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Citizen science reveals widespread negative effects of roads on amphibian distributions

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ABSTRACT

Landscape structure is important for shaping the abundance and distribution of amphibians, but prior studies of landscape effects have been species or ecosystem-specific. Using a large-scale, citizen science-generated database, we examined the effects of habitat composition, road disturbance, and habitat split (i.e. the isolation of wetland from forest by intervening land use) on the distribution and richness of frogs and toads in the eastern and central United States. Undergraduates from nine biology and environmental science courses collated occupancy data and characterized landscape structure at 1617 sampling locations from the North American Amphibian Monitoring Program. Our analysis revealed that anuran species richness and individual species distributions were consistently constrained by both road density and traffic volume. In contrast, developed land around wetlands had small, or even positive effects on anuran species richness and distributions after controlling for road effects. Effects of upland habitat composition varied among species, and habitat split had only weak effects on species richness or individual species distributions. Mechanisms underlying road effects on amphibians involve direct mortality, behavioral barriers to movement, and reduction in the quality of roadside habitats. Our results suggest that the negative effects of roads on amphibians occur across broad geographic regions, affecting even common species, and they underscore the importance of developing effective strategies to mitigate the impacts of roads on amphibian populations.

1. Introduction

Because landscape modification is one of the main drivers of global amphibian declines (Stuart et al., 2004; Cushman, 2006; Wake and Vredenburg, 2008), effective amphibian conservation will likely require management at large spatial scales (Semlitsch, 2000). Species distributions are generally related to two aspects of landscape structure: the types and amounts of habitat available (habitat composition), and the spatial arrangement of habitat (habitat configuration; Turner, 2005). In temperate forest biomes, amphibian occupancy is often greatest in landscapes that have (1) high forest cover (Gibbs, 1998a; Guerry and Hunter, 2002; Porej et al., 2004; Herrmann et al., 2005), (2) low cover by urban infrastructure (Knutson et al., 1999; Lehtinen et al., 1999; Rubbo

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and Kiesecker, 2005; Pillsbury and Miller, 2008; Hamer and Parris, 2011), (3) few discontinuities between breeding and non-breeding habitats (Guerry and Hunter, 2002; Becker et al., 2007, 2010), and (4) high population connectivity (Sjögren Gulve, 1994; Houlahan and Findlay, 2003; Mazerolle et al., 2005; Werner et al., 2007; Cosentino et al., 2011).

Roads may play a particularly significant role in limiting amphibian distributions. Roads directly replace wetland and upland habitat, and they can lower the quality of adjacent habitat by creating edge effects (Marsh and Beckman, 2004) and causing run-off of deicing salts (Karraker et al., 2008). Because amphibians move slowly, individuals are also susceptible to direct mortality when moving across roads (Fahrig et al., 1995; Mazerolle, 2004; Beebee, 2013). For species with biphasic life cycles, roads can increase mortality risk during breeding migrations, ultimately increasing the probability of local extinction (Gibbs and Shriver, 2005). Fragmentation by roads at landscape scales can decrease metapopulation viability by constraining dispersal among populations (Hels and Nachmann, 2002).

Although previous studies have been critical for identifying how landscape structure and road disturbance affect amphibian distributions, these studies have varied widely in spatial extent and led to conclusions that are often site- and species-specific (Cushman, 2006). We examined effects of landscape structure and road disturbance on the distribution and richness of pond-breeding frogs and toads across the central and eastern U.S. through a multi-institutional, undergraduate research project. Approximately 200 undergraduate students in biology and environmental science courses from a network of universities compiled data from the North American Amphibian Monitoring Program (NAAMP), a database of amphibian occupancy collected by citizen scientists. NAAMP uses a standard methodology to collect occupancy data (Weir and Mossman, 2005), so we were able to investigate whether effects of landscape structure and roads on amphibian distributions and species richness are consistent across species and regions.

We addressed three questions chosen at the outset of the project: (1) What aspects of habitat composition and road disturbance best explain anuran occupancy and species richness? (2) Are the effects of road disturbance on anurans more associated with road density or traffic volume? (3) Does the separation of wetlands from upland forest by intervening land use (i.e. habitat split; Becker et al., 2007) threaten amphibian persistence? Because auditory chorus surveys were used to determine anuran presence, relationships between traffic volume and anuran distributions or species richness could be due to detection bias associated with noise during surveys. We used multiple metrics of species richness, estimation of detection probabilities, and structural equation models (SEM; Grace et al., 2010) to determine whether effects of traffic volume were due to interfering noise during surveys. We also used SEMs to disentangle correlations among landscape features characteristic of urban areas.

2. Materials and methods

2.1. Sampling sites and NAAMP data

NAAMP is a citizen-science monitoring initiative organized by the U.S. Geological Survey (Weir and Mossman, 2005). Trained observers are assigned randomly-selected driving routes within their state (Weir and Mossman, 2005). Observers initially traverse routes during the daytime and select 10 sampling locations (hereafter "stops") at least 0.5 km apart where bodies of water are visible within 200 m of the road. Observers conduct 3–4 surveys at each stop per year during pre-determined time windows that span the breeding season of most anurans in the region. At each stop, observers get out of their cars and record any anuran species heard over a 5-min survey period. During each survey, observers also record the number of cars passing by on the road and whether or not noise was present that might interfere with counting or identifying anuran calls.

Undergraduate students from nine biology and environmental science courses compiled anuran data from 1617 NAAMP stops along 406 routes in 13 states (Table A1; latitudinal extent 27.2691 to 48.5939; longitudinal extent −98.1681 to −70.8769). Students characterized landscape structure within 1-km buffers around each stop. To avoid spatial overlap in landscape indices among stops, we compiled data only for stops 1, 4, 7, and 10 within each route, ensuring stops were $\geqslant$2 km apart. For these stops, we first condensed the raw anuran data into summary measures for all surveys of a stop. For each stop, we calculated total number of surveys, proportion of surveys in which interfering noise was recorded, presence or absence of each species across all surveys, total number of species present (species richness) across all surveys, and mean number of cars passing by during anuran counts (traffic volume). Surveys occurred from 1994 to 2012, and the median number of surveys per stop was 12 (range = 1–45).

We modified the raw NAAMP data in two ways to increase their quality. First, we interfaced county-level distribution maps from the National Amphibian Atlas (USGS, 2012) with the NAAMP survey locations and excluded any data from outside a species' known range. Thus, occupancy for each species was considered only within counties where the species was previously known to exist. There were 40 species observed across all stops after excluding data from outside a species' known, native range (Table A2). Second, we combined occupancy data for gray treefrog species (*Hyla chrysoscelis* and *Hyla versicolor*) because their calls can be difficult to distinguish.

2.2. Landscape variables

Landscape variables for each NAAMP stop were characterized by students using qGIS or ArcGIS software to import spatial layers from the National Land Cover Database (NLCD; Fry et al., 2011), the National Wetlands Inventory (NWI), and Open Street Map (OSM). Using these layers, students calculated the following within a buffer with a 1-km radius around each NAAMP stop: proportion of land forested, agricultural, and developed, total wetland area, total linear road length (hereafter "road density"), and total number of habitat types represented (according to NLCD classifications). Habitat split was characterized visually by whether wetlands within 200 m of the stop were separated by an intervening land type (i.e. road, agricultural field, or developed land) from upland forest. State-specific data were divided among participating classes (Table A1).

Several layers of quality control were applied to the landscape data to maximize their accuracy. First, two students independently compiled data for each stop, and these students were required to reach consensus before data were entered into the database. Second, entered values for each variable were sorted by magnitude and unusually high or low values were checked for accuracy by a different set of students or by an instructor. Third, a randomly chosen selection of stops was checked for accuracy for each landscape variable. Where independent calculation differed from the entered value more than 10% of the time, variables were excluded from the analysis. The only variable to fail this criterion was the number of different habitat types within the 1-km buffer (error rate = 23%); error rates for the other variables were $\leqslant$7%. The number of different habitats was quantified by having students record the number of habitats observed visually within the 1-km buffer around stops,