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Aquatic prey subsidies to riparian spiders in a stream with different land use types

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ABSTRACT

Land use related habitat degradation in freshwater ecosystems has considerably increased over the past decades, resulting in effects on the aquatic and the riparian communities. Previous studies, mainly in undisturbed systems, have shown that aquatic emergent insects contribute substantially to the diet of riparian predators. To evaluate the effect of land use on aquatic prey subsidies of riparian spiders, we performed a longitudinal study from June to August 2012 along a first order stream (Rhineland-Palatinate, Germany) covering three land use types: forest, meadow and vineyard. We determined the contribution of aquatic and terrestrial resources to the diet of web-weaving (Tetragnathidae spp.) and ground-dwelling (*Pardosa* sp.) riparian spiders using stable isotope analyses of aquatic emergent insects and terrestrial arthropods. The contribution of aquatic and terrestrial sources differed between Tetragnathidae spp. and *Pardosa* sp. as well as among land use types. Tetragnathidae spp. consumed 80–100% of aquatic insects in the meadows and 45–65% in the forest and vineyards. *Pardosa* sp. consumed 5–15% of aquatic insects in the forest, whereas the proportions of aquatic and terrestrial sources were approximately 50% in the meadow and vineyard. Thus, aquatic emergent insects are an important subsidy to riparian spiders and land use is likely to affect the proportion of aquatic sources in the spider diet.

Introduction

Freshwater ecosystems are facing a broad range of environmental pressures from anthropogenic land use. Habitat degradation, toxic pollution, eutrophication, flow modifications and species invasion have considerably increased over the past decades due to Anthropogenic land use (*e.g.* agriculture, urbanization, *etc.*) and have been reported to reduce freshwater biodiversity (MEA, 2005; Dudgeon et al., 2006). In the riparian zone, aquatic and terrestrial ecosystems are linked through fluxes of energy and nutrients, also termed subsidies (Rowe and Richardson, 2001; Baxter et al., 2005; Post et al., 2007; Richardson et al., 2010). Studying the linkages between these ecosystems is crucial to understand how environmental impacts on one ecosystem can propagate to the adjacent ecosystem (Knight et al., 2005; Paetzold et al., 2011). Aquatic-terrestrial food chains or webs are crucial connections and may offer a pathway of propagation of environmental impact across these ecosystem boundaries (Polis et al., 1997). Whereas many studies examined the role of allochthonous inputs from terrestrial systems (*e.g.* leaf litter input) to aquatic food webs, aquatic prey subsidies to riparian predators as well as terrestrial prey input to streams have only recently received increasing attention (Baxter et al., 2005; Hering and Plachter, 1997; Nakano and Murakami, 2001; Collier et al., 2002). Environmental impacts on aquatic organisms may propagate to the adjacent riparian zone *via* different paths, two of them are: (1) Potential export of metals and/or organic contaminants by emergent insects to riparian predators. Evidence for the potential risk for higher terrestrial trophic levels from biomagnification of aquatic contaminants has been provided by (Cristol et al., 2008, Walters et al., 2008 and Raikow et al., 2011). (2) The loss of aquatic biodiversity, especially the loss of emergent aquatic insects, can affect the adjacent riparian zone through reduced food availability to riparian predators.

Previous studies have shown that aquatic emergent insects can contribute substantially to the diet of riparian predators, such as arthropods, birds, bats, lizards and spiders (Sabo and Power, 2002; Sanzone et al., 2003; Kato et al., 2004; Briers et al., 2005; Paetzold et al., 2005; Marczak and Richardson, 2007). Moreover, experimental studies have shown that a reduction in the flux of emergent insects can affect distribution, growth and density of terrestrial predators (Nakano et al., 1999; Kato et al., 2003; Paetzold and Tockner, 2005; Marczak and Richardson, 2007; Kolb et al., 2012). However, these studies have mainly been performed in undisturbed ecosystems (Baxter et al., 2005). Paetzold et al.

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Table 1
Environmental characterization of the survey sites considering different physico-chemical, riparian vegetation and habitat parameters.

	Parameter	Forest	Meadow	Vineyard
Channel (mean cm)	Width	0.6 ± 0.2	0.5 ± 0.1	0.5 ± 0
	Depth	10 ± 5	15 ± 10	15 ± 10
Physicochemical	Velocity (ms^{-1})	0.25 ± 0.05	0.3 ± 0.05	0.3 ± 0.06
Parameter	Temperature (°C)	14.01 ± 1.5	14.1 ± 1.59	14.8 ± 1.56
	pH	7.59 ± 0.04	7.65 ± 0.04	7.67 ± 0.07
	O_2 (% sat)	94.3 ± 1.15	95.1 ± 0.83	94 ± 0.84
	Conductivity ($\mu S\ cm^{-1}$)	111 ± 3.48	117 ± 5.92	144 ± 4.27
Substratum (%)	Boulder	5	5	0
	Cobble	10	5	0
	Gravel	10	10	0
	Pebble	15	10	10
	Sand	60	70	90
Vegetation (%)	Emersed Macrophytes	0	20	60
	Trees	90	20	20
	Scrubs	0	30	40
	Gravel	10	50	40
Shade (%)		88	12	90
Woody debris (%)		15	5	0

(2011) provided first evidence that stream pollution can control populations and community structure of terrestrial predators *via* sustained alterations in aquatic subsidies. Moreover, land use can also strongly affect terrestrial subsidies to aquatic ecosystems (*i.e.* leaf litter and prey input) (Baxter et al., 2005). A reduction in terrestrial subsidies may propagate along the aquatic food web and in turn lead to changes in the availability of aquatic subsidy (Nakano et al., 1999). Hence, land use may affect aquatic prey subsidies *via* multiple paths.

To examine how changes in freshwater ecosystems resulting from anthropogenic land use may manifest across the ecosystem boundary, we evaluated the effect of land use on aquatic prey subsidies to riparian spiders. We performed a longitudinal study along a first order stream covering three different land use types: forest, meadows and vineyard. Following the method outlined in (Briers et al., 2005) we aimed to use a ^{15}N tracer for a better discrimination of the dietary sources of spiders. We hypothesized (1) that the amount of aquatic subsidy to spiders would decrease from forest to vineyards, due to a loss of sensitive aquatic insects (*e.g.* Ephemeropterans, Plecopterans and Trichopterans) resulting from land use related stressors such as pollution and habitat degradation and (2) that the proportion of aquatic subsidies would be higher for the web-weaving than the ground-dwelling spiders, because *Tetragnatha* build their webs over the stream to catch aquatic insects and is therefore more specialized on these (see Section 2.2).

Methods

Selection of study sites

The study sites were located at the Hainbach, a first order stream within the Rhine river catchment, in Rhineland-Palatinate (South-Western, Germany). The Hainbach is about 10–15 cm deep, 0.5 m wide, and had a mean current velocity of $0.3 \pm 0.06\ m\ s^{-1}$ during the study period. Temperatures ranged from 11 to 16 °C and the mean discharge was approximately $0.015\ m^3\ s^{-1}$. These characteristics were similar at all survey sites. The sampling sites were selected to represent three different land use types. From upstream to downstream the sites are: a relatively undisturbed mixed forest site (N49°14′34.3″; E008°02′42.4″), a meadow (N49°14′18.4″; E008°03′0.00″) with occasional mowing or sheep grazing and a vineyard site (N49°14′09.0″; E008°03′58.1″). The distance between sites was about 1 km (Fig. 1). The forest site had a heterogeneous substrate with riffle and pool sections. The meadow site was similar to it in substrate coverage but channelized and had lower amount of woody debris (Table 1). The vineyard site was strongly channelized and the stream substrate was relatively homogeneous consisting of sand, with 60% and 20% cover of emersed macrophytes and scrubs, respectively. Regarding the riparian zone, the forest bank had almost no slope and was composed mainly by a layer of leaves, whereas meadow and vineyard had a steep slope due to the channelization and were similar in vegetation, mainly grasses and scrubs (Table 1). Pesticides, predominantly fungicides and herbicides, were applied at the vineyard site but we have no information on compounds and amounts. Fishes have been rarely spotted at all sites.

Selection of spider species

Orbweb tetragnathid (*Tetragnatha* sp. and *Metellina* sp.) and ground-dwelling lycosid spiders (*Pardosa* sp.) were selected as terrestrial predators as they are common riparian spiders and were present in the riparian zone of the three land-use types. In addition, they have contrasting prey capture techniques. Tetragnathids use orb webs that are anchored to debris or vegetation protruding from the water to intercept flying insects that emerge from the stream (Forster and Forster, 2005). By contrast, ground dwelling lycosid spiders hunt in the riparian zone and their prey consists of a wide range of invertebrates including terrestrial coleopterans, *lepidopterans*, *orthopterans* and *hemipterans* as well as aquatic insect imagos (Nyffeler, 1999).

Physical-chemical and habitat parameter

Physical-chemical data was sampled every 10 days (before tracer was replaced) using a WTW measuring kit (WTW Multi 340i Set, Wissenschaftlich-Technische Werkstätten GmbH, Weilheim).

Habitat parameter such as substrate description, shading, percentage of reach covered by macrophytes and the structural composition of riparian zones were performed once during the the field study. The description was based on a visual estimation over the length of the surveyed stream reach (75 m) using diagrams from the Rapid Bioassessment Methodology for Rivers and Streams (EPA, 2003) as guides.

Tracer addition

To improve discrimination of aquatic and terrestrial prey according to their isotope signature, we enriched the stream with ^{15}N at the three study sites. The tracer addition was adapted from (Briers et al., 2005) to the discharge of our stream and set to approximately 0.013 g of $^{15}NH_4Cl$ (Cambridge Isotope Laboratories, Inc.