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Influence of stormflow and baseflow phosphorus pressures on stream ecology in agricultural catchments

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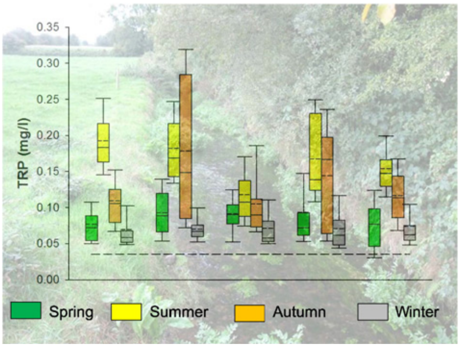
HIGHLIGHTS

- The magnitude and ecological impacts of stormflow and baseflow P pressures were investigated.
- Phosphorus pressures (in terms of concentration) were generally greater during baseflow than during stormflow.
- Baseflow P pressures appeared to impact stream diatom ecology.
- A pilot exercise indicated human and ruminant faecal effluents were contributing to baseflow P pressures.
- Improving river ecological quality likely requires a reduction in point sources.

GRAPHICAL ABSTRACT



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ABSTRACT

Stormflow and baseflow phosphorus (P) concentrations and loads in rivers may exert different ecological pressures during different seasons. These pressures and subsequent impacts are important to disentangle in order to target and monitor the effectiveness of mitigation measures. This study investigated the influence of stormflow and baseflow P pressures on stream ecology in six contrasting agricultural catchments. A five-year high resolution dataset was used consisting of stream discharge, P chemistry, macroinvertebrate and diatom ecology, supported with microbial source tracking and turbidity data.

Total reactive P (TRP) loads delivered during baseflows were low (1–7% of annual loads), but TRP concentrations frequently exceeded the environmental quality standard (EQS) of 0.035 mg L^{-1} during these flows (32–100% of the time in five catchments). A pilot microbial source tracking exercise in one catchment indicated that both human and ruminant faecal effluents were contributing to these baseflow P pressures but were diluted at higher flows. Seasonally, TRP concentrations tended to be highest during summer due to these baseflow P pressures and corresponded well with declines in diatom quality during this time ($R^2 = 0.79$). Diatoms tended to recover by

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Diatoms
Macroinvertebrates

late spring when storm P pressures were most prevalent and there was a poor relationship between antecedent TRP concentrations and diatom quality in spring ($R^2 = 0.23$). Seasonal variations were less apparent in the macroinvertebrate indices; however, there was a good relationship between antecedent TRP concentrations and macroinvertebrate quality during spring ($R^2 = 0.51$) and summer ($R^2 = 0.52$).

Reducing summer point source discharges may be the quickest way to improve ecological river quality, particularly diatom quality in these and similar catchments. Aligning estimates of P sources with ecological impacts and identifying ecological signals which can be attributed to storm P pressures are important next steps for successful management of agricultural catchments at these scales.

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1. Introduction

Eutrophication of rivers is a continuing international concern and phosphorus (P) can sometimes be a key limiting nutrient in many of these water-bodies (McDowell et al., 2009; O'Neil et al., 2012; Dodds and Smith, 2016). Management of eutrophication and other water resource issues in the European Union (EU) is addressed by the Water Framework Directive (WFD) (OJEC, 2000) which is reviewed in six year cycles. This legislative framework requires all EU member states to achieve at least 'good' and non-deteriorating status in all water-bodies. For rivers this includes good ecological and good chemical status but greater emphasis is placed on the former (Borja and Elliott, 2007). The WFD requires that River Basin Management Plans and Programmes of Measures (PoM) are implemented at catchment scales, which offer a natural unit for integrated, ecosystem-based water management.

The major sources of P to rivers include those from human population centres (waste water effluent) and intensive agriculture (organic and inorganic nutrients in runoff), with the former considered to be primarily a point source issue and the latter a more diffuse phenomenon (Bowes et al., 2005). For agriculture, mitigation measures are generally targeted at a combination of residual (e.g. soil P stores where P is also included in the territorial regulations), incidental (e.g. recently applied fertilisers) and point (farmyards and facilities) sources of nutrients (DEFRA, 2004; Swedish Board of Agriculture, 2009; SI 31, 2014). These PoMs under the WFD are expected to contribute to the achievement of good ecological status. However, the results of the first round of River Basin Management Plans show that more than half of Europe's surface water-bodies are in less than good ecological status (European Environment Agency, 2012). Furthermore, national environmental quality standards (EQS) for riverine P concentrations (e.g. 0.035 mg L^{-1} unfiltered molybdate reactive P in Ireland) are still exceeded in many parts of Europe (European Environment Agency, 2010). With the second round of River Basin Management Plans under development, the lack of clear improvements may prompt the introduction of additional mitigation measures. However, the risk of increasing economic burdens on farming communities (or increasing support) will be an important consideration to ensure that existing measures and expectations of improvement (and any further measures) are based on robust supporting science.

Knowledge of the links between agricultural P transfers and ecological quality is improving and an important emerging issue in the scientific literature is the discontinuity between the timing of greatest P transfers from land and the timing of greatest eutrophication risk (Jarvie et al., 2013; Stamm et al., 2013; Withers et al., 2014). The majority of P losses from agriculture generally occur during winter storms, whereas the ecological quality of rivers can be linked to P concentration pressures during periods of ecological sensitivity (spring and summer low river flows; Mainstone and Parr, 2002; Hilton et al., 2006). However, there is high uncertainty regarding the source, magnitude and ecological impacts of baseflow P concentrations in agricultural catchments during the summer season. In groundwater-fed agricultural catchments diffuse P sources can contribute to elevated P concentrations in baseflows owing to slow-flow subsurface pathways linking groundwater to surface water during very long recession periods following storm events (Mellander et al., 2016). Bed sediments may also provide a direct source of P to the water-column during baseflows. However, studies have shown that the significance of the pool of sediment-associated P for soluble P release and nuisance algal proliferation is low (Jarvie et al., 2005) and these sediments may primarily act as chemical sinks for water-column P (Shore et al., 2016). Recent studies have shown that rural point sources can maintain rivers in a eutrophic state in the long durations between storms and especially during dry periods (see Withers et al., 2014).

The literature suggests these point sources of P (and other pollutants) are mostly related to human and animal faecal effluents from municipal waste water outfalls, domestic septic systems and farmyards (Jarvie et al., 2006; Withers et al., 2014; Old et al., 2012). The use of specific tools to detect faecal pollution in rivers and other water bodies is an emerging science (Fenech et al., 2012). Enumerating *Escherichia coli* (*E. coli*) is a standard method for the indirect detection of faecal matter but this bacteria can also be present as part of normal soil flora (Winfield and Groisman, 2003). Microbial source tracking (MST) encompasses several techniques to detect bacteria in water. The most common MST method incorporates molecular techniques to detect host-associated bacteria such as the faecal non-coliform group, *Bacteroidales* (Ahmed et al., 2008; Bernhard and Field, 2000; Kildare et al., 2007). As these strict anaerobes display a high level of association with specific hosts they can be used to approximately distinguish, between human and, for example, agricultural ruminant and other animal faecal pollution (Bernhard and Field, 2000; Harwood et al., 2014; Kildare et al., 2007; Schriewer et al., 2010).

While smaller catchment rivers (<10 km^2) are not fully considered in WFD monitoring, and some rural point source influences may dissapate at larger scales (Gill and Mockler, 2016), there is growing recognition of their ecological importance as nurseries and refugia (Biggs et al., 2016). Accordingly, there needs to be more robust scientific evidence of the ecological impacts of the different P sources delivered from agricultural catchments. The aim of this study was to contribute to this evidence base by combining high resolution nutrient monitoring and microbial source tracking with concurrent ecological quality data in rivers over a five year period from 2010 to 2015. This information is critical for assessing if and how agricultural measures can contribute to the achievement of good ecological status in rivers as required by the WFD.

The objectives were to:

1. Characterise the magnitude of stormflow and baseflow P pressures in agricultural catchments (in terms of their effect on stream P concentrations).
2. Investigate the effects of these pressures on P concentrations seasonally.
3. Investigate concurrent impacts on stream ecology.
4. In a pilot study in one catchment, use microbial source tracking (MST) methods, including host-associated molecular markers, to associate the origin of certain P sources with different sources of faecal pollution.

It was hypothesised that ecological quality declined over the summer period due in part to elevated baseflow P concentrations, which could be linked to point source pressures. The study focused on

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