Urban Forestry & Urban Greening 20 (2016) 365–374

Contents lists available at ScienceDirect

Urban Forestry & Urban Greening

journal homepage: www.elsevier.com/locate/ufug

Responses of anuran communities to rapid urban growth in Shanghai, China

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ARTICLE INFO

Article history:
Received 2 June 2016
Received in revised form 13 October 2016
Accepted 13 October 2016
Available online 22 October 2016

Keywords:
Amphibian
Anuran
Landscape
Pond
Urbanization

ABSTRACT

Urbanization affects amphibian communities through habitat loss, fragmentation, and degradation of habitat quality. The effects of these changes in habitat at different scales vary depending on the sensitivity of individual species. We assessed the breeding distribution of anurans along an urban–rural gradient in Shanghai, China, a region experiencing intensive urbanization. Our results showed that urban density had a significantly negative influence on the overall anuran abundance and diversity and that the responses of individual species to urbanization varied. Pond age was an overall predictor in models describing the responses of *Pelophylax nigromaculatus*, *Fejervarya multistriata*, and *M. fissipes* and total anuran abundance. The quality of habitat at a pond was also important, and the high abundance of *Bufo gargarizans* and *Pelophylax plancyi* was associated with ponds with aquatic vegetation coverage. Urban density showed strong negative effects on *B. gargarizans*, total anuran abundance, and species richness. The broad-scale landscape variables associated with forests, agricultural fields, and wetlands surrounding breeding ponds have been shown to affect anuran abundance and species richness. The response of individual species, total abundance, and species richness to urbanization reflected differences in their ecological requirements. We quantified the effects of urbanization on frogs in a rapidly urbanizing region, and our results demonstrated that both multi-spatial and temporal variables affect anurans in Shanghai. Our results emphasized the importance of anuran conservation planning in urbanized areas to preserve and/or restore terrestrial habitat and to improve connectivity between ponds and other wetlands.

1. Introduction

In 2014, more than half the world's population was living in cities, and in high-income countries, urban populations accounted for as much as 80% of the population (UN, 2014). Urbanization typically occurs at the expense of agricultural land and natural habitats (McKinney, 2002), and is responsible for the widespread decline and loss of many species globally (Czech et al., 2000; Scheffers and Paszkowski, 2012). Human activities have direct negative effects on native plants and animals. Among vertebrates, amphibian communities appear to be particularly vulnerable to the effects of urbanization because they require different breeding, non-breeding, and hibernation habitats during their complex life cycles (Pope et al., 2000; Semlitsch and Bodie, 2003; Cushman, 2006). Most amphibians require aquatic habitats for larval development and terrestrial habitats for juvenile and adult stages. Due to the relatively low dispersal ability of amphibians, these habitats must often be physically linked to allow movement among populations (Kimberling et al., 1996; Scribner et al., 2001). Urbanization can represent a predominant threat to anuran communities by increasing road mortality and habitat isolation, and by modifying both aquatic and terrestrial habitats, impairing water quality, and altering hydroperiods (Hamer and McDonnell, 2008; Smallbone et al., 2011). These factors can impact amphibian communities at multiple spatial scales and the degree of impact may vary depending on the sensitivities of individual species and features of the urban environment (Mazerolle et al., 2005; Price et al., 2005; Gagné and Fahrig, 2007).

Studies of amphibian communities have demonstrated strong associations between local diversity and the composition of the

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http://dx.doi.org/10.1016/j.ufug.2016.10.005
1618-8667/

surrounding landscape (Kolozsvary and Swihart, 1999; Porej et al., 2004). Urbanization can influence amphibian persistence in urban areas through habitat loss, fragmentation/isolation, and degradation of habitat quality (Cushman, 2006; Becker et al., 2007). Amphibian colonization and dispersal abilities may play important roles in adapting to the urbanized landscape. Amphibians with low dispersal ability may be strongly affected by local habitat degradation. Conversely, species of high dispersal ability may have to cross inhospitable areas to successfully colonize suitable habitat elsewhere, and are consequently more threatened by habitat fragmentation (Gibbs, 1998; Cushman, 2006; Tsuji et al., 2011). Previous research has indicated that movement patterns are a key factor determining susceptibility of different species to changes in habitat conditions (Battin, 2004; Stevens et al., 2006; Hamer and McDonnell, 2008).

At broad landscape scales, road and dwelling density and/or the area of forests, agricultural fields, and wetlands surrounding breeding ponds are correlated with amphibian abundance and species richness (Hamer and McDonnell, 2008). Roads and dwellings can influence the migration and dispersal of amphibians between suitable habitats, and increase the extent of impervious surfaces and rates of road mortality (Hartel et al., 2009). Artificial landscapes impose barriers to amphibian migration and habitat re-colonization, and impair the ecological connectivity between required aquatic and terrestrial habitats (Vos and Chardon, 1998; Ficetola and Bernardi, 2004; Price et al., 2005). The loss of wetlands in urban landscapes is directly associated with a decrease in anuran populations because of the number and size of anuran species that use urban ponds as breeding sites (Rubbo and Kiesecker, 2005; Scheffers and Paszkowski, 2013). At local scales (e.g. individual ponds), anuran populations can be influenced by a range of factors, including the complexity and cover of fringing and aquatic vegetation, predatory, hydrology, pond size, and water depth (Parris, 2006; Hamer and McDonnell, 2008; Pillsbury and Miller, 2008).

Amphibian populations are often considered to be depressed on agricultural lands because of intensive management practices (Howe et al., 1998; Hamer et al., 2004; Egea-Serrano et al., 2012). In Asia, paddy fields essentially represent artificially constructed wetlands where many anuran species breed, forage, and hibernate (Roh et al., 2014; Tsuji et al., 2011). Consequently, paddy fields are important for anuran conservation. During the past three decades, there has been rapid urbanization in East Asian countries, primarily due to strategies that have emphasized urban growth at the expense of agricultural and rural development (Liu et al., 2003; Saizen et al., 2006; Yoon, 2009). In the study presented here, we evaluated the influence of landscape features on species richness and community composition of anurans in ponds along an urbanization gradient, and specifically examined the consequences of rapid urbanization and urban growth in Shanghai, China. We created a composite variable using principle component analysis to determine urbanization level, rather than a categorical classification of land use (e.g. "urban" vs. "rural"), in order to quantify continuous differences in community structure in relation to landscape context (Pillsbury and Miller, 2008).

Many studies on the impacts of urbanization on fauna consider spatial patterns, however, few researchers have examined temporal responses of animal community structure to urbanization (but see Birx-Raybuck et al., 2010; Gagné and Fahrig, 2010). We specifically investigated how the abundance and species richness of anurans in ponds was related to the age of ponds. Anuran abundance and species richness in urban landscapes have been shown to rely on variables at different spatial scales, from individual ponds to larger landscapes that may extend for kilometers beyond a pond (Pellet et al., 2004a,b; Rubbo and Kiesecker, 2005; Pillsbury and Miller, 2008; Hamer and Parris, 2011; Kruger et al., 2015). In this study, we assessed the effects of urbanization on anuran communities on a multi-spatial scale in Shanghai, a rapidly urbanizing city. The aim of this study was to evaluate how individual species and anuran community assemblages respond to an urban-rural gradient of urbanization, and to determine which local and landscape variables relating to urbanization influence the distribution of the regional anuran community.

2. Methods

2.1. General information about the study area

Shanghai has the largest human population of any city in China (24.2 million residents) and is the major industrial center of China (National Bureau of Statistics of China, 2014). Currently, 80% of the city's population resides in both urban and suburban areas (Office of Shanghai Chronicles, available online). Shanghai is located on an alluvial plain formed by natural deposition of the Yangtze River and by modern land reclamation projects. This region has many rivers, canals, streams, wetlands and lakes, which serve as the primary habitats for breeding anurans. As a result of urbanization, almost all natural ecosystems have been disturbed, except for a few islands (e.g. Dajinshan and Xiaojinshan islands) located near the shoreline of Shanghai city. Anuran breeding habitats on the Shanghai mainland are currently limited to park ponds, temporary storm water wetlands, as well as rural roadside ditches and some remnant and restored wetlands (including paddy rice fields). Abundance and species richness for all native anuran species in Shanghai have been declining for at least the last half-century because of the increasing rates of habitat fragmentation and loss caused by urbanization (report from a wildlife survey of Shanghai, unpublished).

2.2. Selection of study sites

Our study area was 6340 km^2 and located within the Shanghai Municipality. Potential wetland sites were identified via aerial imagery and field inspection prior to surveying. We selected a total of 28 city green-space (public parks and gardens) ponds for this study (Fig. 1). Because large and/or well-connected habitat patches surrounding a pond would be expected to contain more species (Hanski, 1994), we chose ponds located in parks and gardens with an area of more than 10 ha. The wetlands we investigated were located on city green space, and were often constructed and restored for aesthetic, city greening, and/or recreational purposes by the government. These ponds have similar designs with aquatic vegetation for improvement of water quality, predatory fish (dominant cyprinid species, including *Carassius auratus*, *Pseudorasbora parva*, and *Rhodeus ocellatus*) for recreation, and modified hydroperiods. Because the government manages all city green space, we communicated with Shanghai Landscaping & City Appearance Administrative Bureau to help with pond selection, avoiding ponds that had experienced serious local impacts (e.g. pond draining or vegetation removal) after construction and to determine pond ages. We did not include concrete artificial lakes, small ponds with non-natural edges, or sites that were highly unlikely to support anurans. Ground-dwelling frogs are not adept at climbing vertical surfaces, so the vertical walls on many artificial ponds can only be climbed by tree frogs. Upon metamorphosis, ground-dwelling frogs may not be able to climb out of the pond on to land, and consequently drown. The study sites were chosen to represent a gradient of human settlement intensity from urban to rural areas. Selected sites had to be at least 2000 m apart to ensure independence in landscape analyses. There is little information available on the dispersal distances of Shanghai frogs, but the scale at which landscape variables have been shown to affect anuran abundance and species ranges from 500 m (Price et al., 2005) to