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Anthropogenic land-use stress alters community concordance at the river-riparian interface

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ABSTRACT

Organisms often respond in similar ways to environmental or spatial gradients, particularly at large spatial scales. Yet, while understanding these relationships is important for both basic and applied purposes, such as identifying surrogate taxa for conservation and monitoring purposes, patterns at finer scales and across ecotones are less certain. Our central aim was to explore patterns in community concordance at the river-riparian interface and examine whether concordance was decoupled by increasing anthropogenic stress (a gradient of local land-use intensity). We explored this at 15 sites over three years within the LTER site, Rhine-Main-Observatory, a low mountain river system in central Germany, assessing concordance between four organism groups: riparian spiders and carabid beetles, benthic macroinvertebrates, and combined aquatic macrophytes and riparian plants. This represented three different linkages: (1) predator–prey, (2) direct competition, and (3) habitat associations. While there were no correlations in richness patterns, multivariate community structure was highly concordant between all groups. Anthropogenic stress strongly reduced links between riparian spiders and carabid beetles, likely resulting from their shared resource requirements. However, increasing concordance generally occurred between plants and other groups, although inconsistently between the three groups. We posit that patterns may be resulting from two processes: (1) linkages between directly competing species decouple with increasing anthropogenic stress, and (2) stronger coupling may occur between habitat providers and dependent species when overall habitat complexity is reduced. Our results highlight the complex manner in which anthropogenic stress can influence ecosystem structure, particularly at small scales. Based on these complexities, we recommend considering the full suite of community data to adequately explore biodiversity patterns or when searching for surrogate taxa.

1. Introduction

Biodiversity often responds to environmental or spatial gradients in a consistent manner over large spatial scales (Lamoreux et al., 2006; Qian and Ricklefs, 2008). The concordance in pattern between multiple taxon groups, also termed cross-taxon congruence, is important for both fundamental and applied reasons (Heino, 2010; Howard et al., 1998; Kati et al., 2004), such as understanding multi-organism responses to environmental gradients, and surrogacy for conservation planning and biomonitoring purposes. The complexity of ecosystems can result in an inability to adequately describe biodiversity in many systems, through lack of financial resources or expertise, giving rise to the need for cost-effective solutions in biodiversity and conservation work (Gardner et al., 2008; Heino, 2010). Consequently, much of this research has focused on the development of surrogate or indicator taxa for applied purposes. However, while concordance has been found in a variety of systems and between a wide range of organisms (Bilton et al., 2006; Heino, 2002; Lund and Rahbek, 2002; Su et al., 2004), linkages may be weaker at smaller spatial scales (Kati et al., 2004; Paavola et al., 2006).

Communities showing concordance at large spatial scales may be reflecting similar responses of organisms to environmental factors and comparable latitudinal gradients of community structure (Paavola et al., 2006). Concordance in patterns between organism

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groups at finer spatial scales should theoretically depend on the levels of ecological and physical connectivity between these groups. Spatial subsidies between habitats, for instance, can significantly influence many ecosystem properties and the dynamics of receiving food-webs (Anderson and Polis, 1999; Polis et al., 1997), and dissimilar habitat types have as much potential for cross-boundary transfer of material as do similar habitats (Talley et al., 2006). Freshwater and terrestrial ecosystems are a prime example of such an inter-habitat connection, being strongly linked through the riparian ecotone (Gregory et al., 1991; Talley et al., 2006). Riparian zones represent a unique ecotone with strong interactions and dynamic communities, as well as often harbouring high levels of biodiversity (Naiman and Henri, 1997). Running water ecosystems, in particular, are highly connected to adjacent riparian zones through flows of nutrients (Gende et al., 2002), detritus (Wallace et al., 1997), and organisms (Nakano et al., 1999), but these processes are vulnerable to anthropogenic stressors (Baxter et al., 2005).

Strong biotic interactions can occur between different organism groups across the river-riparian interface, such as between emerging aquatic insects and riparian arthropod predators (i.e. predation) (Hering and Plachter, 1997; Sanzone et al., 2003). These linkages, whether biological or physical, should theoretically influence the level of concordance between different groups and differ depending on the type of associations being considered. For instance, competitive interactions, which play an important role in shaping local communities (Kohler, 1992; McAuliffe, 1984), are likely to be stronger between groups inhabiting the same zone, such as riparian arthropods, rather than spanning across the ecotone. Another important association to consider is the role of habitat provision by plants, with highly concordant relationships previously found between aquatic macro-flora and invertebrates, possibly reflecting a microhabitat provision role of plants (Ormerod et al., 1987).

While ecosystems spanning the globe are currently subjected to a suite of global change related stressors (Tylianakis et al., 2008), rivers in particular are under significant threat (Dudgeon et al., 2006; Vörösmarty et al., 2010). Land-use change related stressors form a major component of the threats to freshwater biodiversity (Dudgeon et al., 2006; Vörösmarty et al., 2010). Land use plays a key role in shaping river ecosystems (Allan, 2004), with urbanisation typically having a greater stress on natural communities than agricultural land use (e.g. Lenat and Crawford, 1994). Urbanisation, can bring with it major changes in pollutant runoff, hydrological regimes, temperature regimes and channel morphology (Allan, 2004). Stressors on these systems can operate in a variety of manners. For instance, recent work has highlighted that human-derived stressors alter the co-occurrence patterns of stream invertebrates through changes in community assembly patterns (Larsen and Ormerod, 2014). As it is well understood that natural external factors can alter stream food webs and processes, it is likely that other processes and community linkages decouple with external anthropogenically-driven influences, such as land-use stress, at the river-riparian interface. For instance, sustained stream pollution can impact riparian spider populations through alteration of cross-system subsidies (Paetzold et al., 2011).

As a transitional area from aquatic to terrestrial, river-riparian interfaces provide an ideal focal area to test concordance between taxon groups across coupled habitats subject to the reciprocal exchange of resource subsidies (metaecosystem flows *sensu* Loreau et al., 2003). Therefore, combined with the importance of understanding linkages between multiple organism groups at fine spatial scales and across ecotones, our central aim was to explore patterns in community concordance at the river-riparian interface and examine whether concordance was decoupled by increasing anthropogenic stress (a gradient of local land-use intensity). We assessed cross-taxon congruence/community concordance of riparian spiders and carabid beetles, benthic invertebrates, and riparian and instream plants in the Rhine-Main-Observatory, a low-mountain river system in central Germany, over three consecutive years. This provides us with three different putative linkages to compare between in the form of: (1) predator–prey (riparian predators-benthic invertebrates), (2) direct competition (spiders–beetles), and (3) habitat associations (i.e. flora-fauna associations such as beetles using plants as habitat; Fig. 1).

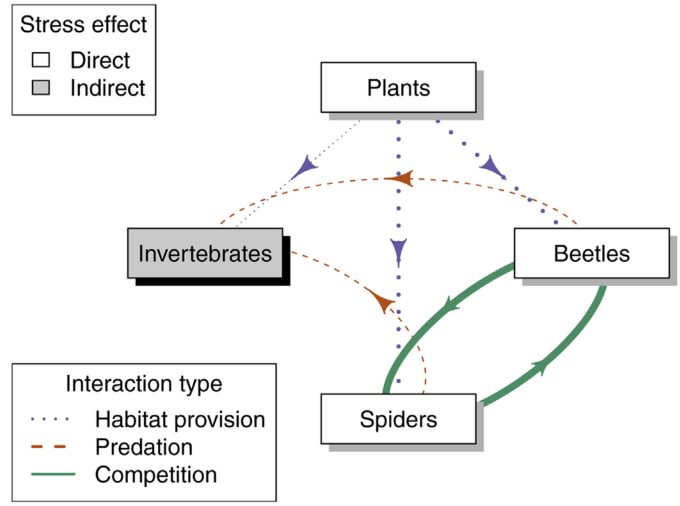

Fig. 1. Hypothesised linkages between the four different organism groups. Different interaction types are indicated by different line types. Hypothesised concordance strengths are indicated by line weights (heavier lines represent stronger concordance in patterns). Whether or not stress is hypothesised to be direct vs. indirect is also displayed. We expect stress will be less direct on the instream communities.

Specifically, we assessed whether the degree of concordance of richness and community structure at 15 sites, each sampled consecutively over 3 years, differed between three levels of anthropogenic stress (a local land use gradient). We developed the following set of hypotheses as indicated in Fig. 1: (1) due to the small spatial scale compared to that which concordance is often examined, concordance between richness and community patterns of different organism groups would be weak in general; (2) highest concordance would be between beetles and spiders, given their shared habitat/resources, and previously reported similarity in important environmental conditions (Lambeets et al., 2008); (3) concordance would decrease between different communities with increasing anthropogenic stress, resulting from more impaired communities and lower functional connectivity (although the opposite might also be true, assuming no asymmetry in the stressor; Ormerod et al., 1987); (4) due to the buffering capacity of rivers (i.e. more indirect effects of terrestrial stressors), and the distance across the aquatic–terrestrial interface, the weakest concordance would occur between benthic invertebrates and the remaining groups.

2. Materials and methods

2.1. Study site

Fifteen sites were sampled along the Kinzig River as part of the Rhine-Main-Observatory (RMO), a long-term ecological research (LTER) site (Fig. A.1). The Kinzig River is a low-mountain river catchment situated in central Germany and flows through a mosaic of different land uses, including forested (mostly low intensity managed forest), agriculture (a mosaic of pastoral and cropping uses) and urban areas (a variety of different settlement sizes). The mean water temperature of the full study reach over the three years was $11.42 \pm 1.81\,^{\circ}C$ (1 SD). Dissolved oxygen averaged $9.78 \pm 0.71\ mg\,L^{-1}$, pH had a mean of 7.74 ± 0.14, and conductivity