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Functional and taxonomic plant diversity for riverbank protection works: Bioengineering techniques close to natural banks and beyond hard engineering

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ABSTRACT

Erosion control is a major issue in the Prealps region since piedmont is subject to both intense flood hazards and anthropic pressure. Riverbank protections may have major impacts on local ecosystem functioning and ecological corridor continuity.

This study aimed to estimate the effects of the types of riverbank protection technique (from pure riprap to pure bioengineering) on the taxonomic and ecological composition of plant communities in comparison with unmanaged riverbanks as the referential system.

Thirty-eight embankments were sampled in the foothills of the French and Swiss Alps. Four distinct riverbank techniques were analyzed and natural young willow stands were chosen as the referential system. At each site, vegetation was sampled along three transects from the waterline to the top of the riverbank. Plant communities were characterized using biological group composition (growth forms and life history, life strategies and distribution in space and time) and functional diversity indices (MFAD, FDc and wFDc).

We identified 177 distinct plant species on 38 sites. Higher species richness levels were observed on bioengineered banks (from an average of 12 species recorded on ripraps to 27 species recorded on bioengineered banks) strongly dominated by Salicaceae species, especially for fascine and cribwall banks. Functional analyses of plant communities highlighted significant differences among bank types (*p*-value: 0.001) for all selected biological groups. Competitive – ruderal strategy, rooting shoots, stems or leaves that lie down or break off, and unisexual – dioecious, as well as pioneer plants and low shrubs (<4 m tall) distinguished bioengineered bank types. Functional diversity indices confirmed these differences among bank types (MFAD: *p*-value: 0.002; FDc: *p*-value: 0.003; wFDc: *p*-value: 0.005). Riprap always showed the lowest levels on functional diversity indices, fascine and cribwall banks were at the medium level and finally mixed and natural banks the highest level. These results confirm the low ecological potential of purely hard engineering techniques and highlight the similarity of bioengineered techniques and unmanaged riverbanks.

1. Introduction

Anthropic pressure highly affects the biodiversity and riparian area functioning of large river systems. The evaluation and the quantification of these impacts are now major issues for ecological researchers (Nilsson and Svedmark, 2002; Urban et al., 2006; Poff et al., 2007; Richardson et al., 2007). Nevertheless, when surveying the ecological efficiency of river restoration, knowledge and skills are sorely lacking. Indeed, Bernhardt and her colleagues reported 37,000 river restoration projects in the United States and only 10% had been assessed or monitored in any way (Bernhardt et al., 2005).

Plant diversity observed in riparian forests is unique (Sabo et al., 2005), and riverine –riparian zones are characterized by diverse and specialized plant communities that are adapted to many and

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various soil moisture rates and hydrological disturbances (Tabacchi et al., 1998). This vegetation constitutes permanent or temporary habitats and shelters for many animal species, which use riparian areas for feeding and reproduction (Semlitsch and Bodie, 2003; Petersen et al., 2004). In addition, riparian corridors are recognized as major components in landscape ecological functioning (Décamps, 2011; Rodriguez-Iturbe et al., 2009). They can facilitate species migration at the regional scale (Johansson et al., 1996; Machtans et al., 1996) and thus decrease physical and ecological discontinuities in the landscape.

In order to understand the general mechanisms or to make studies of complex systems more understandable, species are often grouped into biological groups according to their functional traits. In this sense, the biological groups selected are combinations of plant characteristics that best maximize tradeoffs in resource allocation patterns, life history, and life strategies. Biological group differentiation among species contributes to the sustainability of diversity and thus ecosystem performance (Kraft et al., 2008).

Very often in the western Alps, anthropic pressures reduce riparian corridors to simple riverbank strips.

Most of the structures aimed at preventing erosion of riverbanks and channeling the rivers are still very often designed from a hard civil engineering perspective. However, alternatives based on soft bioengineering approaches such as plant engineering have a long history (Evette et al., 2009) and are currently being developed (Li and Eddleman, 2002). Living plants are indeed useful for sustainable erosion control. Plants are arranged on the sites in a way that mimics natural vegetation stands able to resist intense tracting and shear-stress forces (Gray and Sotir, 1996; Schiechtl and Stern, 1996). In addition to its erosion control capacity, plant engineering is also expected to ensure better plant coverage than artificially reconstructed embankments (Li and Eddleman, 2002) and to facilitate the recovery of indigenous species instead of exotic species in alpine river systems (Cavaillé et al., 2013). One of the hypotheses postulated for using such techniques is that the initial vegetation planting effort is able to trigger the re-establishment of a functional, self-sustainable, and diverse ecological system. Nonetheless, very few studies have quantified ecological outputs of bioengineering techniques for riparian area restoration (Pahl-Wostl, 2006). Much less is known about the functional ecological issues raised by bioengineering techniques. Individual functional trait variations and covariations are a clue for understanding species' ecological capacities with regard to environmental conditions. How efficient are the different bioengineering designs in mitigating ecological destruction in terms of the biodiversity developed following river channelization?

Since 2002 and the seminal work on the environmental and ecological advantages of biological engineering (Li and Eddleman, 2002), few studies have used quantitative methods to assess the efficiency of bioengineering techniques in ecological restoration for riverbank protection. Species and habitat diversity as well as water quality were assessed on a single soil bioengineering project in Airport Town, Shanghai: an increase in species and habitat diversity, and improved aesthetics and water quality were noted after 10 months (Li et al., 2006). Macroinvertebrates of four bioengineered sites were surveyed in the Peachtree-Nancy Creek catchment in Atlanta, GA, USA, where higher biomass and abundance were found in organic habitats (wood and roots) versus inorganic habitats (mud, sand, and rock) across all sites (Sudduth and Meyer, 2006). Januschke tested the biological impact of the removal of bank fixations: riparian habitat diversity doubled in restored sections and the amount of vegetation units and plant and carabid beetle species richness increased (Januschke et al., 2011).

This paper assesses the effect of riverbank correction techniques (hard engineering, bioengineering, and mixed engineering) on the taxonomic and functional structures of plant communities. Riverbank protection techniques were compared to autochthonous natural youth willow riverbank communities. More precisely, we aimed to determine the extent to which the use of such restoration techniques affects the diversity of species and biological groups, diversities taking natural riverbanks as the reference, selecting biological traits to be representative of the main ecological processes (colonization, reproduction, diaspora) (Landolt and Bäumler, 2010; Lavorel et al., 1997).

We hypothesized that plant diversity should be correlated with the embankment techniques. Accordingly, we also hypothesized that the biological traits and diversity of sampled communities should be correlated with the techniques.

2. Materials and method

The study processes including field sampling and statistical analysis is presented in Fig. 1

2.1. Sites

We selected 38 embankments (31 engineered and 7 natural; Table 1) distributed within the highly fragmented landscape of the foothills of the French and Swiss Alps.

Using natural riparian willow stands as a riparian reference ('N', seven samples), we assessed biological diversity on four distinct types of riverbank protection technique:

- Civil engineering riverbank protection technique: riprap protection, noted as "R" (eight samples).
- Mixed riverbank protection technique, combining civil engineering (riprap at the lower part of the bank) and bioengineering techniques, noted as "M" (eight samples).
- Completely bioengineered riverbank protection technique 1: vegetalized cribwall, noted as "C" (seven samples).
- Completely bioengineered riverbank protection technique 2: willow fascines at the lower part of the bank with cuttings, noted as "F" (eight samples).

To minimize species composition changes due to elevation, the study sites ranged between 210 and 700 m above sea level. Regarding the experimental site locations, this range of altitude is relevant with the unit of vegetation 81 described by Ozenda as "lower and mid-mountain: collinear and mountain vegetation belts" (Ozenda and Borel, 2000). Sites were also chosen to ensure comparable, established plant succession sequences for analysis (every streambank construction occurred between 3 and 7 years prior to the study). Structural factors were recorded such as slope gradient, as well as geographical factors such as the country location and sunlight exposure.

2.2. Landscape context

The landscape context including geographical variables, habitat structure, and the degree of human artificialization in the neighborhood of the study sites may have important impacts on riparian plant community structure. To assess the importance of these key variables, a landscape context analysis was performed around each of the study sites. The temporal factor construction year and the topographic factors elevation, slope gradient, sunlight exposure, and country (France or Switzerland) were included in the analysis. Landscape context was assessed using geographical information based on standardized data from two database sources: BD-TOPO© from the French National Institute of Geography and Forest Information (IGN) and VECTOR25 from