2007; Harris et al., 1998; Harding, 1997; Knutson et al., 2004; Koprivnikar et al., 2006; Koumaris and Fahrig, 2016; McDaniel et al., 2008; Ouellet et al., 1997). Woodlots in farmland are important terrestrial habitat for the adult stages of many species (Boissinot et al., 2015; Weyrauch and Grubb, 2004). As well, some species forage in agricultural fields (Attademo et al., 2005; Harding 1997; Peltzer et al., 2010).

Although it is clear that natural areas such as forest patches and wetlands within agricultural landscapes are important for farmland amphibians (da Silva et al., 2011; Knutson et al., 1999; Kolozsvary and Swihart, 1999; Porej et al., 2004), it is not known whether the cropped area of the landscape can be structured in a way that benefits them. Identifying cropped cover patterns that are positively related to amphibian diversity would provide options for maintaining and enhancing amphibian diversity in agricultural regions. These options would be particularly valuable in regions where most of the natural habitats have been lost, and in situations where taking farmland out of production for conservation is not feasible.

The goal of this study is to identity farmland patterns that support amphibian diversity in agricultural landscapes. The specific purpose is to determine if anuran (frog and toad) species richness and abundance are associated with compositional and configurational heterogeneity of the cultivated areas in agricultural landscapes (hereafter 'farmland'). We hypothesized that both compositional and configurational heterogeneity of farmland should benefit anurans. A farmland with a high diversity of crop types should provide resources for different prey arthropod species (Langellotto and Denno 2004; Le Féon et al., 2010; Novotný et al., 2015; Westphal et al., 2003) at different times throughout the growing season, thus providing a more temporally stable prey resource for anurans than a farmland with low crop diversity. In addition, farmlands with smaller crop fields should contain more anurans, due to the benefits of field edges. Edges often have higher arthropod abundance than crop fields (Molina et al., 2014) and therefore may serve as important anuran foraging habitat. We also suspect that field edges could facilitate amphibian movement through agricultural landscapes, as anurans have been shown to use riparian buffers along streams in farmland (Maisonneuve and Rioux, 2001; Maritz and Alexander, 2007). We therefore predicted higher anuran richness and abundance in farmlands with higher crop compositional and configurational heterogeneity.

We tested this prediction in a multi-landscape study in eastern Ontario, Canada. We surveyed anuran richness and abundance in each landscape. We measured farmland compositional heterogeneity as the Shannon diversity of crop types in a landscape and farmland configurational heterogeneity as the mean crop field size in a landscape.

2. Methods

2.1. Study sites

We selected 34 1-km radius agricultural landscapes, each centred on an anuran survey point, in Eastern Ontario, Canada, across an area of approximately 5 000 km^2 within the St. Lawrence River lowlands (Fig. 1). Approximately 47% of this region is farmed, characterized by row crops (primarily corn, soybean, forage crops, and cereal grains), and pasture lands (EOWC, 2007; OMAFRA, 2011). Interspersed with farmland are patches of forest, wetlands, and some urban cover.

We chose 1-km as the landscape size because this is considered a reasonable size to represent the average dispersal and migration movements for amphibians (Guerry and Hunter 2002; Wagner et al., 2014), and landscape variables have been shown to affect anuran occupancy and diversity at this scale in agriculture-dominated regions (Guerry and Hunter 2002; Knutson et al., 1999; Van Buskirk, 2005; Vos and Stumpel, 1996). We followed a methodological framework proposed by Fahrig et al. (2011) to select agricultural landscapes that represent gradients in compositional and configurational farmland heterogeneity. Preliminary