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Effects of habitat loss, habitat configuration and matrix composition on declining wetland species

Pauline E. Quesnelle [a,*], Lenore Fahrig [a], Kathryn E. Lindsay [a,b]

[a] Geomatics and Landscape Ecology Research Laboratory, Ottawa-Carleton Institute of Biology, Carleton University, 1125 Colonel By Drive, Ottawa, Ontario, Canada K1S 5B6
[b] Wildlife and Landscape Science, Environment Canada, Ottawa, Ontario, Canada K1A 0H3

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ABSTRACT

Worldwide declines in wetland birds and turtles are attributed to landscape-scale habitat loss, habitat fragmentation and anthropogenic land use. However, due to multi-collinearity, the relative importance of these factors is largely unknown. We evaluated the relative effects of wetland amount, wetland configuration (measured as the number of wetland patches), and matrix composition (measured as the amount of forest, cropland and road density) on the occurrence of eight declining wetland bird species and two threatened freshwater turtles across 66–70 landscapes. We selected landscapes to minimize correlations among the landscape-scale predictors and to represent the range of variation in each predictor available in the study region. For wetland birds, we found that the amount of wetland at a landscape-scale was more important than the other landscape variables, whereas surprisingly for turtles, the amount of forest in the surrounding landscape was more important than the other landscape variables. Wetland configuration independent of wetland amount was not an important predictor of any species. This is the first study to assess the relative, independent effects of the landscape-scale factors thought to contribute to wetland bird and turtle declines. Our results confirm that wetland loss is the primary landscape-scale factor of wetland bird declines, but suggest that forest loss may play a greater role in freshwater turtle declines than previously realized; minimizing forest loss will have the most positive outcome for freshwater turtle conservation. Therefore, effective conservation planning requires a multi-taxa approach to meet landscape-scale requirements of all declining wetland fauna.

1. Introduction

Worldwide declines of wetland birds and turtles are attributed to wetland loss and fragmentation at a landscape-scale, with anthropogenic land-uses such as roads and development also implicated (Millennium Ecosystem Assessment, 2005). However, the relative contributions of these landscape-scale predictors remain unclear. Wetland birds and turtles have received considerably less attention than other taxa (e.g., amphibians) in landscape ecology, and the effects of landscape structure on their abundance and distribution are less well understood (Attum et al., 2008; Joyal et al., 2001; Tozer et al., 2010; Semlitsch and Bodie, 2003).

Habitat loss generally has strong negative effects on species distribution and abundance relative to weaker and variable effects of habitat fragmentation (Fahrig, 2003). In wetland ecosystems, the loss of wetland habitat has strong negative effects (e.g., Naugle et al., 2001; Tozer et al., 2010). Strong negative effects of wetland isolation (e.g.: Joyal et al., 2001; Smith and Chow-Fraser, 2010; Attum et al., 2008; Shriver et al., 2004) are also reported for wetland birds and turtles, and these are often reported as fragmentation effects. However, estimating the separate effects of wetland loss and wetland fragmentation is difficult because are they typically strongly correlated (Fahrig, 2003). Therefore, the current understanding of the relative importance of habitat loss and fragmentation for wetland birds and turtles is limited.

In addition to the loss and fragmentation of habitat, the composition of the intervening space between habitat (or matrix composition) can also influence species abundance and distribution (Fahrig, 2001; Prugh et al., 2008). The amount of forest cover, agriculture and roads surrounding wetlands have all been suggested to affect wetland birds and turtles. Forest cover is generally expected to be a positive matrix element (Alsfeld et al., 2010). For turtles, upland forest surrounding wetland is important for movement and refugia (i.e.: short-term inactivity; Buhlmann and Gibbons, 2001). Farmland is generally expected to have negative impacts due to increased dispersal mortality (Saumure et al., 2007), reduced wetland quality from nutrient and pollutant runoff (Sterrett et al., 2011), and wetland infilling from sedimentation (Naugle et al., 2001). Lastly, roads generally have negative effects on wildlife populations (Rytwinski and Fahrig, 2012),

* Corresponding author. Tel.: +1 613 520 2600x3859; fax: +1 613 520 3539.
E-mail address: pauline.quesnelle@glel.carleton.ca (P.E. Quesnelle).

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either due to mortality or road avoidance behavior. However, these matrix composition variables can also be correlated with wetland loss and/or fragmentation (e.g.: landscapes with high agriculture often have high wetland loss) or with each other (e.g.: landscapes with low forest cover often have low road density).

Correlations among landscape predictors (multi-collinearity) may confound inferences about the effects of wetland loss, wetland fragmentation and/or matrix composition. For example, Findlay and Houlahan (1997) were not able to determine whether forest cover or road density was the main driver of landscape effects on wetland biota, due to the high correlation between these two variables. High multi-collinearity reduces statistical power and causes the estimation of regression coefficients to be highly error-prone, leading to variability in the estimated direction and magnitude of effects (Eigenbrod et al., 2011). A possible example is the wide range of reported effects of forest cover on wetland birds (e.g., positive, Alsfeld et al., 2010; negative, Budd and Krementz, 2010; no effect, Findlay and Houlahan, 1997).

It may not be possible to avoid multi-collinearity altogether in landscape ecology studies because the underlying processes causing landscape patterns are often linked. However, a comparative mensurative experimental approach which requires a priori selection of landscapes can minimize these correlations, allowing the estimation of separate effects (Fahrig, 2003). We hypothesize that multi-collinearity among landscape-scale variables has not yet been adequately addressed in previous investigations of the effects of landscape structure on wetland birds and turtles. Therefore the relative importance of the major landscape variables causing declines in these species is largely unknown.

While the literature to date suggests that any or all of wetland loss, fragmentation and matrix composition could explain declines in wetland birds and turtles, in a management context it is important to know their relative effects. Landscape-scale variables represent competing landscape-scale management options that could be applied independently of one another. Therefore, estimating their relative effects would help prioritize future conservation management action. For example, if wetland biota respond negatively to wetland fragmentation (independent of wetland loss) then wetland policies should focus specifically on conserving and restoring large wetlands. Because multi-collinearity can confound inferences about species responses to landscape structure and misguide management recommendations, studies with landscape planning or species recovery applications must disentangle the estimated effects of landscape-scale predictors.

Our objective was to determine the relative effects of wetland loss (measured as wetland amount, i.e.: the proportion of wetland area within a landscape), wetland configuration (measured as the number of wetland patches in the landscape) and matrix composition (measured as the amounts of each of forest, agriculture and road density in the landscape) on the occurrence of declining wetland birds and turtles. To do this we used a comparative mensurative experimental approach, wherein we sampled a set of landscapes specifically selected for low multi-collinearity among these landscape variables and to represent the range of variation in each variable in the study area. Previous studies typically refer to fragmentation as both the loss and breaking apart of habitat. In this study, we assessed habitat fragmentation per se (Fahrig, 2003), i.e. an aspect of the spatial configuration of wetlands independent of wetland loss. To avoid confusion over this distinction, we use the term "wetland configuration" rather than fragmentation. We estimated species presence of declining wetland birds and turtles in 66–70 landscapes (depending on the species group), varying in wetland amount and configuration, and in matrix composition.

2. Methods

2.1. Study area

The study was conducted in the Thousand Islands ecosystem in southeastern Ontario, Canada, which is a $\sim$2000 km^2 watershed that drains into the St. Lawrence River (Fig. 1). The rural study area is characterized by 33% forest cover, 20% cropland, 14% pasture and field, 10% wetlands, 22% open water and 1% urban development. This landscape composition is typical of rural northeastern North America (e.g.: Saumure et al., 2007); however there is less cropland in our study area, possibly due to localized reforestation. Forest is deciduous and mixed, and cropland is primarily corn, hay and soy. There are 5 wetland types (Ecological Land Vegetation classification for southern Ontario, OMNR, 2009): (1) shallow open aquatic (water depth <2 m), dominated by floating aquatic vegetation (lily pads; *Nymphaea odorata* and *Nuphar variegata*), and submerged macrophytes (e.g., *Potamogeton* spp.), (2) emergent marsh, dominated by cattail (*Typha* spp.), (3) shrub thicket swamp, primarily willow (*Salix* spp.) and alder (*Alnus* spp.), (4) deciduous swamp, dominated by maple (*Acer* spp.) and ash (*Fraxinus* spp.), and (5) mixed swamp, consisting of maple and white cedar (*Thuja occidentalis*).

2.2. Species groups and specific wetland habitats

We identified habitat for each species group, from the five wetland types in our study area (Sub section 2.1), based on known habitat associations of the species; wetland types were used for habitat identification only.

2.2.1. Wetland birds

We selected 8 wetland bird species that are declining in our region (Crewe et al., 2005): red-winged blackbird (*Agelaius phoeniceus*), swamp sparrow (*Melospiza georgiana*), marsh wren (*Cistothorus palustris*), American coot (*Fulica americana*), common Moorhen (*Gallinula galeata*), sora (*Porzana carolina*), virginia rail (*Rallus limicola*) and least bittern (*Ixobrychus exilis*). Least bittern is designated threatened in Canada and is considered at-risk in 36 US states (NatureServe, 2012). Wetland types identified as habitat for wetland birds were emergent marsh or shrub thicket swamp (i.e., wetland types 2 or 3; Sub section 2.1) (Bannor and Kiviat, 2002; Eddleman et al., 1988; Gibbs et al., 2009; Mowbray, 1997). We excluded wetland patches <0.4 ha (Gibbs et al., 2009).

2.2.2. Turtles

We selected two declining freshwater turtle species. Blanding's turtle (*Emydoidea blandingii*) is designated as threatened in Canada and considered at-risk in 14 of the 15 states in the US within its range (NatureServe, 2012). Eastern musk turtle (*Sternotherus odoratus*; hereafter 'musk turtle') is designated as threatened in Canada and considered at-risk in three US states (NatureServe, 2012). Wetland types identified as wetland habitat for Blanding's turtle were shallow open aquatic wetland adjacent to any other wetland type (i.e., wetland types 1 and 2 or 3 or 4 or 5, Sub section 2.1) (Joyal et al., 2001; Sajwaj and Lang, 2000). For musk turtle, shallow open aquatic wetland (i.e., wetland type 1, Sub section 2.1) located on a lake or river network (Edmonds and Brooks, 1996; Picard et al., 2011) was identified as wetland habitat.

2.3. Study design and landscape selection

Here we define "landscape" as the spatial area within which the landscape variables were calculated (i.e.: spatial scale). We based landscape size on movement distances and home range estimates