



Landscape context is more important than wetland buffers for farmland amphibians

Margaret E. Sawatzky¹, Amanda E. Martin^{*,1}, Lenore Fahrig

Geomatics and Landscape Ecology Laboratory, Carleton University, 1125 Colonel By Drive, Ottawa, ON, K1S 5B6, Canada



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ABSTRACT

In regions with high rates of wetland loss, remnant wetlands and constructed ponds can provide important breeding habitat for amphibians. However, such wetlands are often embedded in a matrix of agricultural fields, potentially putting species within these wetlands at risk. One recommendation for conservation of amphibians in agriculture-dominated landscapes is to maintain a buffer of permanent vegetation around the wetland. However, it is not clear how wide wetland buffers must be to effectively conserve amphibians in agriculture-dominated landscapes or what vegetation types are suitable buffer vegetation. Furthermore, it is not clear whether wetland buffers produce similar—or better—conservation outcomes for amphibians than actions conducted at larger spatial extents. We addressed these questions using data from anuran (frog and toad) breeding call surveys in 36 wetlands in rural eastern Ontario, Canada. First, we tested for the effects of 49 different wetland buffer measurements on anuran richness, relative anuran abundance, and the abundance/probability of occurrence of individual species. These 49 measurements represented all combinations of seven different ways to measure the wetland buffer size and seven types of buffer vegetation. Wetland buffer size was measured as the minimum width of buffer vegetation contiguous with the wetland and proportion of the area within 5, 16, 30, 50, 120, or 300 m of the wetland containing buffer vegetation that was contiguous with the wetland. Then, to compare the strength of effect of wetland buffers versus landscape context on anurans, we compared the wetland buffer measurement with the strongest positive effect on each anuran response (from the previous analysis) to the effects of three landscape-scale variables: area of woodland; area of wetlands, streams, rivers, and lakes; and road density. We did not detect positive effects of wetland buffers on anuran richness or relative anuran abundance. This is because positive effects of wetland buffers on individual species were rare, i.e. positive effects were only supported for two of the six species with enough data to model individually: American toads (*Anaxyrus americanus*) and green frogs (*Lithobates clamitans*). Furthermore, we found that the landscape context had much stronger effects on relative anuran abundance than the wetland buffer, with effect sizes ranging from 4 (road density) to 14 (woodland cover) times that of the wetland buffer. These findings suggest that guidelines for anuran conservation in agricultural landscapes should generally focus on protection of terrestrial habitat at the landscape scale rather than on maintenance of wetland buffers.

1. Introduction

Wetland loss has been implicated in global declines in amphibian abundance and diversity. For example, a meta-analysis found that amphibian abundance was consistently lower in landscapes with less wetland cover than in landscapes with more wetland cover (Quesnelle et al., 2015). Similarly, amphibian richness has been shown to increase with the total amount of wetland in the landscape (e.g. Houlahan and Findlay, 2003). The importance of wetlands for amphibians is not surprising, given that many require freshwater habitat for at least part

of their life cycles.

Most wetland loss has occurred through conversion of wetlands to agricultural fields. In their global meta-analysis of the causes of wetland loss, van Asselen et al. (2013) found that cropland expansion was responsible for 58% of documented wetland losses. In Europe and North America—which have experienced the largest overall losses of wetland (Davidson, 2014)—50% of ponds, small lakes, inland marshes, and coastal marshes were converted to intensive agricultural land between 1900 and 1985, approximately halving the breeding habitat available to amphibians (Millennium Ecosystem Assessment, 2005).

* Corresponding author.

E-mail addresses: margaret.sawatzky@glel.carleton.ca (M.E. Sawatzky), amanda.martin@canada.ca (A.E. Martin), lenore.fahrig@carleton.ca (L. Fahrig).

¹ Present address: Environment and Climate Change Canada, National Wildlife Research Centre, 1125 Colonel By Drive, Ottawa, ON, K1S 5B6, Canada.

In regions with high rates of wetland loss, remnant wetlands and constructed ponds can provide important breeding habitat for amphibians (e.g. Collins and Fahrig, 2017; Knutson et al., 2004). However, such wetlands are often embedded in a matrix of agricultural and other human-dominated land cover types, potentially putting species within these wetlands at risk.

One recommendation for conservation of amphibians in agriculture-dominated landscapes is to maintain a buffer of permanent vegetation surrounding the wetland (e.g. Coukell et al., 2004). Such wetland buffers may benefit amphibians by providing habitat for species that require terrestrial habitat for some portion of their life cycle. For example, amphibian richness and species occurrence often increase with the amount of woodland cover in the surrounding area (e.g. Collins and Fahrig, 2017; Findlay et al., 2001; Herrmann et al., 2005; Houlahan and Findlay, 2003; Koumaris and Fahrig, 2016). Wetland buffers may also improve water quality. For example, Madison et al. (1992) found that vegetated riparian buffers 30 m in width could trap up to 99% of atrazine and nitrate in agricultural run off. Such pesticides and fertilizers can have negative effects on amphibian survival and growth rates in agricultural wetlands (Baker et al., 2013).

However, it is not clear how large wetland buffers must be to effectively conserve amphibians in agriculture-dominated landscapes. Most recommended buffer widths in North America, for example, are ≤ 30 m (Coukell et al., 2004; Ontario Farm Environmental Coalition, 2004). However, population viability analyses have suggested that these buffers are not wide enough to provide the terrestrial habitat needed to support viable amphibian populations (Harper et al., 2008). Mark-recapture, radiotelemetry, and genetic studies suggest that amphibians frequently move and forage within 300 m of their breeding habitat (Baldwin et al., 2006; Forester et al., 2006; Semlitsch, 2008; Semlitsch and Bodie, 2003). Thus buffers may need to be at least 300 m wide to adequately protect terrestrial habitat for wetland-breeding amphibians. Wider buffers may also be needed to mitigate fertilizer and pesticide use in the surrounding landscape. For example, Sawatzky (2016) found that the strongest effects of land cover (e.g. woodland cover, row crop cover) on pesticide concentrations in ponds typically occurred when land cover was measured within at least 150 m of ponds. This suggests that buffers may need to be at least 150 m wide to effectively reduce pesticide levels in wetlands. To our knowledge, no empirical studies to date have investigated how wide wetland buffers must be to benefit amphibians in agricultural environments.

Additionally, it is not clear whether wetland buffers, by virtue of being contiguous with wetland edges, produce better conservation outcomes for amphibians than conservation actions conducted at larger spatial extents. Many studies have shown that amphibians can be affected by the landscape context of a wetland (e.g. woodland cover, wetland cover, road density in the surrounding landscape) at scales much larger than even the maximum government-recommended buffer width of 300 m in our study region (Ontario; Coukell et al., 2004; Ontario Farm Environmental Coalition, 2004), i.e. within 500–3000 m of breeding wetlands (e.g. Findlay et al., 2001; Hartel et al., 2010; Herrmann et al., 2005; Houlahan and Findlay, 2003; Jeliakzov et al., 2014; Rubbo and Kiesecker, 2005). Such effects may occur, at least in part, because water quality is affected by the surrounding landscape context. For example, Houlahan and Findlay (2004) found effects of forest cover on water nutrient levels up to 4 km from the wetland edge. Such effects may also occur because juvenile and adult amphibians interact with (and are thus affected by) the landscape context during dispersal from their natal/breeding pond, and such dispersal movements may cover several km (Baldwin et al., 2006; Forester et al., 2006; Semlitsch, 2008; Semlitsch and Bodie, 2003). Additionally, some amphibians may be affected by the landscape context of a wetland because they overwinter in terrestrial habitats (Semlitsch and Bodie, 2003).

We conducted breeding call surveys for frogs and toads (i.e. anurans) in 36 wetlands in agriculture-dominated landscapes in rural eastern Ontario, Canada, to address the following questions:

- (1) Can wetland buffers increase anuran species richness and relative abundance in agricultural wetlands? And, if so, how wide should these buffers be?
- (2) How strong are wetland buffer effects on anurans, relative to the effects of the landscape context of the wetland, i.e. woodland cover, water cover, and road density in the surrounding landscape?

2. Methods

2.1. Overview

To determine if wetland buffers can benefit amphibians in agriculture-dominated landscapes, we tested for relationships between each anuran response—anuran richness, relative anuran abundance (i.e. the combined abundance across species), and the abundance/occurrence of individual species—and 49 different measurements of the wetland buffer size across 36 sample landscapes in rural eastern Ontario, Canada (Fig. 1). We measured the wetland buffer size in two ways, either as (a) the minimum width of suitable buffer vegetation contiguous with the edge of the study wetland, or (b) the proportion of the area within 5, 16, 30, 50, 120, or 300 m of the wetland containing buffer vegetation that was contiguous with the wetland (Fig. 2). Thus in the second approach we tested for effects of wetland buffer size on anurans within six recommended buffer widths. We accounted for uncertainty in the type(s) of suitable vegetation for a wetland buffer (e.g. all permanent vegetation or woodland only) by making each of the above seven measurements for each of seven types of wetland buffer vegetation.

To compare the strength of effect of the wetland buffer size versus landscape context on anurans, we compared the ‘best’ wetland buffer measurement—the one with the strongest positive effect on an anuran response (from the analyses above)—to the effects of three landscape-scale variables: woodland cover (the area of woodland within the landscape, divided by the total landscape area), water cover (the area of wetlands, streams, rivers, and lakes within the landscape, divided by the landscape area), and road density (the total length of roads within the landscape, divided by the landscape area). To select the appropriate landscape scale for these measurements, we first tested relationships between each anuran response and each landscape variable measured at four landscape scales, i.e. the area within 0.5, 1, 1.5, or 2 km of the edges of the sampled wetlands. In tests comparing the effects of the wetland buffer to the effects of landscape-scale variables on anuran responses, we included each landscape variable at its ‘scale of effect,’ defined as the landscape scale that produced the strongest relationship with each anuran response. The relative strengths of the relationships between an anuran response and wetland buffer size, woodland cover, water cover, and road density were measured as the model-averaged, standardized slopes of the relationships, based on model selection using the small-samples Akaike Information Criterion (AICc).

2.2. Site selection

All study wetlands were located in rural eastern Ontario, Canada, which is in the easternmost portion of the Lake Simcoe-Rideau Ecoregion (Fig. 1; Crins et al., 2009). Land use in eastern Ontario is dominated by agriculture, with $\sim 63\%$ of farmland used for crop production (primarily corn, soybean, and hay) and $\sim 15\%$ used as pasture for livestock (OMAFRA, 2016). The dominant natural land cover type in the region is woodland.

We selected 36 study wetlands (Fig. 1). Wetlands were primarily selected to maximize variation in the size of the wooded wetland buffer and landscape-scale woodland cover while minimizing the correlation between these variables. During site selection, the size of the wooded wetland buffer was measured as the woodland area contiguous with wetland edges using aerial photographs (Google, 2015; OMNR, 2009). Landscape-scale woodland cover was measured as the total woodland cover within a 1-km radius of potential study wetlands, irrespective of

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