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A multi-faceted framework of diversity for prioritizing the conservation of fish assemblages

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ABSTRACT

Floodplain waterbodies and their biodiversity are increasingly threatened by human activities. Given the limited resources available to protect them, methods to identify the most valuable areas for biodiversity conservation are urgently needed. In this study, we used freshwater fish assemblages in floodplain waterbodies to propose an innovative method for selecting priority areas based on four aspects of their diversity: taxonomic (i.e. according to species classification), functional (i.e. relationship between species and ecosystem processes), natural heritage (i.e. species threat level), and socio-economic (i.e. species interest to anglers and fishermen) diversity. To quantitatively evaluate those aspects, we selected nine indices derived either from metrics computed at the species level and then combined for each assemblage (species rarity, origin, biodiversity conservation concern, functional uniqueness, functional originality, fishing interest), or from metrics directly computed at the assemblage level (species richness, assemblage rarity, diversity of biological traits). Each of these indices belongs to one of the four aspects of diversity. A synthetic index defined as the sum of the standardized aspects of diversity was used to assess the multi-faceted diversity of fish assemblages. We also investigated whether the two main environmental gradients at the catchment (distance from the sea) and at the floodplain (lateral connectivity of the waterbodies) scales influenced the diversity of fish assemblages, and consequently their potential conservation value. Finally, we propose that the floodplain waterbodies that should be conserved as a priority are those located in the downstream part of the catchment and which have a substantial lateral connectivity with the main channel.

1. Introduction

In view of the numerous and growing threats affecting aquatic biodiversity, conservation measures are urgently needed to preserve the most threatened and crucial freshwater ecosystems (Geist, 2011; Strayer and Dudgeon, 2010; Vörösmarty et al., 2010). Resources (e.g. money, time, people) are often limited, and as it is not possible to preserve all river stretches, it is essential to identify priority areas for biodiversity conservation (Bergerot et al., 2008; Myers et al., 2000; Thorp et al., 2008).

Several approaches and procedures have been proposed for identifying priority areas for conservation (e.g. Darwall and Vié, 2005; Margules and Pressey, 2000). Some of these have focused on only one or two aspects of the biological diversity, usually on species richness and/or endemism (Arzamendia and Giraudo, 2011; Myers et al., 2000; Tisseuil et al., 2013; Trebilco et al., 2011) but sometimes also on the threatened status of species (Bragazza, 2009) or species rarity (Solymos and Feher, 2005), while others have combined several criteria to assess the conservation value of assemblages of species (Abellan et al., 2005; Bergerot et al., 2008; Rainho and Palmeirim, in press; Stewart, 2011). Although methods based on just a few aspects of diversity are easier to apply because of the small amount of information required on each species, Mouchet et al. (2010) have pointed out that considering the taxonomic diversity alone is not sufficient to evaluate the diversity of communities because, for instance, species do not all have equal effects on ecosystem functioning. Furthermore, Ceballos and Ehrlich (2006) and Orme et al. (2005) have shown that the priority areas identified for biodiversity conservation differ depending on whether the method used was based on species richness, endemism or threatened status of species.

Against this background, we propose here a method for prioritizing areas based on four aspects of diversity: taxonomic, natural

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heritage, functional and socio-economic diversity. This method is based on the assumption that an area has a high conservation priority if it simultaneously presents numerous threatened (Darwall and Vié, 2005; Fattorini, 2006), rare (Abellan et al., 2005), native (Bergerot et al., 2008), functionally original and unique (Walker, 1992) species, as well as species having a strong socio-economic interest (Regan et al., 2007). In addition to these species characteristics, high conservation priority is hypothesized for areas where species assemblages are functionally rich (Walker, 1992) and original in their taxonomic composition in comparison with the other areas assessed (Kanno et al., 2012).

The taxonomic, natural heritage and functional aspects of diversity have been well described, and a variety of indices have been taken into account when identifying the priority areas for conservation (e.g. Abellan et al., 2005; Bergerot et al., 2008; Mouillot et al., 2013; Ricotta, 2005). However, as far as we are aware, the evaluation of the socio-economic diversity of assemblages has been overlooked in previous prioritization methods despite the acknowledged importance of biodiversity for human activities and well-being (Millennium Ecosystem Assessment, 2005). We have also considered several indices within each aspect of diversity and assessed their non-redundancy (Gallardo et al., 2011) and complementarity (Villéger et al., 2008), which must be considered when combining several indices or metrics (Lyashevska and Farnsworth, 2012).

We applied this innovative method to a series of floodplain waterbodies in a large catchment in southwest France, the Garonne. Floodplain waterbodies have been recognized as essential for the functioning of freshwater ecosystems (Amoros and Bornette, 2002; Petts and Amoros, 1996). These wetlands have been shown to provide suitable conditions for primary production by higher plants (Keruzoré et al., 2013) and for higher levels of aquatic diversity of organisms (Ward, 1998) such as macroinvertebrates (Gallardo et al., 2008), zooplankton (Kattel, 2012) and fish (Bolland et al., 2012; Lasne et al., 2007a). However, these important ecosystems and their biodiversity are increasingly threatened by human activities, such as agricultural practice, changes in the flow regime, and climate change (Kattel, 2012; Tockner and Stanford, 2002). In this study, the floodplain waterbodies were prioritized on the basis of the conservation value of their fish assemblages. Fish constitute one of the most severely threatened taxonomic groups (Darwall and Vié, 2005) due to their high sensitivity to the various changes affecting aquatic habitats (Oberdorff et al., 2002). Furthermore, fish fauna is commonly taken into account when assessing the quality of aquatic ecosystems (Gozlan, 2012; Kanno et al., 2012; Strecker et al., 2011). In addition, floodplain waterbodies are important ecosystems in the development cycle of several fish species where they may perform spawning, nursery and feeding functions (Copp, 1989; Gozlan et al., 1998; Nunn et al., 2007).

Finally, we assessed the influence of environmental characteristics on the prioritization of floodplain waterbodies. At the scale of a large catchment, the main factor that determines the composition of fish assemblages is the distance from the sea (Buisson et al., 2008; Ibarra et al., 2005; Lasne et al., 2007b). In the case of floodplain waterbodies, it has been demonstrated that the lateral connectivity between the waterbody and the main channel also influences the structure of fish assemblages (Amoros and Bornette, 2002; Bolland et al., 2012; Lasne et al., 2007a).

The objectives of this study were therefore (i) to propose a method for prioritizing areas for the conservation of floodplain fish assemblages based on various aspects of their diversity and (ii) to find out whether the distance from the sea and the lateral connectivity between the waterbody and the main channel had any effect on the prioritization proposed.

2. Materials and methods

2.1. Study area

The Garonne catchment is located in southwest France (Fig. 1). It drains a 56,536 km^2 catchment area, and the main channel flows over 580 km from its source in Spain to the Atlantic Ocean (see Gozlan et al., 1998; Ibarra et al., 2005 for more details). Its flow is influenced both by precipitation and snow melt, resulting in a flood peak in May–June and a period of low flow during the summer. Within this catchment, there is a wide diversity of floodplain waterbodies that are evenly distributed between the estuary of the Garonne River and its source. Natural floodplains are composed of various aquatic habitats ranging from lotic to lentic habitats, including floodplain waterbodies that are characterized by their level of connectivity with the main channel, their substrate (grain-size and geochemical composition), and their shape and size (Amoros and Bornette, 2002). Overall, the Garonne River and its floodplain waterbodies are very slightly impacted by human activities and the riverscape has kept most of its natural characteristics.

2.2. Data collection

In this study, we focused on the fish assemblages present in the floodplain waterbodies located along the French segment of the Garonne River. We selected 40 out of the 180 waterbodies identified along the mainstream river (Fig. 1) which were evenly distributed along the upstream–downstream gradient, had contrasting levels of lateral connectivity to the main channel, were not (or least) impacted by human activities, were submerged during the sampling period and accessible for sampling as well. We used a Point Abundance Sampling (PAS) electrofishing protocol according to Nelva et al. (1979) and Lasne et al. (2007a) to assess the composition of fish assemblages in these 40 waterbodies. This rapid and cheap method provides reproducible and quantitative samples, and hence permits spatial comparisons between sampling sites. Thirty PAS were randomly performed by wading along the entire length of each waterbody. At each PAS, the operator plunged the activated anode of a portable electrofishing apparatus as quickly as possible. According to Laffaille et al. (2005), the anode was kept turning in an area of 1 m^2 for at least 30 s to capture all species using several fine-mesh dipnets. Fish species were identified before being returned alive to the water. Presence–absence data from all the PAS conducted in a waterbody were pooled. We also collected information about the lateral connectivity between the waterbody and the main channel. The waterbodies were divided into three categories according to Gozlan et al. (1998) and Lasne et al. (2008): always connected, partially connected and not connected to the main channel during the sampling period. The distance of each waterbody from the sea was also calculated using ArcGIS 10 software (ESRI, 2011). The levels of connectivity were evenly represented along the upstream–downstream gradient suggesting that there was no marked relationship between the two variables (Kruskal–Wallis chi-squared = 0.269, p-value = 0.874).

2.3. Indices of diversity

Numerous indices have been developed to assess biodiversity (e.g. Feld et al., 2009; Pavoine and Bonsall, 2011; Ricotta, 2005; Roset et al., 2007; Vačkář et al., 2012). We selected eight indices that can be roughly assigned to three categories: taxonomic diversity, functional diversity and natural heritage diversity. The socio-economic aspect of diversity, which has been poorly explored to date, was also taken into account using an index based on the fishing interest of each fish species. These nine indices were