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Eurasian beaver activity increases water storage, attenuates flow and mitigates diffuse pollution from intensively-managed grasslands

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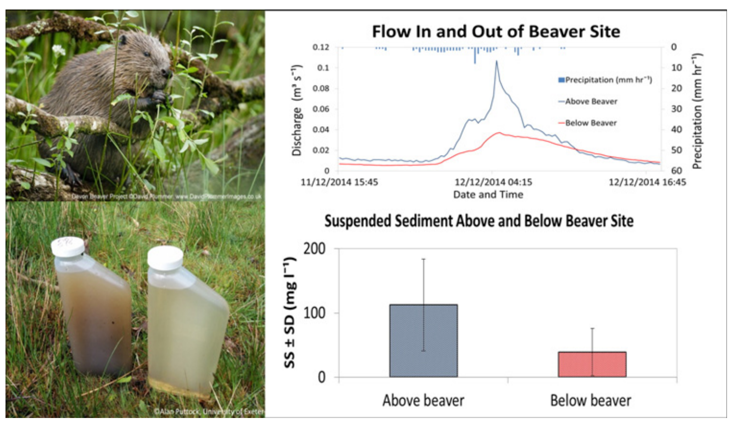
HIGHLIGHTS

- Beavers in wooded site, on first order tributary draining from agricultural land.
- Beaver activity has resulted in major changes to ecosystem structure at the site.
- Beaver activity increased water storage within site and attenuated flow.
- Reduced sediment, N and P, but more DOC in water leaving site.
- Important implications for nature based solutions to catchment management issues.

GRAPHICAL ABSTRACT



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ABSTRACT

Beavers are the archetypal keystone species, which can profoundly alter ecosystem structure and function through their ecosystem engineering activity, most notably the building of dams. This can have a major impact upon water resource management, flow regimes and water quality. Previous research has predominantly focused on the activities of North American beaver (*Castor canadensis*) located in very different environments, to the intensive lowland agricultural landscapes of the United Kingdom and elsewhere in Europe.

Two Eurasian beavers (*Castor fiber*) were introduced to a wooded site, situated on a first order tributary, draining from intensively managed grassland. The site was monitored to understand impacts upon water storage, flow regimes and water quality. Results indicated that beaver activity, primarily via the creation of 13 dams, has increased water storage within the site (holding ca. 1000 m^3 in beaver ponds) and beavers were likely to have had a significant flow attenuation impact, as determined from peak discharges (mean 30 ± 19% reduction), total discharges (mean 34 ± 9% reduction) and peak rainfall to peak discharge lag times (mean 29 ± 21% increase) during storm events. Event monitoring of water entering and leaving the site showed lower concentrations of suspended sediment, nitrogen and phosphate leaving the site (e.g. for suspended sediment; average entering site: 112 ± 72 mg l^{-1}, average leaving site: 39 ± 37 mg l^{-1}). Combined with attenuated flows, this resulted in lower diffuse pollutant loads in water downstream. Conversely, dissolved organic carbon concentrations and loads downstream were higher. These observed changes are argued to be directly attributable to beaver activity at the site which has created a diverse wetland environment, reducing downstream hydrological connectivity.

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Results have important implications for beaver reintroduction programs which may provide nature based solutions to the catchment-scale water resource management issues that are faced in agricultural landscapes.

1. Introduction

Beavers are widely referred to as ecosystem engineers (Hartman and Tornlov, 2006; Wright et al., 2002) as they modify river systems and surrounding riparian areas to create suitable habitat for themselves which subsequently benefits a wide range of other species. Beavers are also termed keystone species, having a disproportionately large impact upon fluvial ecosystems, relative to their abundance (McKinstry et al., 2001). The biggest hydrological impact of beavers results from their dam building ability and the consequent impoundment of large volumes of water in ponds (Butler and Malanson, 2005; Hood and Bayley, 2008). Dam and pond features can alter hydrological regimes, both locally and downstream (Burchsted and Daniels, 2014; Polvi and Wohl, 2012) whilst beavers also create bank side burrows, lodges, tunnels and canals to facilitate access to foraging areas (Gurnell, 1998). All of the aforementioned activities increase the structural heterogeneity of their environment (Rolauffs et al., 2001) having not only hydrological and geomorphological impacts, but creating a diverse range of habitats with significant (positive) biodiversity implications (Rosell et al., 2005).

Eurasian beavers (*Castor fiber*) were previously common across Europe including the UK. However, populations were greatly reduced by human activities, particularly over-hunting (Collen and Gibson, 2000), being effectively absent from the United Kingdom by the 16th Century (Conroy and Kitchener, 1996). Stimulated by the EC Habitats Directive, reintroduction programs have seen the re-establishment of Eurasian beaver colonies across northwest Europe (de Visscher et al., 2014), including Scotland (Jones and Campbell-Palmer, 2014). However, in England, there is currently only one known wild population, subject to a rigorous five year monitoring program (Natural England, 2015).

In addition to reported biodiversity benefits (Correll et al., 2000), it has been suggested that beavers could play a key role in the provision of environmental ecosystem services (EES) and as a nature based solution for the management of our river catchments (Brazier et al., 2016). Beaver dams can reduce channel flow velocity (Burchsted and Daniels, 2014) and attenuate storm event hydrographs (Nyssen et al., 2011) with positive impacts on flood risk alleviation (Collen and Gibson, 2000). During drier periods, increased water storage capacity (Hammerson, 1994) can help to maintain base flows, alleviating the risk of droughts downstream (Leidholt-Bruner et al., 1992). The altered flow regimes and water storage capacity also modify nutrient and chemical cycling in freshwater systems. Pond-dam complexes often act as sediment traps, storing fine sediments and nutrients which alter in-pond nutrient cycling (Klotz, 2007) supporting a positive effect on downstream water quality (Naiman et al., 1986).

Knowledge of how beavers impact on the environment and the role they may play in the provision of ecosystem services is vital to inform policy regarding both the reintroduction of *C. fiber* in the United Kingdom and the wider management of these animals in intensively-managed agricultural catchments worldwide (Burchsted and Daniels, 2014). However, much of the available research into the impacts of beavers focuses on the North American beaver (*C. Canadensis*) rather than the Eurasian beaver (*C. fiber*). Whilst there are behavioural similarities between the two species (Rosell et al., 2005), differences, particularly in the European landscape; with intensive agriculture and dense networks of infrastructure mean that their impacts cannot be presumed directly comparable with North American studies (Gurnell, 1998).

Therefore, to quantify the impacts of reintroducing the Eurasian beaver upon water storage, water quality and flow regimes this study addresses the following hypotheses:

H1. Beaver constructed features including dams, canals and burrows/lodges, significantly increase water storage within the landscape.

H2. Beaver dams significantly alter flow regimes resulting in attenuated storm flows.

H3. Beaver ponds act as sinks for diffuse pollutants, significantly improving water quality downstream.

2. Methods

2.1. Study site

Research was undertaken at the Devon Beaver Project controlled reintroduction site in Devon, South West England (DWT, 2013). The site is situated on a small first order stream in the headwaters of the River Tamar catchment, which is the only flow input to the site. Drainage ditches around the perimeter hydrologically isolate the site, ensuring that flow in can confidently be compared with flow out (also via one channel only). The site experiences a temperate climate with a mean annual temperature of 14 °C and mean annual rainfall of 918 mm (Met Office, 2015). In March 2011, a pair of Eurasian beavers was introduced to a 3 ha enclosure, dominated by mature willow and birch woodland, in addition to gorse scrub. Upstream, the site has a 20 ha contributing area dominated by grazed grassland. As illustrated in Fig. 1, beaver activity at the site has created a complex wetland environment, dominated by ponds, dams and an extensive canal network (DWT, 2013).

2.2. Experimental design, data collection and data analysis

2.2.1. Site structure and water storage

To quantify the spatial extent of surface water across this complex site, a combination of walkover, conventional ground-based surveys and unmanned aerial vehicle (UAV) surveys were undertaken. The walkover survey was undertaken prior to beaver reintroduction in 2010 as this was the best approach to survey the very densely vegetated site. The ground-based surveys utilised a Leica Total Station (TCR1205) to map the surface area of each pond and the average depth of each pond at the same time every year (March) from 2013, when seasonal reductions in vegetation cover allowed deployment of such hardware. Whilst being a highly complex site displaying a rapid and ongoing change, these data permitted an estimate of annual changes in both surface areas and pond volumes (area multiplied by mean of surveyed depth at 5–10 positons within the pond) to be made from 2013 to 2016. The UAV surveys were undertaken during the winters of 2014 and 2016 (See Puttock et al., 2015 for further details), to provide high-resolution ortho-mosaic images of the site (see Fig. 2). Winter flights were undertaken to minimise occlusion of the terrain and underlying pond structure by the deciduous vegetation canopy. Each pond (Fig. 2) was equipped with a dipwell at its deepest point to monitor water level from October 2014 onwards. Prior to these manual measurements of pond depths and bathymetry were made in parallel with annual total station surveys. Dipwells were instrumented with HOBO U20L pressure sensors (Onset, Bourne USA) with a 0–4 m range and 0.1% measurement accuracy (i.e. 4 mm measurement increments), recording data on a 15 min time step. Water level was calculated relative to atmospheric pressure recorded on site using HOBOware Pro 10.8 (Onset Bourne USA).