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Forty-year trends in the flux and concentration of phosphorus in British rivers

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ABSTRACT

Given the importance of phosphorus (P) in the eutrophication of natural waters, this study considered the long-term time series of total phosphorus (TP) and total reactive phosphorus (TRP) in British rivers from 1974 to 2012. The approach included not only trend analysis of fluxes and concentrations but also change point analysis. TP and TRP concentrations and fluxes in British rivers have declined since the mid-1980s. Over the last decade of the record the majority of individual sites did show significant downward trends in TP and TRP concentrations but, in 28% of cases for TRP concentration and 14% of cases for TP concentration, the decadal trend was a significant increase. Out of 230 sites, 136 showed a significant step decrease in TRP concentration; no sites showed a significant step increase. The modal year for the step changes for both TRP concentration and flux was 1997. Step changes are likely associated with improvements made at sewage treatment works to comply with the Urban Waste Water Treatment Directive (91/271/EEC). The decrease in TRP concentration due to the step change were in the range of 0.68% and 89% with a geometric mean of 22%, with the rest of the decrease accounted by long-term, persistent downward trend.

1. Introduction

Phosphorus (P) is an essential nutrient for the metabolic functioning of all forms of life, it plays a crucial role in controlling productivity in both terrestrial and aquatic ecosystems (Correll, 1998; Caraco, 2009). As an essential element for crop production phosphorus is vital for production of our food and bioresources; however inefficiencies in P use management and losses of P from agriculture and waste streams are a major source of impairments to water quality and security (Jarvie et al., 2015).

Phosphorus from point and diffuse sources are a major contributor to eutrophication and impairment of surface water quality at the global scale (Hecky and Kilham, 1988; Mainstone and Parr, 2002). Contributions of these sources differ depending on catchment characteristics such as population and land use (Smith et al., 1999). Point sources usually contain a high proportion of soluble and more biologically available phosphorus (Jarvie et al., 2006) while diffuse sources are generally in particulate forms (P sorbed to soil particles) (EA, 2015). The contributions of agricultural diffuse P loadings (e.g. farmyard runoff, pig slurry, erosion from fields) can be substantially higher than from urban sources such as sewage treatment works (STW) effluent (Comber et al., 2013; Naden et al., 2016), road runoff and septic effluent (Edwards and Withers, 2008). Equally, in some UK catchments STWs have been reported as the dominant source of P, eg. Iversen et al. (1997) and Parr and Mainstone (1997), but spatial budgets for P flux are generally lacking. Worrall et al. (2016) in their geographically weighted regression analysis of TRP and TP fluxes across the UK found significant roles for urban land use alongside and in comparison to significant roles for a range of soil types and agricultural land uses (Fig. 1). For the flux of TP the most important source was urban land use which was found to be exporting 1.65 tonnes P/km^2 of urban land use (Worrall et al., 2016), but that study could not detail what were the specific sources were within urban land use.

A proportion of P loadings from diffuse and point sources within a catchment can accumulate in soils and aquatic sediments along transport pathways; this accumulated P can be remobilized or recycled, acting as a continuing source of P transport with residence times of years to decades (Sharpley et al., 2013). This source of P has been referred to as "legacy-phosphorus" and can cause

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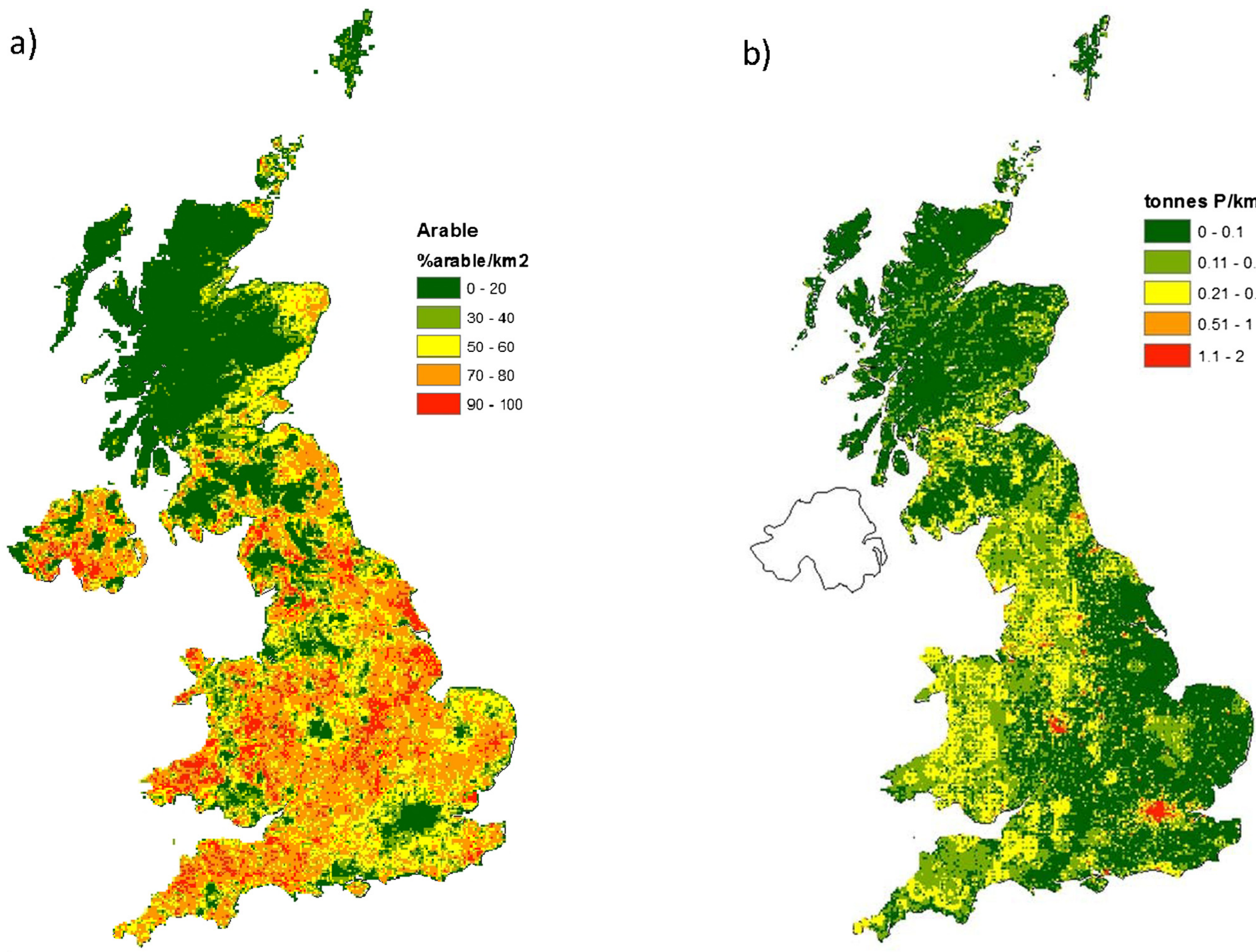

Fig. 1. Comparison of: a) land use (given as percentage arable land use per km^2); and b) TP flux export per km^2 for Great Britain from Worrall et al. (2016).

considerable delay in recovery of water quality impairment (Jarvie et al., 2013a; May et al., 2012; Powers et al., 2016).

The European Commission's Urban Waste Water Treatment Directive (UWWTD – European Commission, 1991: 91/271/EEC) was brought into restrict the pollution of natural waters by wastewater including limiting urban water as a source of P. As a result of the UWWTD numerous actions have been taken to reduce direct phosphorus inputs into rivers from sewage treatment works (STW), most notably tertiary treatment of effluent (Defra, 2002; Neal et al., 2010a).

The UK lowlands have large population densities and thus rivers are highly vulnerable to P-sourced eutrophication (Neal et al., 2010a). Mainstone and Parr (2002) have pointed out that catchments might be more sensitive to point sources such as STWs as they supply a similar flux of P even at low flows. Indeed, based upon observations from 54 monitoring sites, Jarvie et al. (2006) showed that even in rural areas with highly intensive agricultural P loadings, point P sources (wastewater) can represent a greater risk for river eutrophication linked to the dominant contributions of effluent P under baseflow conditions and periods of greatest ecological sensitivity – this should viewed in contrast to the work cited above (Comber et al., 2013; Naden et al., 2016). White and Hammond (2007) estimated that the total SRP (soluble reactive phosphorus) load of UK catchments was composed of 78% household, 13% agriculture, 4% industry and 6% background contributions; and for total TP load 73% household, 20% agriculture, 3% industry and 4% background contributions.

The UK has accomplished considerable progress on P remediation; however it still falls behind other EU members states such as Denmark, Sweden, Finland and the Netherlands where whole territories have been treated as sensitive areas, and also a large proportion of the countries like Germany and France have been designated the same way (Mainstone and Parr, 2002; IEEP, 1999). By 2002, only 2% of STWs in the UK had P-stripping installations (Foy, 2007). Muscutt and Withers (1996) carried out a study among 98 rivers in England and Wales and reported that 80% of the rivers were failing a target limit of 0.1 mg/l mean orthophosphate concentration (DoE, 1993). However, the UK has increased investment and accelerated implementation of the UWWTD at STWs in the last decade (Bowes et al., 2010): investment in England was almost doubled from £9600 M in the period 1990–2000 to £16,100 M in the years between 2000 and 2015; with a total investment of £39,126 M on STWs overall in the UK for the years between 1990 and 2015 (DEFRA, 2015). These actions have started to pay off with considerable reduction of phosphorus concentrations in many UK rivers (Kinniburgh and Barnett, 2010; Bowes et al., 2009; Neal et al., 2010c). Earl et al. (2014) found significant decreases in phosphate concentrations at the tidal limit in 68 out of 119 UK catchments that they considered between 1993 and 2003 which they ascribe to decreased use of polyphosphate in detergents and the introduction of the UWWTD. Nevertheless, the extent to which riverine phosphorus remediation will achieve the desired level of ecological improvement and also the