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Biodiversity and ecosystem purification service in an alluvial wetland

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ABSTRACT

Alluvial wetlands provide an important regulating service, the water purification, through the removal of excess nutrients. In those habitats, nitrogen removal by the denitrifying bacterial community is hypothesized to interact with the co-existing invertebrate communities. Yet, few studies reported the infield relationship between invertebrate and microbial communities, where biotic and abiotic interactions are complex. We aimed at exploring the relationship between the invertebrate diversity and microbial denitrification process involved in the water purification service in an alluvial wetland. Subterranean water samplings were seasonally collected from April 2013 to March 2014. Eleven hyporheic habitats were accessed through piezometers dispersed over a meander located in the alluvial plain of the Garonne River (Southwest of France). Physicochemical, hydraulic characteristics, bacterial and invertebrate communities were simultaneously investigated as related factors for potential denitrification rates.

Significant spatial gradients of invertebrate diversity, potential denitrification rates, the concentrations of dissolved oxygen, dissolved organic carbon, ammonium and nitrate ions and conductivity were observed in the groundwater of the Monbequi meander. The autumn campaign (9th October), which was performed after a long period of hydrological stability and low discharge, showed a significantly positive linear relationship between invertebrate diversity and potential denitrification rates. An overall significant and positive correlation between invertebrate and bacterial communities' compositions was found over the four seasons. When each season was considered independently, this relationship was only significant during the autumn campaign. Such observations indicated the positive cross-communities' interactions that existed between the invertebrate diversity—bacterial communities' composition and their activity of denitrification. The autumn campaign was suggested to be regarded as a "hot moment" to observe this biodiversity/function relationship, when biological influences on water purification processes were probably not concealed by stronger influences of physical factors. Furthermore, this study showed that optimal potential nitrate removal was supported by a combination of biotic and abiotic conditions: relatively low temperature, oxygen and nitrate concentrations, diverse invertebrate fauna, relatively high dissolved organic carbon and ammonium concentrations.

1. Introduction

The rapid growth of human populations and associated environmental changes inevitably affect and cause the rapid decline of biodiversity of terrestrial, marine and freshwater ecosystems. As a result, such biodiversity loss may impair ecosystem function and the delivery of ecosystem services for humanity (Millennium Ecosystem Assessment (MA), 2005; Hooper et al., 2005; Worm et al., 2006; Cardinale et al., 2012). Ecosystem services are the conditions and processes by which natural ecosystems and their species sustain and fulfill human needs (Daily, 1997). The relationship between these services and biodiversity thus received a growing interest (Kremen, 2005; Science for Environment Policy, 2015), in order to bridge the gap between ecological studies and managers and decision-makers (Griebler et al., 2014). Indeed, such knowledge is crucial, not only for effective conservation of biodiversity and related ecosystem services, but also for improvements of integrative and sustainable management of ecosystems.

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Several models and hypotheses were proposed to explore the relationship between biodiversity and ecosystem functions (BEF) and services, including null hypothesis (weak support by Giller and O'Donovan, 2002), linear relationship (Tilman, 1997), idiosyncratic model (Lawton, 1994), "rivet" hypothesis (Ehrlich and Ehrlich, 1981), redundant species and "insurance" relationship (Loreau et al., 2001). Two classic examples are: (i) different pollination service of wild and managed bees servicing different crops (Kremen et al., 2002); (ii) a distinct positive correlation between the number of plant species and various ecosystem functions (e.g. decomposition and primary production) in a long-term grassland experiment (Tilman et al., 2001). Most foci were given to terrestrial ecosystem services and the biodiversity that directly provided these services. However, few assessments of biodiversity and aquatic ecosystem service relationships were reported (Lecerf and Richardson, 2010). They quantified that field surveys accounts for only 9 out of 45 BEF relationships in streams. On the other hand, most BEF studies in streams were based on experimental manipulations, especially on laboratory microcosms. The implication of environmental factors is unavoidable when moving from closed (laboratory experiments) to open systems (*in situ* experiments and field survey), consequently increasing the difficulty to observe the BEF relationships. Furthermore, BEF relationship observations from field survey are rare especially from groundwater and concerning quantitative approaches of invertebrates and water purification capacity (Boulton et al., 2008).

Water purification is an important natural regulating service (MA, 2005) that implies several biogeochemical processes in riverine systems. In agriculturally dominated watersheds, this natural purification service significantly contributes to attenuate the emission of diffuse nitrate loadings caused by fertilizers application and others non-point sources (Arrate et al., 1997; Sánchez-Pérez et al., 2003; Mander et al., 2005; Lewandowski and Nützmann, 2010; Jégo et al., 2012). Many studies have examined nutrient dynamics in the natural water, with particular focus on nitrogen, because the increasing nitrogen contamination attracts attention, especially in groundwater (Peyrard et al., 2011; Bernard-Jannin et al., 2017). As they support important agricultural activities, groundwater of alluvial plains often suffers from nitrate pollution (Sánchez-Pérez et al., 2003; Liu et al., 2005; Almasri and Kaluarachchi, 2007). In the nitrogen dynamic, one hot issue is the nitrate removal. Several studies show that the hyporheic zone contributes to nitrogen retention and/or transformation. The land water continuum 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 (Sánchez-Pérez et al., 1991a, 1991b; Takatert et al., 1999). Alluvial wetlands play a key role in water quality regulation through the synergy in river–groundwater exchanges, living biota and biogeochemical processes. As surface water contains rich oxygen and organic matter and groundwater contains abundant nutriment elements, the mixed water between those two systems (the hyporheic zone) has a significant impact on water quality and biogeochemistry cycling (Sánchez-Pérez and Trémolières, 2003; Vervier et al., 2009; Marmonier et al., 2012).

In the hyporheic zone of riverine systems, the major pathways that occur in the nitrate dynamic include denitrification, anaerobic ammonium oxidation (ANAMMOX), dissimilatory nitrate reduction to ammonium and microbial immobilization (Burt et al., 1999; Hinkle et al., 2001; Rivett et al., 2008; Peyrard et al., 2011; Ligi et al., 2014). In the hyporheic medium of a river meander, the denitrification process can permanently remove nitrate from natural interstitial water (Bernard-Jannin et al., 2017). Regarded as one important pathway for nitrate removal, thus the denitrification can be used as a proxy for the water purification service.

This microbial denitrification activity is being controlled not only by bottom up (e.g. nutrients, and temperature), but also by top-down (predation) factors. Previous studies revealed that invertebrates act as important mediators between nitrogen-cycle microbes and dissolved inorganic nitrogen (Ostroumov, 2011; Stief, 2013). These cross communities interactions work *via* grazing and gardening effects on the biofilm and associated microbes, thus contributing significantly to nitrogen cycling and removal (Marshall and Hall, 2004; Bonaglia et al., 2014; Liu et al., 2014). However, nearly all of these BEF studies have been synthetic, species-poor experiments, and subject to prompting criticism for missing direct relevance to natural ecosystems that are more complex, species-rich and open (Loreau et al., 2001; Ostfield and LoGiudice, 2003; Boulton et al., 2008). Very few studies showing the indirect contribution of invertebrate diversity on microbial denitrification activity are observed in fields, particularly in the hyporheic groundwater of alluvial wetlands in river floodplains.

As the major nitrate attenuation process in groundwater of alluvial wetland, denitrification is not only influenced by biological effects as mentioned above (Iribar et al., 2008, 2015), but also by hydrological and physicochemical conditions (Jones and Holmes, 1996; Sánchez-Pérez and Trémolières, 1997; Sánchez-Pérez and Trémolières, 2003; Sánchez-Pérez et al., 2003; Weng et al., 2003). These abiotic influences include potential direct controls by nitrate availability (Martin and Mulholland, 2001; Kemp and Dodds, 2002), organic carbon supply (Lewandowski and Nützmann, 2010; Peyrard et al., 2011), dissolved oxygen concentration (Kemp and Dodds, 2002) as well as potential indirect controls by water temperature (Pattinson et al., 1998) and surface land use (Kemp and Dodds, 2009; Jahangir et al., 2010; Hoffmann et al., 2014). Hydrological regime with floods and droughts events is an important factor shaping the physical environment as well as biotic assemblages, especially in the hyporheic zones of alluvial wetlands. Hydrologic factors influence fine sediment charges (Wondzell and Swanson, 1999), and also control sediment permeability and residence time of water (Valett et al., 1996; Olsen and Townsend, 2005). These environmental variations and their complex interactions with biotic factors may obscure the links between biodiversity and denitrification in the natural ecosystem.

The aim of this study was to explore the relationship between invertebrate diversity and denitrification in an alluvial wetland, where groundwater is connected to the river and subjected to nitrate pollution coming from agricultural land. We hypothesized that, if a positive relationship between invertebrate diversity and microbial denitrification function exists, this positive interaction may be explained by the positive cross-community effects between invertebrate and microbial communities' compositions. So, the general temporal and spatial patterns of this alluvial wetland characteristics were firstly described, then the relationship between invertebrate diversity and potential denitrification activity in field conditions was tested. The results of this test were explained with the exploration of the relationship between invertebrate diversity and the microbial community composition. Finally, the biotic and abiotic factors witch control the microbial denitrification activity were investigated.

2. Materials and methods

2.1. Study site and sampling strategy

The study site is a riparian zone of 50 ha located within a meander of the Garonne river close to the village of Monbequi, 50 km north of Toulouse city in the Southwest of France (43°53′30″N; 1°12′25″E) (Fig. 1). Water level and water discharge were recorded by a gauging station, located 2 km upstream of the study site, at