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Plant ecological traits highlight the effects of landscape on riparian plant communities along an urban–rural gradient

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ABSTRACT

Urban landscapes are characterized by an urban matrix often unfavorable for biodiversity, interspersed with remnant corridors such as riparian areas. Those are increasingly threatened by urban expansion and land use change worldwide. We investigated the effect of the two components, matrix versus corridor, by comparing the riparian plant diversity and the community-level ecological traits along an urbanization gradient. Species distribution was surveyed at a local-scale along an urban riparian corridor in Strasbourg, eastern France. Ninety plots were sampled along an urbanization gradient. Several plant metrics were measured using both plant richness (R) and mean ecological trait values of species weighted by their abundance (CWM). The surroundings of each plot were first described by selecting representative variables of matrix and corridor. Secondly, the distribution of plant species according to a given *i* ecological trait was analyzed in relation with different levels of urbanization. Using mixed effects models, we verified whether matrix or corridor variables best explain the distribution of traits. Three levels of urbanization were detected, termed urban, suburban and peri-urban, based on landscape composition. Neither the peri-urban nor the suburban level affected plant metrics. At the urban level, and whatever indicator value was considered, the CWM*i* metrics clearly decreased, whereas species richness R*i* increased. The upstream distance to the nearest natural area and tree cover were the most influential variables on CWM*i* metrics, whereas R*i* metrics were mainly driven by built component and landscape heterogeneity. Matrix variables were more important in explaining R*i* metrics while corridor features affected CWM*i* metrics. These results highlight the preponderance of the corridor effect on plant ecological types and the importance of the matrix on the selection and/or the implantation of novel species. Thus, the urbanization gradient may operate simultaneously on the abundance of local species and impose the recruitment of new co-existing species. This study suggests that ecological type responds to the urbanization gradient and may be an alternative tool to understand plant distribution rather than plant diversity.

1. Introduction

The expansion of cities leads to a complex mosaic of biological and physical patches in a matrix of massive and extensive infrastructures (Zipperer et al., 2000). This "created by man" environment spreads across natural areas (McDonnell and Pickett, 1990), often without a clear boundary between urban and natural or semi-natural areas (Clergeau et al., 2006). Consequently, small vegetated patches including remnant natural areas and novel urban environments such as parks and gardens have replaced the large agricultural and semi-natural areas. These patches are often isolated from each other and are under the influence of a set of selective pressures (Williams et al., 2009). In this context, corridors, such as riparian corridors, become an interesting tool to mitigate landscape fragmentation and preserve biodiversity by enhancing flora and fauna dispersals from one area to another (Hess and Fischer, 2001).

Riparian corridors are recognized as biological-ways or greenways (Bryant, 2006) for maintaining and restoring connectivity within urban and peri-urban landscape in conservation plans. It led

Abbreviations: CWM*i*, community weighted mean, i.e. average trait expression across all species of a community, weighted by their abundance, according to the given *i* trait; R*i*, species richness according to the given *i* trait.

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to the integration of criteria for landscape connectivity into land use planning. However, integrating green and blue ways requires a better understanding of urban ecological processes from the rural to the urban center area. Riparian areas have been recognized for their high level of biodiversity related to flood regimes and to geomorphic channel processes (Naiman et al., 1993), but urbanization has led to significant changes in diversity and species richness of riparian plant communities (Meek et al., 2010). Indeed, urban riparian corridors are commonly characterized by narrow strips of vegetation alongside watercourses creating a spatially homogeneous environment. However some species specific to riparian areas are present in at least 50% of the studied urban sites (Oneal and Rotenberry, 2008). Urban development can promote an increase in species richness, most often through the addition of non-native species that benefit from urban disturbances (Burton et al., 2005; Pennington et al., 2010). This addition also slows down the establishment of native species (Moffatt et al., 2004).

The study of species communities along riparian corridors firstly focused on the physical features of corridors such as their width (Rodewald and Bakermans, 2006; Spackman and Hughes, 1995) or their soil type (Ives et al., 2011). In addition, urban impacts are usually studied applying the “gradient paradigm” which supposes that environmental variations are ordered in space and dependent on land cover changes (McDonnell and Pickett, 1990; McKinney, 2002). Landscape parameters then often focus on the matrix's composition (e.g. land-use classes, distance to nearest road), soil properties or demographic data (Burton et al., 2005; Hahs and McDonnell, 2006; Moffatt et al., 2004; Oneal and Rotenberry, 2008; Pennington et al., 2010). Indeed, previous experiments showed how landscape linkage depends on the landscape surrounding (Baum et al., 2004) and how habitat configuration and matrix structure could interact to facilitate species movement (Fletcher et al., 2014).

To study the impact of urbanized landscape on riparian plant communities, previous studies standardly used species richness, Shannon diversity index or evenness as testing variables, revealing taxonomic modifications rather than real functional changes. In fact the range and the distribution of values within single traits frequently provide the most appropriate information to analyze the relationships between community structure and ecosystem processes (Lavorel and Garnier, 2002; Lizée et al., 2011). Indeed, the distribution of traits will better describe the community's functional composition and diversity than any other index based solely on species richness or on species abundance distributions (Norberg, 2004; Ricotta and Moretti, 2011). The concept of plant functional type suggests that species can be grouped according to common responses to the environment (Lavorel and Garnier, 2002). It also helps to understand how plant species are sorted according to the nature of environmental gradient (Garnier and Navas, 2012). In the present study, changes in plant functional type were assessed using an indicator value related to moisture change, soil alteration and light requirement (Landolt et al., 2010), indirectly providing information about environmental variables (Diekmann, 2003; Douda, 2010; Schaffers and Sỳkora, 2000).

Many studies focused on broad-scales (Moffatt et al., 2004; Oneal and Rotenberry, 2008), whereas we chose to study the impact of the urban landscape on plant communities along a riparian corridor on a local scale in order to examine the environmental effect of the urban dynamic. Based on structural and functional aspects of the corridor, one can assume that riparian species and their ecological traits distribution is both affected by the structural features of the corridor, such as width and distance to the nearest natural area, and by the surrounding landscape, i.e. the neighboring matrix's composition and configuration (Hess and Fischer, 2001). To test this hypothesis, the emphasis was put on the riparian area along the Bruche River, within the metropolitan area of Strasbourg (North Eastern France). Specific objectives were to: (1) test if the function of habitat of the corridor for the riparian species would rather be affected by the surrounding matrix or by structural features of the corridor, (2) determine the effects of corridor versus matrix's features on community-level traits, and (3) evaluate the effective contribution of plant ecological types in the understanding of changes of riparian plant communities in response to urbanization.

2. Materials and methods

2.1. Study site

The study was carried out in the metropolitan area of Strasbourg (48°35′N, 7°45′E) in the North Eastern region of France. Strasbourg and its conurbation occupy an area of 78.26 km^2 in the floodplain of the Rhine River delimited by the Vosges Mountains on the East and by the Black Forest Mountains, Germany, on the West. The climate is characterized by annual precipitation between 600 mm and 800 mm per year, cold and dry winters and hot summers. Recent urbanization has developed around an important hydrographical network composed of the main tributary of the Rhine River, the Ill River and its secondary tributary the Bruche River and numerous artificial channels. This situation offers a large number of potential habitats but also potential ways of dispersal.

The study was conducted at a local-scale, focusing on 15 sites located along the Bruche River in Eastern Strasbourg (Fig. 1). The Bruche River connects the Vosges Mountains to Strasbourg along a functional flooding area with geomorphological dynamics. However the bed of the Bruche River has undergone many adjustments in recent decades as it gets closer to the city. Its hydrological regime is pluvio-oceanic, i.e. high water in winter and low water in summer, and flooding generally occurs from March to April. The soil is composed of cobbled to sandy alluvial deposits with siliceous trend. The riparian area is narrow and offers a continuous forested strip associated to lateral meadows or cultivated areas. The riparian forested habitat is composed of a post-pioneer vegetation with willows, poplars and alders under which grows an often exuberant nitrophilous herbaceous flora (Schnitzler et al., 2003). Study sites were identified along an urban–rural land use gradient using aerial photos taken in 2007 (IGN, 2007). Selected sites are located between the river confluence (near the urban center) and the limits of the Strasbourg conurbation. In order to keep reproducible hydrogeomorphological conditions, the sites were selected out of still mobile meanders.

2.2. Sampling and floristic data

At each site, three 50 m^2 (5 m × 10 m) quadrats were sampled on each riverbank, i.e. a total of 90 quadrats, in order to strengthen the sampling. Each quadrat was established at the limit of high waters, separated from each other by 6 m. The entire spontaneous flora was collected from mid-June to mid-July 2012. Juvenile trees, shrubs and herbaceous species were taken into account as well as exotics according to Schnitzler et al. (2007). A cover abundance was assigned to each species. Total species richness and the richness of exotic species were calculated. As ecological scales provide a valuable tool for habitat calibration, indicator values of moisture, soil feature and light for each species were gathered from Landolt et al. (2010). Indicator value was assigned to species with respect to several environmental characteristics on the following scale: light requirement (scale 1: deep shade, to 5: full light), moisture (scale 1: very dry, to 5: flooded, i.e. submerged) and soil reaction (scale 1: extremely acid, to 5: alkaline, high pH). For each indicator value, two kinds of community-level trait metrics were measured: the first one was a richness value, the indicator value of which was equal or higher to 4 (on a scale of 5). Thus, the