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Does land use impact on groundwater invertebrate diversity and functionality in floodplains?

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ABSTRACT

Land use change, especially the transformation of riparian forest to agricultural fields, plays an important role in groundwater quality, yet little is known about the effects of land use change on groundwater invertebrate assemblages and diversity. This study assesses for the first time the effect of land use (agricultural *vs.* forest use) on the groundwater invertebrate community of four river floodplains representative of variable conditions across SW Europe (the Garonne River in France, and the Bidasoa, Ebro and Tajo Rivers in Spain). Groundwater invertebrate and water samples were collected quarterly in 8–12 piezometers located in each floodplain over a year. Taxonomic and functional diversity indices and ecosystem services (*i.e.* biogeochemical filtration and particulate organic matter breakdown) were calculated. The taxonomic and functional diversity of groundwater invertebrate communities increased linearly with the increasing surface occupied by riparian forests and decreased under intensified agriculture use. Moreover, the provision of key ecosystem services related to the biogeochemical filtration and particulate organic matter breakdown also increased 2-fold under more natural forest land. According to regression models, this is likely due to the pressure of agricultural practices on groundwater quality, with high concentrations of nitrates and sulphates exerting a negative influence over groundwater invertebrate diversity and their associated ecosystem services. The results of this study have important management implications, and suggest that the presence of large riparian corridors enhances groundwater invertebrate diversity and functionality in floodplains deeply disturbed by agricultural practices.

1. Introduction

Subterranean habitats have been traditionally considered as biological deserts, only interesting as a major source of water resources (Gibert et al., 1994). However, recent studies have demonstrated that groundwater systems are home to a great variety of cryptic and endemic organisms (Avramov, 2014; Deharveng et al., 2009; Sket, 1999), which provide important ecosystem services ranging from water purification and bioremediation to water infiltration and transport (Boulton et al., 2008). Unfortunately, the spread of groundwater habitats has also favoured their degradation, mainly because of intensification of agriculture, forest clearance, industrial activities, groundwater extraction, river flow regulation, and waste water discharge (Boulton et al., 2010; Danielopol et al., 2003; Griebler et al., 2010; Tockner et al., 2008). These pressures reduce the hydrological connection between ground and surface waters, and favour the accumulation of pollutants that impair the characteristic biological structure and functionality of groundwaters (Danielopol et al., 2003; Korbel et al., 2013).

Since the early 2000s, the importance of groundwater as a living ecosystem has increased. Scientists and environmental managers

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are working to develop guidelines and strategies for the conservation of groundwater ecosystems, taking into account their biota and functionality (Gibert and Culver, 2009; Gibert et al., 2009; Gibert and Deharveng, 2002). The majority of studies focus on describing groundwater invertebrate (also called stygofauna) distribution patterns, such as the recent European PASCALIS project (http://pascalis.univ-lyon1.fr/; Castellarini et al., 2007; Gibert et al., 2009). Results from this project have identified temperate areas as hotspots of groundwater biodiversity, and have suggested that the full potential of groundwater ecosystems as sources of biodiversity and ecosystem services is still to be fully comprehended (Deharveng et al., 2009). For this reason, researchers have proposed the use of groundwater invertebrates as bioindicators of ecological groundwater health in the same way that they are used in surface waters (Boulton et al., 2008; Griebler et al., 2010; Iepure et al., 2013; Korbel and Hose, 2011).

The distribution of groundwater organisms indeed responds to hydrogeological and environmental factors, such as floods, dissolved organic carbon, and the concentration of nutrients and pollutants (Castellarini et al., 2007; Danielopol et al., 1994; Di Lorenzo et al., 2014; Iepure et al., 2014, 2013; Mösslacher, 2000; Schmidt et al., 2007), which makes them suitable candidates to reflect the ecological status of subterranean habitats (Stein et al., 2010). Furthermore, groundwater invertebrates contribute to the functioning of groundwater ecosystems, and consequently to the provision of groundwater ecosystem services used by humankind (Griebler and Avramov, 2015). For example, amphipods and isopods are keystone taxa groups that enhance the decomposition of organic matter, which in turn stimulates bacterial growth and activity, supporting the biodegradation of contaminants (Tomlinson and Boulton, 2010; Ward et al., 1998). These crustaceans also recycle nutrients through the excretion of faecal pellets, and increase the flux of oxygenated water through burrowing (Hakenkamp and Palmer, 2000). However, such functional processes have been poorly studied, preventing the development of consistent ecological criteria for assessing groundwater ecological status. More research is thus needed to ascertain the response of subterranean biodiversity patterns and functionality to both natural and human-induced changes (Culver and Sket, 2000; Deharveng et al., 2009; Hancock et al., 2005; Korbel et al., 2013).

One of the most interesting subterranean habitats is the hyporheic zone, which is the area of mixing between surface and subsurface water (White, 1993; Wondzell, 2011). These two systems have different oxygen, organic matter and nutrient content, so their water mix has a significant impact on biogeochemistry cycling and biotic communities (Boulton et al., 1998; Brunke and Gonser, 1997; Krause et al., 2013; Marmonier et al., 2012; Sánchez-Pérez et al., 2003a,b; Sánchez-Pérez and Trémolières, 2003; Schmidt and Hahn, 2012; Vervier et al., 2009). These ecosystems support important agricultural activities, and, consequently, groundwater often suffer from nitrogen pollution (Arrate et al., 1997; Almasri and Kaluarachchi, 2007; Liu et al., 2005; Sánchez-Pérez et al., 2003a,b). Several studies show that the hyporheic zone (*i.e.* surface-groundwater interface) contributes to nitrogen retention and/or transformation of the land-surface water continuum (Sabater et al., 2003; Weng et al., 2003). This zone supports the purification of water by its ability to eliminate nitrates during their infiltration through the vegetation-soil system to groundwater, but also through diffusion from groundwater to surface water (Sanchez-Perez et al., 1991a,b; Takatert et al., 1999). However, little is known about the groundwater biota and its role in these purification processes, and, definitely in the general ecosystem functioning.

To this end, this study evaluates for the first time the effect of land use on the groundwater invertebrate community of the hyporheic zone in four river floodplains located across SW Europe. First, we hypothesized that riparian vegetation areas would show higher groundwater invertebrate diversity than agricultural areas, since riparian vegetation often support better water quality (Sanchez-Perez et al., 1991b; Takatert et al., 1999) and provide greater heterogeneity of food and habitat resources for biota (Hancock and Boulton, 2008; Jasinska and Knott, 2000). Moreover, we expected the groundwater invertebrate community to change along a land use gradient, showing varying characteristic taxa and functions. For example, the vegetation of riparian forest areas adds debris to the system, increasing the organic matter content in soils and groundwater. Consequently, the presence of detritivores and omnivores, which are essential for organic matter decomposition and nutrient cycling in groundwater ecosystems, is favoured (Avramov, 2014; Boulton et al., 2008; Vannote et al., 1980). In contrast, pollution-tolerant taxa are likely to dominate agricultural areas because of the high levels of fertilizers and manures employed, as was observed by Dumas and Lescher-Moutoué (2001). Thus, our study allows us to evaluate the overall role of riparian corridors as natural biofilters of pollutants from agricultural areas. Ultimately, this study is essential for understanding the local variation in groundwater assemblages and their response to human pressures, contributing to the development of suitable conservation and management policies.

2. Material and methods

2.1. Study area

For this study, we selected four river floodplains located in South-western Europe: Garonne, Ebro, Bidasoa and Tajo. Floodplains were selected in areas characterized by a combination of agricultural occupation and patches of natural riparian forest that might favour the potential degradation of agricultural pollutants. The study covers a wide gradient of climatic and environmental conditions, from floodplains with little forest use to others with a high forest surface. To our knowledge, no studies on groundwater invertebrates have been performed in any of the four selected floodplains.

The Garonne study area was located 30 km north of Toulouse in South-West France (UTM 355758/4861267; Fig. 1, Table 1). This floodplain site is dominated by agriculture, mainly corn, sunflower and poplar plantations (Table 1). Its riparian forest is dominated

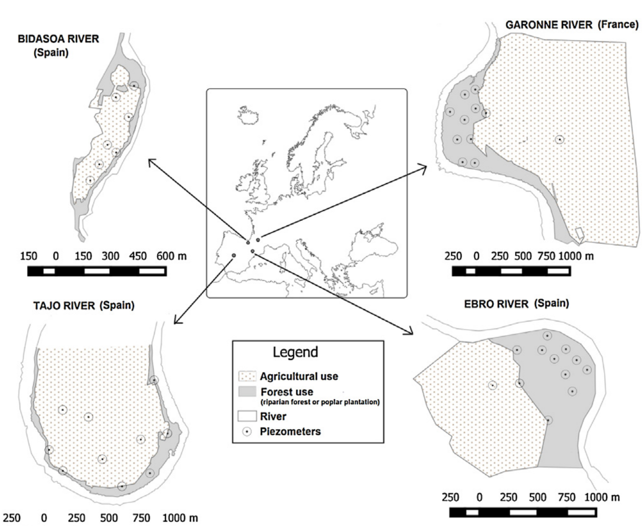

Fig. 1. Study area location and piezometric network of each studied river floodplain. The study area is composed by four river floodplains located in South-western Europe (Garonne, Ebro, Bidasoa and Tajo Rivers). Samples were collected in the piezometric network (8–12 piezometers) of each floodplain.