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Environmental response of an Irish estuary to changing land management practices

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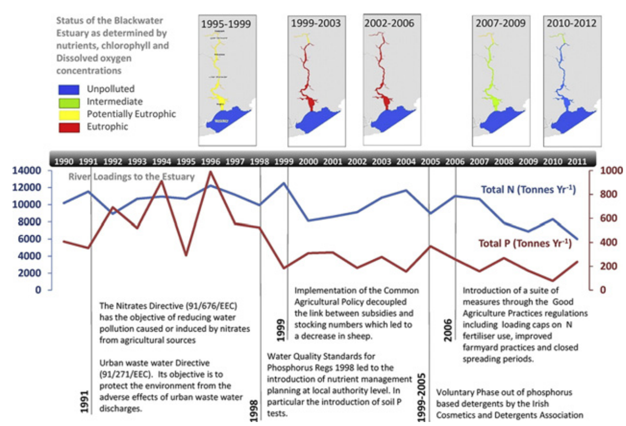
HIGHLIGHTS

- Implications of improved environmental practices on nutrient transport were examined.
- Reduced fertiliser usage and timing was linked to reduced estuarine nutrient loadings.
- P and water column chlorophyll improved while N remained stable in the estuary.
- Nutrient transport through an estuarine system depends on internal nutrient cycling.

GRAPHICAL ABSTRACT



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ABSTRACT

Anthropogenic pressures have led to problems of nutrient over-enrichment and eutrophication in estuarine and coastal systems on a global scale. Recent improvements in farming practices, specifically a decrease in fertiliser application rates, have reduced nutrient loadings in Ireland. In line with national and European Directives, monitoring of Irish estuarine systems has been conducted for the last 30 years, allowing a comparison of the effectiveness of measures undertaken to improve water quality and chemical and biological trends. The Blackwater Estuary, which drains a large agricultural catchment on the south coast of Ireland, has experienced a decrease in calculated nitrogen (N) (17%) and phosphorus (P) (20%) loads in the last decade. Monitored long-term river inputs reflect the reductions while estuarine P concentrations, chlorophyll and dissolved oxygen saturation show concurrent improvement. Consistently high N concentrations suggest a decoupling between N loads and estuarine responses. This highlights the complex interaction between N and P load reductions, and biochemical processes relating to remineralisation and primary production which can alter the effectiveness of the estuarine filter in reducing nutrient transport to the coastal zone. Effective management and reduction of both diffuse and point nutrient sources to surface waters require a consideration of the processes which may alter the effectiveness of measures in estuarine and coastal waters.

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1. Introduction

Increased nutrient enrichment derived from the rise of agricultural fertiliser use, human population pressures and atmospheric deposition has resulted in deleterious impacts on surface waters along the land–ocean continuum over past decades (Kronvang et al., 1993; Boesch, 2002). The European Union has specifically aimed at reducing nutrient inputs through the adoption of the Nitrates and Urban Waste Water Treatment Directives (1991) and the Water Framework Directive (WFD) 2000. Decreases in the loadings of nutrients and organic matter that cause eutrophication have been documented in a number of systems in Europe and worldwide (Testa et al., 2008; Duarte et al., 2009; Windolf et al., 2012). However, while measures have been shown to be effective in reducing the use of nitrogen (N) and phosphorus (P) fertiliser (Lalor et al., 2010; Bouraoui and Grizzetti, 2011) and loss of nutrients from wastewater treatment plants and industrial discharges (Schindler, 2006; Kronvang et al., 2008), future demands for food production will likely augment the intensity of agricultural practices in many countries.

Following the implementation of mitigating measures, recovery of surface waters from impairment is expected to vary depending on catchment characteristics including forestry cover, agriculture and the degree of urbanisation. Furthermore, natural factors such as geology, soils, climate, and hydrology will largely determine background water quality and legacy accumulation of anthropogenic nutrients in soils (Jordan et al., 2012; Taylor et al., 2012; Vermaat et al., 2012).

The specific response of estuarine and coastal systems to decreases in diffuse and point source loads can differ greatly due to their inherent chemical, biological and physical gradients and complex biogeochemical cycles. Estuaries can act as a source of nutrients, especially P (Deborde et al., 2007; Van Der Zee et al., 2007) and silica (Legovic et al., 1996; Cabeçadas et al., 1999), due to organic material recycling, desorption and diffusion of P from sediment pore waters during early digenesis (Deborde et al., 2008; Delgard et al., 2012). Secondly, they may act as a sink or source of N through the balance between nitrification–denitrification and ammonification-anammox (Abril et al., 2000; Garnier et al., 2006; Seitzinger et al., 2006). Finally, biological assimilation can also act to filter nutrients as they pass through the estuarine system. However, the response of primary producers to nutrient availability will depend largely on physical and biological constraints such as light, residence time, grazing and ocean exchange (Cloern, 2001; Carstensen et al., 2011; O'Boyle et al., 2015). Studies which trace N and P flows from the source to the coastal zone allow the determination of not only the effectiveness of mitigation but enhance understanding of response trajectories. This will assist in the future targeting of actions to be applied specifically in light of current and future programmes of measures to be undertaken under the Nitrates Directive, WFD, and Marine Strategy Framework Directive (MSFD).

To investigate the link between measures and improvements in water quality, the Blackwater catchment and estuary in southern Ireland, which has seen a substantial enhancement in water quality in the last decade, was selected. The trophic status of the estuary, having previously been classified as eutrophic by the EPA's Trophic Status Assessment Scheme (TSAS), has shown a marked improvement and is now classed as unpolluted with respect to eutrophication. Monitoring has been undertaken since 1990 to track river loads and since 1992 to evaluate the biochemical status of the estuarine system. Coupled with this, an assessment of nutrient source apportionment in the catchment has been carried out for the years 1990, 2000 and 2010. This is done as part of a national source apportionment exercise undertaken to meet the reporting requirements of the Oslo–Paris Convention on the Protection of the North Eastern Atlantic (OSPAR). The combination of these data is now a valuable tool which can be used to determine the links between improvements in practices and the response of an estuarine and coastal system.

The objectives of this study were; 1) to determine whether decreases in overall loads and changes in load apportionment to the estuarine catchment have occurred in the last 20 years; 2) to examine potential links between trends in calculated catchment nutrient loads, measured river loads and downstream estuarine concentrations; 3) to determine the impacts of any changes on physico-chemical and biological parameters within the estuarine system and 4) to identify the measures that have been most effective in reducing nutrient loss from the catchment to the estuary.

2. Materials and methods

2.1. Study site

The Blackwater Estuary drains a large agricultural basin in southern Ireland with a catchment area of 3307.5 km^2. Livestock constitute the main farming activity in the area with over 50% of the agricultural land dedicated to pasture and 30% to the production of silage. A number of small towns and villages also occupy the catchment while the town of Youghal (treatment population 10,000), which lacks a waste water treatment plant, lies at the estuary mouth. The south of Ireland is a temperate region, with highest rainfall and river flows occurring in the autumn/winter months. Median freshwater discharge is 106.6 m^3/s, with winter (October–March) flows being twice those of the summer periods. The Blackwater Estuary is shallow (average depth 4.2 m) and mesotidal with a tidal range of 3.6 m, a surface area of 12.1 km^2 and an intertidal area of 4.5 km^2. The estuary is generally well-mixed although stratification occurs in the mid-estuarine region.

2.2. Catchment nutrient load estimations

The quantification of nutrient sources to the Blackwater catchment was based on historic reporting procedures which have been undertaken to comply with requirements under OSPAR. In order to identify trends, load calculations were undertaken for 1990, 2000 and 2010. These years were chosen as the largest body of information was available at this time step. A detailed account of load calculations for, diffuse (inorganic and organic fertilisers, land use, unsewered population) and point (waste water treatment plants, industry) sources of nutrients is described below. In cases where actual data sets of direct discharges and pathway processes are unavailable, coefficients have been applied based on commonly agreed methods and previously measured rates (OSPAR, 2011; O'Sullivan, 2002).

2.2.1. Inorganic and organic fertilisers

Agricultural data for farm area usage (cereals, potatoes, silage, hay, pasture) and livestock densities (cattle, sheep) were obtained from the Central Statistics Office (CSO) of Ireland for the three years and are delimited into area per electoral district (ED). National inorganic fertiliser application rates of Nitrogen (N) and Phosphorus (P) per land use type were sourced from a national farm study (Lalor et al., 2010). As the survey only encompasses 1995–2008 the 1995 and 2008 application rates were used for 1990 and 2010 respectively. Justification for the use of 1995 and 2008 in lieu of 1990 and 2010 is based on the relatively small change in recorded fertiliser sales between 1990 and 1995 (2.5% increase for N and 0.7% decrease for P) and 2008 and 2010 (2008 fertiliser sales are within the standard deviation of the sales values for 2009–2011 (years used in the comparison of actual river loadings with calculated loads) for N (2008 = 309,000 tonnes; 2009–2011 = 327,670 ± 29,940) and P (2008 = 26,000; 2009–2011 = 26,000 ± 5200). As fertiliser sales are correlated with fertiliser application rates (Lalor et al., 2010) it can be assumed that the values used in the study are representative of actual application rates. Annual excretion rates per livestock type were obtained from the Good Agricultural Practice for Protection of Waters S.I. No. 101 of 2009 (Government of Ireland,