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A multiscale assessment protocol to quantify effects of restoration works on alluvial vegetation communities

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ABSTRACT

Vegetation mapping is a legal obligation in environmental monitoring prompting the need for easy-to-read methods of quantifying changes in vegetation dynamics. Transition matrix modelling provides an alternative approach to qualitative assessment promoting quantification for revealing current complex changes effects on the trajectory of ecosystems. Transition matrix models (TMMs) and two newly developed metrics, the pixel change (PCI) and zonal change (ZCI) indices, were combined into a methodological scheme that provides a multiscale assessment protocol. This protocol was applied during a field study along the Old Rhine River in order to assess complex shifts in alluvial vegetation communities in relation to restoration works and natural processes. The restoration works aim to restore lateral mobility through instream flow increase and controlled bank erosion with artificial groynes implementation. Characterisation of spatial and temporal pathways was carried out using a 'before-after control-impact' (BACI) design, and a fuzzy coding approach has shed further light on shifts in aquatic vegetation functional traits. The multiscale assessment protocol highlighted (i) an increase in alluvial habitat types, including habitats of European concern (Natura 2000), and (ii) low time-scale aquatic vegetation recovery. Both ZCI and PCI recorded high values along the restored section with controlled bank erosion, indicating strong ecosystem change. Use of functional traits detected three requirements for the successful establishment of aquatic vegetation in the restored river section, i.e. high degree of flexibility, flow variation tolerance, and fine-sediment adaptability. Subject to the reliability and availability of vegetation mapping, the method opens the possibility of an efficient tool for precisely monitoring alluvial vegetation communities and identifying pathways. It also discriminates event effects, e.g. natural process effects vs. human-induced effects. At full potential, such a protocol may reveal community responses to disturbance during conservation, restoration and management decision-making projects.

1. Introduction

Current trends in nature environmental public policies are usually based on surveys using habitat type classifications, e.g. the European Nature Information System (Louvel et al., 2013), the Corine Biotope classification (Bissardon et al., 1997) and the phytosociological approach (Bardat et al., 2004; Bensettiti et al., 2000; Braun-Blanquet, 1932). Vegetation characteristics and environmental conditions have long been recognised as convenient and reliable habitat type descriptors. Vegetation surveys, habitat classifications and multivariate statistical analysis allow the description of vegetation characteristics and identification of possible ecological succession pathways (Khan et al., 2016; Meyer et al., 2013; Řehounková and Prach, 2008; Van Geest et al., 2005).

The concept of trajectory is connected to that of ecological successions, based on the idea that an ecosystem can travel along different pathways (Hobbs and Norton, 1996). The main idea of the restoration ecology is to take into account such pathways, and spatial and temporal dimensions (Clewell and Aronson, 2013). During their summary of how restoration success has been evaluated in restoration projects, Ruiz-Jaen and Aide (2005a) found that vegetation characteristics were one of the main attributes for evaluation success (Ruiz-Jaén and Aide,

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2005b). Although qualitative description of vegetation characteristics is useful for illustrating restoration trajectories, it rarely allows quantification and prediction of restoration success (Anand and Desrochers, 2004). Despite this, managers frequently request quantification of potential biological community dynamics at newly restored sites or ongoing restoration projects, especially along large rivers (Jungwirth et al., 2002; Palmer et al., 2005; Pander and Geist, 2013; Woolsey et al., 2007).

Gallet and Sawtschuk (2014) recently described transition matrix modelling as a new approach for highlighting restoration effects on habitat types using vegetation maps. Such maps are currently produced for most managed and restored sites due to a legal obligation to map sites during ecological monitoring (Hearn et al., 2011). If such maps are produced repeatedly over time, and have good reliability, they can be used for transition matrix modelling to analyse trajectories (Godron and Lepart, 1973; Sawtschuk and Bioret, 2012; Turner, 1990). Transition matrix models (TMMs) are based on calculating the probability that a piece of land will change from one state to another (Usher, 1992). This approach has mostly been used on (i) well-understood ecosystems in terms of plant ecology and environmental factors, and (ii) sites that have a rate of vegetational change high enough to be observed over time (Balzter, 2000; Hobbs and Legg, 1984; Lippe et al., 1985). Large rivers and their associated alluvial landscapes satisfy most of these criteria. Few studies have yet used the method on fluvial hydrosystems, partly due to their biocomplexity (Amoros and Bornette, 2002). More than many other ecosystems (White and Pickett, 1985), fluvial hydrosystems are usually subjected to internal patch dynamics that create an on-going turnover of different states that together define the stable state (Beisner et al., 2003; Hughes et al., 2005). Fluvial hydrosystem complexity is also a result of the high degree of natural processes, i.e. internal river dynamics operating at different spatial and temporal scales (Amoros and Bornette, 2002), that are frequently combined with human impacts, e.g. restoration actions or disturbance. Viewing fluvial hydrosystems as a mosaic of patches and investigating mechanisms of the spatial and temporal dynamic at different scales could prove a useful approach for examining interrelationships (Pringle et al., 1988). Many patch-to-patch variations defined over small areas could potentially have important ramifications at the landscape scale (Baker, 1989).

We thus developed a multiscale assessment protocol for evaluating whether changes in vegetation dynamics defined over small areas (patch or pixel) necessarily lead to changes at the landscape scale, thereby acting as a multi-scale indicator of the ongoing stable state. The methodological scheme of this protocol combined TMMs used by Gallet and Sawtschuk (2014) with two newly proposed metrics for this study, the pixel change (PCI) and zonal change (ZCI) indices. This protocol was applied during a field study monitoring an experimental restoration programme of controlled bank erosion with artificial groynes implementation, aimed at restoring lateral mobility along the Old Rhine River (Pinte et al., 2015). The field study was incorporated into a monitoring framework based on the "before-after control-impact" (BACI) protocol (Smith et al., 1993). The field study had two main aims, (i) to undertake a dry run of the multiscale assessment protocol along a fluvial hydrosystem, and (ii) to assess the effect of controlled bank erosion on riparian and aquatic vegetation dynamics, also using an additional approach on shifts in aquatic vegetation functional traits as recommended by Cadotte et al. (2011).

2. Material and methods

2.1. Methodological scheme of the multiscale assessment protocol

The methodological scheme (Fig. 1) was based on two vegetation maps taken at date 1 (d1) and date 2 (d2), displaying three main habitat types (A, B and C). Habitat types were defined as phytosociological syntaxa (e.g. *Phalaridetum arundinaceae* Libbert 1931, *Potamion pectinati* Carstensen 1955) or other natural biotopes (e.g. unvegetated river gravel banks). Phytosociological syntaxa were identified by determining vegetation relevés. Vegetation mapping was undertaken using commonly available GIS softwares (ArcGis 10.3, ESRI, Redlands, US; QGIS 2.14 Development Team).

Mapping software transformation tools were used to convert the maps to raster format, as explained by Gallet and Sawtschuk (2014) and to convert raster images into ASCII files. Before running (McGarigal et al., 2012), prerequisites such as pixel size were made consistent with field survey precision. Raster transformation was used to develop indices of change in vegetation dynamics at two different scales: (i) at large-scale, the zonal change index (ZCI) and (ii) at the local scale, the pixel change index (PCI).

The ZCI was based on the PCh_i, percentage of change in total area filled by each habitat type i within the landscape between d1 and d2. ASCII files promoted the development of the ZCI with Fragstats software (McGarigal et al., 2012). The ZCI was calculated between two dates-states, where N is the number of habitat types, and P_i is the percentage of total area filled by habitat type i on each date (d1 and d2). The 'Class' scale PLAND metric in Fragstats software (McGarigal et al., 2012) was useful to obtain the $P_{i.}$ The ZCI provides the sum of PCh_i within the landscape between d1 and d2 (loss or gain). This sum was divided by two in order to account for loss-gain in each habitat (Eq. (1)).

$$Zonal\ Change\ Index,\ ZCI\ (\%) = \frac{\sum_{i=1}^{N} PCh_i}{2} = \frac{\sum_{i=1}^{N} |P_{i(d1)} - P_{i(d2)}|}{2} \tag{1}$$

We defined the pixel change index (PCI) as the relative frequency of pixel number (PN) that changed from one habitat type to another between d1 and d2 (Eq. (2)). The latter was obtained thanks to the combination of the two raster images. This generated a transition matrix (d1 × d2) informing on both stable and dynamic transitions from one habitat type to another (or the same) between two dates (d1 and d2), with the surface area concerned for each type of transition.

$$Pixel\ Change\ Index,\ PCI\ (\%) = \frac{\sum_{i=1}^{N} PN\,(changed)}{\sum_{i=1}^{N} Total\ PN} \tag{2}$$

The PCI decreases if the system gains in stability between two dates. This provides an add-on index to the potential stability index described in Gallet and Sawtschuk (2014). Output results from the TMMs and PCI permit to identify the role of spatial heterogeneity and temporal variability, by focusing on changes from one pixel to another.

Reading both PCI and ZCI together is of fundamental importance, allowing definition of both local- and large-scale potential effects (Fig. 1). A high ZCI alongside a high PCI (with approximately equal values) reflects an ecosystem trajectory change towards a novel stable state. A PCI value higher than the ZCI value indicates the current stable state, with low zonal variation and natural dynamics maintained, while a low ZCI and a low PCI (with approximately equal values) reflect a lack of internal patch dynamics.

2.2. Application in the field

2.2.1. Study site and description

Since the mid-19th century, the upper Rhine River has been strongly modified by engineering works (Uehlinger et al., 2009). The original 3 km wide braided and anastomosed channel has been transformed into a 200 m wide stable channel, inducing bed degradation and sediment coarsening (Dittrich et al., 2010). These improvements resulted in the purging of part of its coarse load (Maire, 1997), leading to a loss of ecological functionality, especially along the Old Rhine River, a 50 km by-passed single-bed paved channel located at the border between France and Germany. The upstream part of the Rhine from "Village-Neuf" (Kilometric point – KP 174), near the border between