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Human impact on plant biodiversity in functional floodplains of heavily modified rivers – A comparative study along German Federal Waterways

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ABSTRACT

Rivers and their floodplains have been strongly influenced by human actions, such as river training measures, flow regulation, bank stabilization, or intensive land use. These alterations threaten the biodiversity of floodplains. While the effects of individual factors on plant species composition and diversity in riparian systems have been frequently studied, it is yet unknown how multiple stressors act in concert and whether the effects remain visible across regions.

We chose the floodplains of German Federal Waterways (rivers with a high frequency of shipping traffic) to study the main drivers of plant species composition and biodiversity along heavily modified rivers and aimed to show whether natural differences obscure the effects of human alterations. We recorded the vegetation of river banks, grassland, and alluvial forest fragments in 20 study sites distributed across Germany.

Species composition differed from natural floodplain alliances and showed a trend towards terrestrialization and an increase of common species that show no specific preference for floodplain habitats. Despite natural differences such as topography and climate having the strongest influence on plant composition and diversity, the effects of anthropogenic influence (e.g. land use, shipping traffic) remained visible. River construction tended to increase species diversity since the terrestrial species pool is bigger than the one of floodplain specialists. For restoration and ecological river management not only species numbers but their composition and ecological specifics should be considered, and local conditions need to be taken into account.

1. Introduction

The large rivers and streams of temperate regions have been severely altered by human actions (Giller & Malmqvist, 1998). Rivers and their floodplains are – in their natural state – among the most species-rich ecosystems. Therefore they are especially sensitive to alterations, which indeed have led to the deterioration of these ecosystems worldwide (Funk et al., 2013; Malanson, 1993; Tockner and Stanford, 2002). In Germany, 90% of the floodplains are degraded by human action (Brunotte et al., 2009) and similar numbers apply to European and North American riparian areas (Tockner and Stanford, 2002). Especially navigable waterways, which are used for shipping traffic, are highly modified (Wolter, 2001).

Since the protection of riparian habitats has received increasing attention in international policy, e.g. in the European Habitats

Abbreviations: ATKIS, German Official Topographic Cartografic Information System; BfG, German Federal Institute of Hydrology; CBD, Convention on Biodiversity; CCA, canonical correspondence analysis; Cf, confer (compare); CSR, ecological strategy types after Grime (1979): competitive-stress-ruderal; ED, edge density; EIV, Ellenberg indicator value; EM, Ellenberg indicator value for moisture (L, light, N, nutrients), et al., and others; EV, explained variance; fig, figure; GRM, general regression models; IDH, intermediate disturbance hypothesis; LS, landscape; MEA, Millennium Ecosystem Assessment; Mgmt, management; NMS, non-metric multidimensional scaling; RL, red list; SP, spatial autocorrelation; sp, species; tab, table; WSA, Waterways and Shipping Office; WSV, German Waterways and Shipping Administration.

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Directive (92/43/EEC, The Council of the European Communities, 1992), the Convention on Biodiversity (CBD, United Nations, 1992), the Millennium Ecosystem Assessment (MEA, 2005), and the European Water Framework Directive (2000/60/EC, European Community, 2000), also heavily modified rivers such as waterways came in the focus of biodiversity research (e.g. Pataki et al., 2013). As human interventions are inevitable to maintain the infrastructure of waterways, construction measures that consider ecological conservation issues are recommended (Wolter, 2001; Pataki et al., 2013). Anthropogenic modifications of rivers and riverscapes are diverse (Allan, 2004). The most important forms of river regulation are modification of river dynamics, river dredging, straightening of the river channel, stabilization of banks and building of artificial levees (Deiller et al., 2001; Van Looy et al., 2004; Ward, 1998).

River regulation and channelization lead to a shift in species composition (Baart et al., 2013) and to a decrease in species numbers (Franklin et al., 2001; Jansson et al., 2000; Nilsson et al., 1991; Uowolo et al., 2005). This decrease in species richness has been studied frequently and is valid across continents (Dynesius et al., 2004). Poff and Zimmerman (2010) reviewed 165 papers on the ecological effects of flow alterations, of which 92% reported decreases in ecological response parameters (e.g. species numbers).

When considering human influences on ecosystems, land-use changes such as deforestation, urbanization, or especially the intensification of agricultural land use are seen as the main driver for biodiversity loss (Sala et al., 2000; Waldhardt, 2003). This seems to be true also in floodplains (Donath et al., 2015; Härdtle et al., 2006; Méndez-Toribio et al., 2014). In an earlier case study on the diversity of plants along the banks of a canal in comparison to those of a river (Harvolk et al., 2014), we found that land use patterns and landscape structure were related to biodiversity distribution along both systems under study. In that context, Méndez-Toribio et al. (2014) explain that intensive land use causes negative edge effects like pesticide runoff, which negatively influence species richness. In contrast, diverse land use and landscape structure patterns may increase the species pool at the landscape level (Liu et al., 2013).

In total, the distribution patterns of vegetation are influenced by factors operating on the local and on the regional scale; they are driven by natural as well as anthropogenic disturbance (Ward, 1998). However, the relative importance of natural regional differences compared to anthropogenic effects still remains unknown.

Studies on the effects of anthropogenic alterations of rivers and their closest surroundings were mostly case studies along single riparian systems (Banasova et al., 2004; Härdtle et al., 2006; Hupp et al., 2009; Martins et al., 2013). Since every river system is unique in respect to the aforementioned natural disturbance (e.g. hydraulic regime or microtopography), generalizations are difficult (Bendix and Hupp, 2000; Giller and Malmqvist, 1998). In addition, very few studies analyzed human impacts on ecosystems across regions (Douda, 2010; Dynesius et al., 2004). However, they focused on only one single aspect of anthropogenic disturbance, like regulation (Nilsson and Berggren, 2000; Nilsson and Jansson, 1995), channelization (Franklin et al., 2001), or river embankment (Van Looy et al., 2004). While these singled-out effects of human impacts are well-studied, it remains unclear how strongly each of them influences species distribution and biodiversity when multiple stressors are affecting the system, and whether those patterns remain visible across regions (but see Tabacchi et al., 1996). Consequently, Bendix and Hupp (2000) ask for a multidimensional context when investigating the influence of different-scale variables on floodplain vegetation.

In accordance, we are interested in the influence of different types of human interventions on plant species distribution across several different riparian systems, and whether natural differences between systems (e.g. geographic, climatic, topographic) mask these effects. To this end we have assessed the floodplain vegetation in 20 study sites along German Federal Waterways that are used for shipping traffic. The German Federal Waterways serve as a good example to study effects of river regulation, construction, and maintenance since they are managed by one administration, following similar regulations (WaStrG, 2013). Our study sites differed in regulation, bank protection, traffic intensity, and surrounding land use, and they were evenly distributed across Germany, thus covering a gradient of continentality and elevation. With this set of study sites we aim to answer the following questions:

(1) Which plant species are found in alluvial forests, flood meadows, and the bank vegetation along rivers under high anthropogenic pressure?
(2) How do these habitats differ from ‘natural’ riparian habitats and do they provide space for endangered floodplain species?
(3) Which are the main driving factors for species composition and species diversity?
(4) How strongly does river management influence species composition and diversity compared to natural driving factors?

2. Materials and methods

2.1. Study sites

German Federal Waterways are navigable surface waters under state administration. They make up 29.8% of the German surface waters (total length: 6900 km). 77% of them are rivers and streams, 23% are artificial canals (Wolter, 2001). Our study comprised 20 study sites that were selected from the total of the German Federal Waterways, applying a stratified random scheme to achieve an even distribution across all waterways. We a priori classified the rivers and streams according to a grouping into ‘mountainous areas’ vs. ‘plains’ (Koenzen, 2005), ‘steep longitudinal slopes’ (>0.5‰ inclination) vs. ‘flat slopes’ (≤0.5‰ inclination) (Koenzen, 2005), and ‘regulated’ (by barrages or other transversal structures) vs. ‘free-flowing’ (BMVBS, 2009). The classification resulted in 5 classes, which are summarized in Table 1.

Within each class, we randomly selected 4 study sites (see Fig. 1) from a total of 11 rivers (Danube: 4 sites; Rhine, Elbe: 3 sites; Main, Lower Havel: 2 sites; Oder, Mosel, Neckar, Saar, Saale, Weser: 1 site).

Canals were excluded from the present study since their species composition differs substantially from that of natural rivers (cf. Harvolk et al., 2014). Similarly, we excluded waterways with less than 1 Mio tons of transported goods per year (WSV, 2013), as these rivers are of minor importance for traffic and are thus less intensely managed. Since we were interested in the ‘normal landscape’ without further influence of settlements or nature conservation measures, river stretches within settlements or within nature conservation areas were excluded. This left 19.5% of the total waterway length for selection.

A study site covered 1 km of floodplain length along the respective river and the extent of the functional floodplain (Brunotte et al., 2009), thus the 20 study sites differed in size (from 9.6 ha to 333.4 ha). The functional floodplain is defined as the area directly inundated by the river at high water levels, while the

Table 1
Classification of German Federal Waterways for stratified random selection.

Class	Landscape	Inclination	Regulation
1	Mountainous	≤0.5‰	Free-flowing
2	Plains	≤0.5‰	Free-flowing
3	Mountainous	>0.5‰	Regulated
4	Mountainous	≤0.5‰	Regulated
5	Plains	≤0.5‰	Regulated