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Riparian swallows as integrators of landscape change in a multiuse river system: Implications for aquatic-to-terrestrial transfers of contaminants

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HIGHLIGHTS

- We characterized the land use and land cover (LULC) of 11 riverine study sites.
- We examined selenium (Se) and mercury (Hg) concentrations in riparian swallows.
- Relationships were evident between LULC and contaminant concentrations.
- Contaminant concentrations were higher in adult than in juvenile birds.

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ABSTRACT

Recent research has highlighted the transfer of contaminants from aquatic to terrestrial ecosystems via predation of aquatic emergent insects by riparian consumers. The influence of adjacent land use and land cover (LULC) on aquatic-to-terrestrial contaminant transfer, however, has received limited attention. From 2010 to 2012, at 11 river reaches in the Scioto River basin (OH, USA), we investigated the relationships between LULC and selenium (Se) and mercury (Hg) concentrations in four species of riparian swallows. Hg concentrations in swallows were significantly higher at rural reaches than at urban reaches ($t = -3.58$, $P < 0.001$, $df = 30$), whereas Se concentrations were positively associated with adjacent land cover characterized by mature tree cover ($R^2 = 0.49$, $P = 0.006$). To an extent, these relationships appear to be mediated by swallow reliance on aquatic emergent insects. For example, tree swallows (*Tachycineta bicolor*) at urban reaches exhibited a higher proportion of aquatic prey in their diet, fed at a higher trophic level, and exhibited elevated Se levels. We also found that both Se and Hg concentrations in adult swallows were significantly higher than those observed in nestlings at both urban and rural reaches (Se: $t = -2.83$, $P = 0.033$, $df = 3$; Hg: $t = -3.22$, $P = 0.024$, $df = 3$). Collectively, our results indicate that riparian swallows integrate contaminant exposure in linked aquatic–terrestrial systems and that LULC may strongly regulate aquatic contaminant flux to terrestrial consumers.

1. Introduction

Movement of materials across the landscape has been central to the study of food webs (Polis et al., 1997, 2004). At the aquatic–terrestrial interface, ecological subsidies, or the flux of material from one habitat or ecosystem to another (Nakano and Murakami, 2001) has emerged as a central theme of cross-boundary linkages (Akamatsu et al., 2004; Vander Zanden and Sanzone, 2004; Ballinger and Lake, 2006). Whereas the contribution of terrestrial systems to aquatic food webs via inputs of nutrients and organic matter is well recognized, recent investigations have focused on the importance of aquatic prey subsidies to the energy budgets of riparian consumers (reviewed in Baxter et al., 2005). A classic example is the reliance of grizzly bears (*Ursus arctos horribilis*) on fish as an important nutrient source (Mattson and Reinhart, 1995; Varley and Schullery, 1996). Others have shown that aquatic prey represent important food sources to riparian bats (Fukui et al., 2006; Hagen and Sabo, 2012), raccoons (*Procyon lotor*) (Bigler et al., 1975; Lord et al., 2002), piscivorous birds (Vessel, 1978; Hamas, 1994), lizards (Sabo and Power, 2002), and terrestrial arthropods (Henschel et al., 2001; Paetzold et al., 2005; Dreyer et al., 2012).

In particular, aquatic insects that emerge from the stream as adults (hereafter, 'aquatic emergent insects') can be a critical food source for insectivorous riparian bird species (Keast, 1990; Iwata et al., 2003). For example, Sweeney and Vannote (1982) found that swarming activity by mayflies attracted nighthawks (*Chordeiles minor*) to areas of emergence, and Iwata et al. (2003) reported that flycatchers and gleaners foraged intensively on aquatic emergent insects in a pattern

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that mirrored aquatic insect distribution, suggesting that the dynamics of insect emergence can influence avian foraging behavior.

Within the context of the energetic pathways that link aquatic and terrestrial ecosystems, there is growing interest in food-web studies at the land–water ecotone. Many investigators have found that the high reliance of riparian birds on aquatic prey resources can expose them to contaminants found in aquatic systems (see Sullivan and Rodewald, 2012). Cristol et al. (2008) demonstrated that mercury (Hg) can bioconcentrate in terrestrial bird species living near contaminated water sources, while Wada et al. (2009) found that adrenocortical responses and thyroid hormones were suppressed in tree swallows (*Tachycineta bicolor*) living near a river contaminated with mercury. In the Chilliwack River of southern British Columbia, resident American Dippers (*Cinclus mexicanus*) (i.e., those birds who remain in the mainstem Chilliwack River year-round and have high proportions of contaminated salmon fry in their diet) were found to have higher polychlorinated biphenyl (PCB) and Hg concentrations than their migratory counterparts (i.e., those birds who are found on the Chilliwack mainstem only during the winter and that have a significantly smaller proportion of fish fry in their diet; Morrissey et al., 2004). Several studies have described the bioconcentration of PCBs in tree swallows from aquatic insect prey (Echols et al., 2004; Maul et al., 2006). Echols et al. (2004), for instance, found that PCB concentrations in tree swallow nestlings closely tracked concentrations in aquatic insects. Maul et al. (2006) implicated aquatic insects of the family Chironomidae as the key vector of PCBs to nestling tree swallows from a lake in Illinois, USA.

Differences in age-related contaminant exposure patterns among birds have also been documented. For example, Malinga et al. (2010) noted a positive correlation between age and biomagnification of contaminants in Glaucus gulls (*Larus hyperboreus*) in the Arctic. Likewise, Evers et al. (2005) found that concentrations of methylmercury (MeHg) in adult tree swallows were higher than in nestlings. The authors suggest that differences in prey intake between adult and juvenile birds, as well as the ability of young to transfer MeHg from blood into feathers during rapid growth, may account for such age-based variation.

Given the widespread contamination of aquatic systems (Fitzgerald et al., 1998; Hammerschmidt and Fitzgerald, 2005; Blocksom et al., 2010), the amount of currently available information on aquatic-to-terrestrial contaminant fluxes does not reflect the potential scale of the problem. In particular, although the impacts of land use and land cover (LULC) on riparian birds have been widely investigated (Sullivan et al., 2007; Luther et al., 2008; Pennington et al., 2008; Oneal and Rotenberry, 2009), the relationships between LULC and contaminant exposure to riparian birds from aquatic systems is poorly understood. For example, riparian swallow species [e.g., bank (*Riparia riparia*), northern rough-winged (*Stelgidopteryx serripennis*), tree, and cliff (*Petrochelidon pyrrhonota*) swallows] are susceptible to biomagnification of contaminants because of their dependence on a mixture of stream, riparian, and terrestrial food sources and habitats (Harris and Elliot, 2000; Dods et al., 2005; Custer, 2011). During the reproductive season, riparian swallows tend to forage within several hundred meters (m) of their nest sites (Quinney and Ankney, 1985; Dunn and Hannon, 1992), making them apt bioindicators of local stream and riparian conditions. Land-management practices that alter aquatic resource utilization by swallows might be expected to strongly influence their exposure to aquatic contaminants. Roux and Marra (2007), for instance, found that lead (Pb) concentrations in urban passerine birds were significantly higher than in their rural counterparts, which corresponded with relative Pb concentrations found in soils.

Our objective was to explore the relationships between adjacent (to the river) patterns in LULC and the magnitude of Hg and Se concentrations in four species of riparian swallows as mediated by aquatic-to-terrestrial contaminant fluxes. Because of historic and contemporary differences in land-management and chemical use, we hypothesized that concentrations of contaminants in river sediments, aquatic emergent insects, and riparian swallows would be greater at urban than at rural reaches. Consequently, we anticipated that contaminant exposure to swallows would also differ by LULC class, but would be mediated by the degree of aquatic resource utilization such that swallows feeding at rural reaches (i.e., comprised of a mixture of forest, grassland, and agriculture) would exhibit greater reliance on aquatic emergent insects than swallows feeding at urban reaches, where aquatic emergent insect communities have been shown to exhibit reduced diversity (Stepenuck et al., 2002) and biomass (Lenat and Crawford, 1994; Meyer and Sullivan, in press). Finally, we expected that adult swallows would exhibit greater biomagnification of contaminants than nestlings at both urban and rural reaches.

2. Materials and methods

2.1. Study system and experimental design

The Scioto River is a multiuse river that drains ~16,882 km^2 in central and southern Ohio, flowing for 372 km through agricultural (69%), forested (21%), and urban (9%) landscapes (White et al., 2005; Blocksom and Johnson, 2009). The Olentangy River meets the Scioto in Columbus, the 15th largest city in the US by population (1,178,899 people; USCB, 2010). Once downstream of the city, the Scioto is free-flowing and exhibits riparian zones dominated by deciduous forest, row crops (corn and soybean), and smaller urban centers.

From 2010 to 2012, we conducted coordinated sampling of riparian swallows, riverine sediment and aquatic insects, and aquatic and riparian vegetation at eleven river reaches [defined as a river segment based on similar valley features and channel geomorphology (~1 kilometer [km] for this study)] of the Scioto River watershed, representing a gradient of urban to rural (i.e., mixture of forest, grassland, and agriculture) landscapes (Fig. 1). Study reaches were distributed along the length of the river and were separated by an average distance of 18.4 river kilometers (km), although there was significant variability (SD = 16.8 km). Because of the spatial distribution of LULC patterns in the basin, a degree of clustering among LULC types was unavoidable. We used ArcGIS 10.1 (ESRI, Redlands, CA, USA) to calculate percent cover by vegetation class within 500 meters (m) of the channel following Zelt and Johnson (2005), and performed ground-based surveys to document bridge crossings, vegetation structure, and vegetation composition.

2.2. Field and laboratory methods

2.2.1. Sediment

In either 2010 or 2012, we collected five sediment cores (~10 cm in depth) from each reach at approximately equidistant locations along the length of the reach (Walters et al., 2010). We collected sediment cores by push-coring approximately 2 cm with a polycarbonate coring device. We sealed sediment composite samples in plastic sleeves, placed them on ice, and froze them at −20 °C until analysis (Lutz, 2008).

2.2.2. Periphyton and vegetation

Following methods used in Bartel et al. (2010) and Pennington and Blair (2011), we surveyed riparian vegetation along three 100-m transects (upstream, middle, downstream) along both banks (perpendicular to the stream, $n = 6$/reach) at each reach. At each transect, we established three 5 m × 5 m quadrats, located at 0, 50, and 100-m from the river's edge. We then estimated vegetation cover by height (<3 m, 3–5 m, and >5 m) and identified all trees, shrubs, grasses, and other herbaceous plants to species. We visually estimated the percent coverage of vegetation overhanging the water's edge along both banks and counted standing dead trees of diameter at breast height (dbh) >10 cm.

For stable isotope analysis, we collected five terrestrial vegetation samples per transect on both sides of the river (along survey transects):