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Estimating the effects of land use at different scales on high ecological status in Irish rivers

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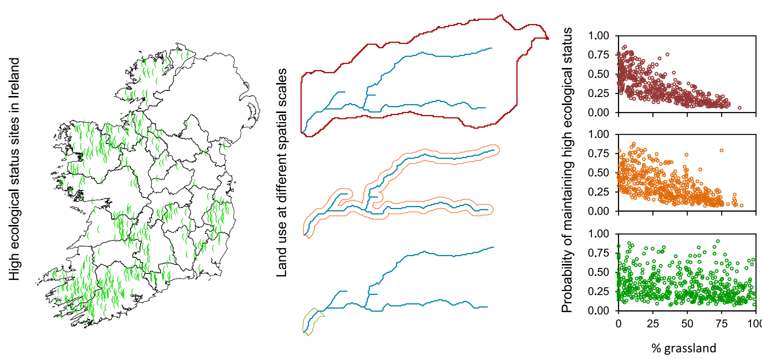
HIGHLIGHTS

- It is unclear what factors affect the stability of high ecological status in rivers
- The effects of land use and environmental variables were investigated
- Grassland at the catchment and riparian scale caused variability in status
- Management should focus on upstream river alterations and critical source areas

GRAPHICAL ABSTRACT



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ABSTRACT

High ecological status at river sites is an indicator of minimal disturbance from anthropogenic activities and the presence of ecologically important species and communities. However, a lack of clarity on what factors cause sites to lose high ecological status is limiting the ability to maintain the quality of these sites. Examination of ecological status records at 508 high status river sites throughout the Republic of Ireland revealed that 337 had fallen below high status at some point between 2001 and 2012 due to changes in invertebrate communities. A geographical information system was used to characterise land use and environmental variables in the catchment, riparian and reach areas upstream of the sites. The relationships between these variables at the three spatial scales and whether or not river sites had maintained high ecological status were then estimated by multiple logistic regression and propensity modelling. The results indicated that grassland at either catchment or riparian scales had a greater negative impact on high ecological status than at the reach scale. This effect appeared to be strongest for upland, steeply sloping rivers that are subject to high rainfall, possibly due to the presence of sensitive biota and/or a greater potential for erosion. These results highlighted the need for better management of grassland upstream of the high status sites, with a focus on river alterations and critical source areas of nutrients, sediments and pesticides that are hydrologically connected to the river. Sustainable management practices and land use planning in those areas will need to be considered carefully if the aim of maintaining high ecological status at river sites is to be achieved.

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1. Introduction

Anthropogenic activities have caused the quality of rivers around the world to decline to a point where management of catchment areas is necessary (World Water Assessment Programme, 2015). The Water Framework Directive (WFD) (OJEC, 2000) is a major regulatory instrument within the European Union (EU) that is based on the catchment management principle. For surface waters, one of a series of aims included in the WFD is to achieve at least 'good' ecological status for all waters and to maintain good or 'high' ecological status where it exists by target dates – up to 2027. Based on monitoring data, there was expected to be a 10% increase in the numbers of water bodies achieving good status between 2009 and 2015 (EEA, 2012). However, the situation is unclear for the numbers of sites expected to maintain high status, as the trends are less frequently reported. In the UK the number of high status rivers appears to be stable (Defra, 2014), but in the Republic of Ireland they have been declining periodically (White et al., 2014). This is a cause for concern because the high status category contains minimally disturbed rivers and 'reference sites' (sites against which the status of other rivers are determined), and because they support ecologically important species and communities (Aroviita et al., 2009; Hering et al., 2010). Understanding and managing these rivers should therefore be a priority, but has been largely overlooked because of the need to achieve good status in all surface waters (Hering et al., 2010; Irvine and Ní Chuanigh, 2013).

Managing high status rivers should be based on a sound understanding of the factors that affect their quality, including the type and magnitude of anthropogenic pressures, as well as the abiotic and biotic responses to those pressures (Schindler, 2006; Tetzlaff et al., 2007). Rivers are subject to multiple pressures that operate at different spatial scales, for example, point sources of pollution such as discharge from water treatment plants in urban areas and diffuse sources of pollution such as pesticide rich runoff from fields in agricultural areas (Tockner et al., 2010). These pressures alter the abiotic state of the river system (e.g. hydrochemistry, hydromorphology), which in turn alters the state of the biotic communities present (IMPRESS, 2002). The interplay between anthropogenic pressures and the abiotic and biotic response will vary from one catchment to another due to inherent differences in land management, soil type, climate, hydrology, topography and biology (Crossman et al., 2014; Kelly-Quinn et al., 2002). Notwithstanding this, broad-scale relationships between pressures and biological communities across multiple catchments can identify influential pressures at the population, rather than at the individual catchment level. These relationships provide valuable information that can inform strategic level catchment management and can help scientists to generalise the results of more controlled experiments that are limited in spatial scale (Foy and Kirk, 1995; Kail and Wolter, 2013).

Studies relating catchment characteristics to ecological status have shown catchment or riparian land use (a proxy for a range of individual pressures) to be the most influential characteristics, which are therefore asserted as the main reasons for rivers not achieving good status (Donohue et al., 2006; Kail and Wolter, 2013; Lorenz and Feld, 2012; Wasson et al., 2010). However, having been primarily concerned with achieving good status in degraded water bodies, it is unclear if those study findings are transferable to the more pristine, high status rivers. More specifically, previous studies outside of the EU indicate that local reach scale pressures and/or environmental variables are more important than land use in shaping the biological communities of more pristine rivers (Allan, 2004; Death and Joy, 2004; Wang et al., 1997, 2003). Assessment of ecological status for the WFD accounts for some environmental variables by establishing river types that provide specific reference conditions (Kelly-Quinn et al., 2002; River Basin Districts, 2005). However, because river types tend to have been established on a limited number of environmental variables across a limited number of sites, other variables may also influence ecological status (Bouleau and Pont, 2015; Moss, 2008a).

Estimating the effects of land use on ecological status is even more complicated when these environmental variables and land use are also related to each other, as this confounding makes causal inference challenging (Downes, 2010; Kail and Wolter, 2013). However, disentangling these effects will be essential if the effects of anthropogenic pressures are to be accurately resolved and appropriate management implemented to protect high ecological status. A number of approaches can be used to account for confounding in observational experiments, but propensity modelling is the most robust and accordingly, is the favoured approach in clinical and medical fields of research (Austin, 2011; Rosenbaum and Rubin, 1983). Having also been successfully applied to two multiple catchment studies (Pearson et al., 2015; Yuan, 2010), it also shows promise for wider application to catchment science issues.

In addition to potentially causing spatial variation in ecological status, environmental variables also cause temporal variation in biological communities over varying timescales, depending on the biota being studied (Mykrä et al., 2012; Snell et al., 2014). It is therefore important to capture this temporal variation when considering the effects of land use, especially because variation is amplified by anthropogenic pressures (Hering et al., 2010; Irvine, 2004). Despite the importance of this temporal variability, previous studies investigating the effects of land use on ecological status mainly utilised single samples to assess ecological status (e.g. Donohue et al., 2006; Wasson et al., 2010). While this approach is useful for identifying the pressures that prevent river sites from attaining a certain ecological status, it does not provide insights into the pressures that prevent river sites from maintaining that status over a period of time, an important consideration for high ecological status. With the wealth of WFD monitoring data that now exists, it may be possible to investigate the effects of land use pressures on the stability of high ecological status at river sites, albeit on a tri-annual basis with sampling frequencies that may not fully reflect how rapidly some biological communities vary (Moss, 2008a).

The objectives of this study were to i) identify which land uses affect the likelihood of river sites maintaining high ecological status over a 12 year period, ii) determine if the environmental variables that covary with land use cause those affects to be exaggerated or understated, and iii) determine at what scales land use has the greatest effect. To achieve these objectives, records of ecological status at 508 river sites throughout the Republic of Ireland were examined, and land use and environmental variables in the upstream catchment, riparian and reach areas were characterised. The relationships between these variables at the three spatial scales and whether or not river sites had maintained high ecological status were estimated using multiple logistic regression and propensity modelling approaches.

2. Methods

2.1. River monitoring sites and ecological status

This study took place in the Republic of Ireland, which is dominated by a rolling landscape but with some mountainous areas, especially in the west. Annual rainfall is high, ranging from 750 mm in the east to 1250 mm in the west and exceeding 2000 mm in mountainous areas. The landscape is highly dissected by rivers and streams, a high percentage of which are at high ecological status (~12%) (White et al., 2014), which could also facilitate a statistical analysis. The sites investigated here comprised 654 sites that were assigned high ecological status by the Irish Environmental Protection Agency (EPA) during the 2007 to 2009 and/or 2010 to 2012 monitoring periods. Also, monitoring records between 2001 and 2012 were analysed for these sites and only sites with a full record of ecological status were included for further analysis, giving a sample size of 508 (Fig. 1).

The overall ecological status of a site is based on measurements of biological (phytoplankton, aquatic flora, invertebrates and fish), physiochemical (e.g. nutrients, dissolved oxygen and temperature)

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