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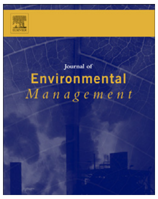

Research article

Forest cover correlates with good biological water quality. Insights from a regional study (Wallonia, Belgium)

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ABSTRACT

Forested catchments are generally assumed to provide higher quality water in opposition to agricultural and urban catchments. However, this should be tested in various ecological contexts and through the study of multiple variables describing water quality. Indeed, interactions between ecological variables, multiple land use and land cover (LULC) types, and water quality variables render the relationship between forest cover and water quality highly complex. Furthermore, the question of the scale at which land use within stream catchments most influences stream water quality and ecosystem health remains only partially answered. This paper quantifies, at the regional scale and across five natural ecoregions of Wallonia (Belgium), the forest cover effect on biological water quality indices (based on diatoms and macroinvertebrates) at the riparian and catchment scales. Main results show that forest cover – considered alone – explains around one third of the biological water quality at the regional scale and from 15 to 70% depending on the ecoregion studied. Forest cover is systematically positively correlated with higher biological water quality. When removing spatial, local morphological variations, or population density effect, forest cover still accounts for over 10% of the total biological water quality variation. Partitioning variance shows that physico-chemical water quality is one of the main drivers of biological water quality and that anthropogenic pressures often explain an important part of it (shared or not with forest cover). The proportion of forest cover in each catchment at the regional scale and across all ecoregions but the Loam region is more positively correlated with high water quality than when considering the proportion of forest cover in the riparian zones only. This suggests that catchment-wide impacts and *a fortiori* catchment-wide protection measures are the main drivers of river ecological water quality. However, distinctive results from the agricultural and highly human impacted Loam region show that riparian forests are positively linked to water quality and should therefore be preserved.

1. Introduction

1.1. *Freshwaters and water quality*

Despite its crucial importance for the life of all beings (Haddadin, 2001; UN-Water, 2014), water and freshwater systems in particular are directly threatened by human activities (Loh et al., 2005; Meybeck, 2003; Millennium Ecosystem Assessment, 2005; Vörösmarty et al., 2010). In response to global degradation of ecosystems and their services, water quality management is at the core of policies such as the US Clean Water Act (1972) and the European Water Framework Directive (Directive, 2000/60/CE) (European Commission, 2000). Water quality can be described by a huge number of variables which can broadly be classified into physical, chemical and biological categories (Boyd, 2015; Chapman, 1992). These groups of variables provide complementary information and

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are inter-related, but biological indicators have the advantage to assimilate long-term disturbance and stress trends in freshwater ecosystems while avoiding the complexity, costliness and high temporal variability linked to physico-chemical measurements (Allan, 2004; Bere and Tundisi, 2010; Giorgio et al., 2016). Among biological indicators, benthic macroinvertebrates are often used to determine the water quality notably because of their sensitivity to pollution, limited mobility, rapid response to external disturbance and dependence on the land environment around the stream (Mahler and Barber, 2017; Sharma and Rawat, 2009). Phytobenthos – of which diatoms are the main component – present a reduced mobility, a short generation time and a rapid response to environmental changes. Diatoms are tightly linked to physico-chemical changes. Being preserved in sediments, they are a good indicator of eutrophication, acidification and organic pollution (Delgado et al., 2012; Lobo et al., 2016). Therefore integrating information from diatoms and macroinvertebrates allows a better assessment of stream ecological integrity by bringing nuances in the responses to multiple pressures (Giorgio et al., 2016; Hering et al., 2006; Marzin et al., 2012; Soininen and Könönen, 2004).

1.2. *Land use and land cover impact on water quality*

Land use and Land cover (LULC) are key landscape elements affecting water quality through their impact on non-point source pollution resulting from complex run-off and landscape interactions. Giri and Qiu (2016) stress the importance of assessing the relationship between LULC and water quality. According to them, improving the understanding of these relationships can help managing water quality in unmonitored watersheds but also providing recommendations to watershed managers and policymakers in the land planning decision process. Related to catchment and riparian degradation in particular, the question addressing the scale at which land use within stream catchments most influences stream water quality and ecosystem health remains only partially answered (Allan, 2004; Johnson et al., 1997; Sheldon et al., 2012; Sponseller et al., 2001). Several studies suggest that prevailing (Kail et al., 2012; Riva-Murray et al., 2002) and past (Harding et al., 1998) LULC characteristics of the whole stream catchments affect surface water quality. Other studies emphasise the impact of riparian LULC on water quality or stream habitat (Dosskey et al., 2010; Jackson et al., 2015). Finally, some studies compare scales of influence (i.e. catchment scale versus riparian scale), obtaining nuanced results on the land use effect on stream water quality according notably to the type of biological indicators and the ecological context of the sampling sites (Kosuth et al., 2010; Marzin et al., 2012, 2012; Sponseller et al., 2001). These studies show that assessing both scales of influence bring deeper insights when studying LULC impact on water quality (Vondracek et al., 2005).

Regarding the type of LULC, negative impact of agricultural intensification is reported in the literature (Stoate et al., 2001) mainly explained by the following processes: increased sedimentation, modified hydrological regimes, loss of high quality habitat, contamination from pesticides, increases in surface water nutriments (mainly N and P) (Allan, 2004; Herringshaw et al., 2011; Mahler and Barber, 2017). Urban land use – despite covering small areas – and urban intensification are also reported to negatively affect water quality (Kosuth et al., 2010; Riva-Murray et al., 2002). Forest, on the contrary, is usually associated with water containing less sediments and fewer nutriments (Neary et al., 2009; TEEB, 2010). This is mainly true for undisturbed forest and most of the time. Indeed, this must be nuanced with regard to sediments and nutrients leaching under certain events such as wildfires (Pacheco et al., 2015; Santos et al., 2015; Shakesby, 2011) or clearcuts (Borrelli et al., 2017). Some studies showed a positive impact of forest cover on instream water quality (Kosuth et al., 2010; Tong and Chen, 2002), on fish, macroinvertebrate and algal biomass (Stephenson and Morin, 2009). Specifically, forested riparian buffer zones are believed to have a positive impact on water quality through notably the reduction of the sediment load and nutrient concentrations in water (Dosskey et al., 2010; Fernandes et al., 2014; Naiman et al., 2010; Scarsbrook and Halliday, 1999). However, this is nuanced by studies explicitly assessing the effect of riparian forest compared to forest proportion in the whole catchment. For example, Stephenson and Morin (2009), in their study of the partial effects of forest cover on biomass and community structure metrics of algae, invertebrates and fish, never detected a significant partial effect of forest cover at the riparian scale. In conclusion, regarding LULC impact on biological water quality, literature shows general trends, especially opposing agricultural and urban LULC – associated with a negative effect on water quality – and forested land – broadly positively related with water quality, see e.g. Ding et al. (2013), Kosuth et al. (2010) or Theodoropoulos et al. (2015). However, issues of scales of influence and nuances brought by the type of studied biological indicators and the ecological context of study sites remain to be further explored. Also, to our knowledge and as observed by Tanaka et al. (2016), only few studies integrate information from macroinvertebrates, diatoms and physico-chemical water quality variables to get a broader picture of the forest cover impact on water quality. These questions are of major concern for land managers in enhancing or maintaining good water quality and in particular regarding environmental land use conflicts that have been reported to contribute to water quality degradation (Pacheco and Sanches Fernandes, 2016) and biodiversity decline (Valle Junior et al., 2015).

1.3. *Objectives*

The main objective of this paper is, at the regional scale and across five natural ecoregions, to quantify the forest cover effect on biological water quality indices at the riparian and catchment scales. This objective is addressed through: (i) the comparison of this link‘s power at riparian and catchment scales, (ii) the assessment of this link while controlling for spatial, local morphology and population pressure variations, (iii) the quantification of independent and shared effects between forest cover and the physico-chemical water quality, anthropogenic pressures (agriculture and population density) and local morphology.

2. Material and methods

2.1. *Study area*

The study area is the southern region of Belgium (Wallonia) covering 16 898 km^2 (ca. 55% of Belgium's area, see Fig. 1 A). We work on 173 headwaters stations located on the publically managed river network where biological and physico-chemical water quality data are monitored by the Walloon Public Service [WPS (SPW - DGO3, n.d.), Fig. 1 B). These stations monitor headwater waterbodies and have non-overlapping upstream catchments (Fig. 1 B &D). Fig. 1 D shows forest cover distribution in waterbodies.

Wallonia presents relatively contrasted landscapes and can be divided into five natural ecoregions (Fig. 1 A and Table S1 in supplementary materials). Noirfalise (1988) delineated these ecoregions according to pedological, botanical and agro-ecological criteria. Main ecological differences are found across an elevation gradient from the Loam to the Ardenne ecoregion. The Loam and the Condroz ecoregions located in lower elevation areas (Fig. 1 C)