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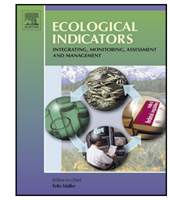

How does forest cover impact water flows and ecosystem services? Insights from "real-life" catchments in Wallonia (Belgium)

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ABSTRACT

While planet boundaries are being crossed and ecosystems degraded, the Ecosystem Service (ES) concept represents a potential decision-making tool for improved natural resources management. The main aim of this paper is to assess the impact of forest cover on water related ES in Wallonia (Belgium) in terms of quantity and timing. We developed an approach based on easily accessible data, monitored in several countries and using straightforward statistical methods. This led us to study ES at "real-life" catchments scale: 22 catchments – from 30 to 250 km^2– with mixed land covers were studied. We approached the water supply and flood protection services through 5 indicators extracted from 10 hydrological years (2005–2014) discharge data series. These were computed annually and seasonally (vegetation period from March to September and "non-vegetation" period the rest of the year). The water supply was assessed through the specific volume *Vs*, the baseflow index *BFI* and the specific discharge exceeded 95% of the time $Q_{95}s$ whereas the flood protection service was approached through the specific discharge exceeded 5% of the time $Q_{05}s$ and the flashiness index *FI*. Our study gives two main insights. First, statistical analyses show that forest cover negatively impact water supply when studying annual and "non-vegetation" period flows in general (*Vs*) but positively when studying low flows ($Q_{95}s$). Regarding flood protection a slightly negative impact of forest cover on high flows ($Q_{05}s$) was highlighted in the "non-vegetation" period. Results also show a negative impact of forests annually and in the vegetation period on the flashy behaviour of the catchment thus a positive impact on the flood protection ES. The "year" effect is overall highly significant testifying the importance of climatic factors. Rainfall is often significant and can be considered as a main driver of these ES. Secondly, analyzing the quality of the models produced and the results overall we assume that other variables characterizing the catchments such as topography or soil types do play a significant role in the delivery of these ES. This questions the use of land cover proxies in assessing and mapping of hydrological ES at a complex landscape scale. We thus recommend further research to keep improving land cover proxies if they are used.

1. Introduction

Ecosystem Services (ES) can be defined as the benefit people obtain from nature (MEA, 2003). In the present context of the overtaking of planet boundaries (Rockström et al., 2009; Steffen et al., 2015) and the degradation of ecosystems and their services (Costanza et al., 2014; MEA, 2005) the ES concept can raise awareness about the importance of preserving ecosystems and biodiversity (MEA, 2005). Haines-Young and Potschin (2010) suggest a representation of this concept at the interface of ecosystems and human well-being in the form of a 'cascade' model. This framework is based on the idea that a sort of 'production chain' starts from the ecosystems biophysical structures and processes which lead to functions that create services providing benefits and socio-economic values to human beings. Human society retroacts on ecosystems through pressures but also restoration actions. Following this view, the ES concept has the potential to be a decision-making tool for improved natural resources management (de Groot et al., 2010). To achieve this potential there is a need for quantifying accurately every component of the ES 'cascade' through suitable indicators (Braat and de Groot, 2012; Müller and Burkhard, 2012; Seppelt et al., 2011). In order to do so, one of

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the main challenges is to deal with the high complexity of the ecosystems functioning and the complex dynamics characterizing the links between processes – functions and services at different temporal and spatial scales (Bastian et al., 2012; Carvalho-Santos et al., 2014; de Groot et al., 2010; Swetnam et al., 2011; Turner and Daily, 2008; Villa et al., 2014). Assessing ES to support land planning decision-making remains thus a challenge due to multiple sources of uncertainty such as data scarcity, functional knowledge gaps, demand variability, etc. (Jacobs et al., 2013). In practice however, and even if research is done to improve them, land cover based proxies are used in local or national ES assessments (Albert et al., 2015; Koschke et al., 2012; UK NEA, 2014). Arguably, policies such as the EU biodiversity strategy 2020 targets (European Commission, 2011) requiring member states to assess and map ecosystems and their services provide an incentive for using such techniques. Indeed, these methods, and in particular one commonly used known as the 'matrix model' (Burkhard et al., 2010), allow for straightforward ES mapping. However, one may question the validity of these maps as uncertainties are high and variable, in particular in terms of the expected direct and univocal links between land cover and ES provided.

Among ES being mapped, those related to water are of prime importance. Water is indeed the most essential component for the life of all beings, it is at the core of sustainable development and is of major importance to healthy ecosystems, socio-economic development and to the survival of human beings (Haddadin, 2001; UN Water, 2014). Land cover and in particular forests have an impact on hydrological services through their impact on water cycle flows [see Fig. 1 for an adaptation of the ES 'cascade' model to hydrological services provision by forests by Carvalho-Santos et al. (2014)]. As shown on Fig. 1, these services are delivered according to three dimensions: quantity (i.e. total water yield), timing (i.e. seasonal distribution of flows) and quality (i.e. removal and breakdown of pollutants and trapping of sediments) (Brauman et al., 2007). Forests are seen as the main ecosystems interacting with water, due to their height, dense and irregular crown canopy resulting in a high leaf area index and lower albedo, architecture of their spread root system widely prospecting soil horizons, wide horizontal distribution and vertical coverage (Calder, 2002; Salemi et al., 2012; Zhang et al., 2001). By explicitly listing operating processes and functions, Fig. 1 highlights the complexity of water-related ES assessments as different functions may impact the same hydrological service in opposite ways.

Despite the fact that many studies were conducted to measure the impact of forest cover on water cycle components (Brown et al., 2005; Farley et al., 2005; Robinson et al., 2003), relationships between water flows (quantity and timing) and forests have been controversial since Pliny the Elder (Andréassian, 2004). Nevertheless, the associated assumed effects on processes are a high evapotranspiration, the promotion of infiltration compared to surface runoff or rapid drainage (at least on low slopes), increase of soil moisture content, recharge of groundwater and the gradual release of water (Aussenac, 1996; Bruijnzeel, 2004; Calder, 2002; Office National des Forêts, 1999). Many of these studies are paired-catchment studies [see Bosch and Hewlett (1982) for a review] where catchment size is for the vast majority less than 2 km^2 limited by the fact that these experiments require controlling most of the factors impacting water flows while having pure and distinct land covers between catchments. These studies report an increase of annual water yield when forest cover is replaced by lower vegetation cover. At a global scale, which is out of the scope of this study, authors argue that forest cover raises the precipitation events likelihood and increases water yield by contributing to the availability of atmospheric moisture vapor and the transport across continents (see Ellison et al. (2012) for a "forest-water yield" debate review). In this context of inextricable link between forest and water, many authors acknowledge the fact that more research is needed to study the impact of forest cover on water fluxes at different latitudes, in different contexts (e.g. different soil types) and at different spatial and temporal scales (Brown et al., 2013; Cosandey et al., 2005; Garmendia et al., 2012; Price, 2011). Regarding hydrological services assessment and the impact of land cover on these ES, the 'catchment' appears to be a relevant spatial unit of study because of its integrative character (Granier, 2007) and its reality as component of the landscape. Numerous studies focus on measuring precisely the water cycle fluxes at the stand scale but can hardly be extrapolated (Oishi et al., 2008; Schume et al., 2003; Schwärzel et al., 2009; Unsworth et al., 2004; Vincke et al., 2005; Wilson et al., 2001). Carvalho-Santos et al. (2015) assess and map hydrological services at the catchment scale through physically based modelling, highlighting the fact that daily rainfall – runoff models were stated to be really robust methods by Crossman et al. (2013) but are not often used in the ES sphere. Indeed these require vast amount of data, are complex and time consuming to calibrate and are often applied on one single catchment. Finally global changes push scientists to claim for renewing studies linking hydrological processes and land cover. Global changes which affect water quality and quantity (climate change, land use change and invasive species) question the assumption that studies from the last decades can be used to face future conditions (Bates et al., 2008; Huntington, 2010; Vose et al., 2011).

Regarding this context, the main aim of this paper is to assess the impact of forest cover on water related ES (i.e. water supply and water damage mitigation) in Wallonia (Belgium) in terms of quantity (i.e. water yield) and timing (i.e. seasonal distribution of flows). In order to do so and to ensure replicability, we developed an approach (i) based on easily accessible data, monitored in many countries, (ii) using robust but simple and straightforward statistical methods and (iii) with main processes run in open source statistical software. This will lead us to study ES at "real-life" catchments scale ranging from 30 to 250 km^2 with mixed land covers with a focus on forest cover. In doing so, we also aim to provide information to the debate of using land cover proxies versus more advanced methodologies to derive indicators used to map water related services at a complex landscape scale but meaningful in land planning processes.

This document is structured as follow: first we present the study area in Section 2; then we describe our approach globally and then detailing the hydrological (i.e. extraction of hydrological indicators) and physical description of the studied catchments, the rainfall over the period of study computation, and the study of the impact of forest cover on hydrological services in itself. Third, we present the results and finally discuss them in Section 5, highlighting key findings but also discussing strengths and limitations of our study and presenting research perspectives.

2. Study area

The study area corresponds to the "Ardenne" region (4°7′42″ to 6°24′40″ E, 42°27′00″ to 50°41′00″ N in WGS84 geographic coordinate system; Fig. 2). The Ardenne is an ecologically, geologically and lithologically relatively homogeneous region located to the South-East of Wallonia (South of Belgium). It covers 5711 km^2 corresponding to 33% of the Walloon region and 19% of Belgium. This high plateau dissected by several rivers constitutes the western protruding end of the "Rhine great schistose massif" (see Noirfalise (1988) for a more detailed description). This region was chosen for several reasons. The main one is that focusing on this study area allows to best control the geological factor, which plays an important role in the spatial distribution of the water (Grandry et al., 2013). The Ardenne is entirely located on the same aquifer: "the