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Nutrient pressures and ecological responses to nutrient loading reductions in Danish streams, lakes and coastal waters

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Abstract

The Danish National Aquatic Monitoring and Assessment Programme (NOVA) was launched in 1988 following the adoption of the first Danish Action Plan on the Aquatic Environment in 1987 with the aim to reduce by 50% the nitrogen (N) loading and by 80% the phosphorus (P) loading to the aquatic environment. The 14 years of experience gathered from NOVA have shown that discharges of total N (TN) and P (TP) from point sources to the Danish Aquatic Environment have been reduced by 69% (N) and 82% (P) during the period 1989–2002. Consequently, the P concentration has decreased markedly in most Danish lakes and estuaries. Considerable changes in agricultural practice have resulted in a reduction of the net N-surplus from 136 to 88 kg N ha^{-1} yr^{-1} (41%) and the net P-surplus from 19 to 11 kg P ha^{-1} yr^{-1} (42%) during the period 1985–2002. Despite these efforts Danish agriculture is today the major source of both N (>80%) and P (>50%) in Danish streams, lakes and coastal waters. A non-parametric statistical trend analysis of TN concentrations in streams draining dominantly agricultural catchments has shown a significant ($p<0.05$) downward trend in 48 streams with the downward trend being stronger in loamy compared to sandy catchments, and more pronounced with increasing dominance of agricultural exploitation in the catchments. In contrast, a statistical trend analysis of TP concentrations in streams draining agricultural catchments did not reveal any significant trends. The large reduction in nutrient loading from point and non-point sources has in general improved the ecological conditions of Danish lakes in the form of increased summer Secchi depth, decreased chlorophyll *a* and reduced phytoplankton biomass. Major changes have also occurred in the fish communities in lakes, with positive cascading effects on water quality. In Danish estuaries and coastal waters only a few significant improvements in the ecological quality have been observed, although it is expected that the observed reduced nutrient concentrations are likely to improve the ecological quality of estuaries and coastal waters in Denmark in the long term.

Keywords: Nutrients; Pressures; State; Trends; Ecological impacts; Freshwater; Estuaries

1. Introduction

Excess nitrogen (N) and phosphorus (P) loading from point and non-point sources is considered one of

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the main factors damaging the ecological quality of streams, lakes and estuaries and the deteriorating quality of ground water (Meybeck, 1982; Iserman, 1990; Sabater et al., 1990; European Environment Agency, 1995, 1999; Jordan et al., 1997). The measures introduced in various countries to reduce nutrient pollution and hence improve water quality have had varying success. In many larger rivers the ecological quality has improved due to a reduction in point source discharges (European Environment Agency, 1999), whereas the ecological quality of smaller streams, being ecologically important for the aquatic biota, has seldom been improved (Pieterse et al., 2003). Thus, the efforts to reduce point source nutrient inputs to rivers, lakes, estuaries and coastal waters has been successful in many countries world wide, but improvements in ecological quality were in many cases dampened by nutrient losses from non-point sources (e.g. Thornton et al., 1999).

The newly adopted EU Water Framework Directive (WFD) aims at protecting different water bodies to prevent further deterioration and to protect and enhance the status of aquatic ecosystems (European Parliament and of the Council 2000/60/EC, 2000). The implementation of the WFD involves different steps where River Basin Authorities shall (i) perform an analysis of pressures and impacts (before 2005); (ii) develop monitoring programmes (before 2007); and (iii) implement mitigation strategies in the form of River Basin Management Plans (before 2009). An important part of the WFD is that reference conditions of different water body types should be detailed and applied in the target setting of ecological quality criteria in water bodies for judgement of the fulfilment of quality objectives (guideline).

It is essential to document the chemical and ecological responses to previous reductions of nutrient loading to the aquatic environment in order to improve our knowledge of important issues such as: (i) time lag and inertia in nutrient turnover from soil to surface water (e.g. Stålnacke et al., 2003); (ii) quantitative responses to different management measures against non-point pollution (Kronvang et al., 1999); and (iii) ecosystem responses to reduced nutrient pollution, including system resilience (Jeppesen et al., 1999).

Many countries have developed monitoring programmes and protocols that enable a reliable quantification of nitrogen (N) and phosphorus (P) loadings and concentrations in the aquatic environment (e.g. Kronvang et al., 1993; Kronvang et al., 1995). Data from such monitoring programmes can be of great help in understanding the various hydrological and biogeochemical processes governing N and P cycling in terrestrial, freshwater and marine environments and their ecological impacts (Kronvang et al., 1993). Together with existing models the experience gathered can assist catchment managers in making predictions of nutrient reductions and ecological effects in the aquatic environment (e.g. Heathwaite et al., 2000; Pieterse et al., 2003).

In Denmark, the first River Basin Management Plans for reduction of N, P and organic matter pollution of surface waters were adopted in the early 1970s (Andersen, 1994). The Danish Parliament adopted the first National Action Plan in 1987 with the aim to reduce by 50% the N-loading and by 80% the P-loading of surface waters, and at the same time the Danish National Aquatic Monitoring and Assessment Programme (NOVA) was launched (Kronvang et al., 1993). The 14 years of experience from the NOVA programme serve as a multiple catchment scale experiment for documenting nutrient responses to changes in point sources discharges and agricultural practices and in land–water interactions. As shown by Stålnacke et al. (2003) in an analysis of relationships between intensity of agricultural production and resulting N loads in Latvian rivers, there seems to be inertia between soil-surface water N interactions, such that nutrient loads carried by rivers were not reduced despite the large decrease in fertilizer input to agricultural land. Moreover, resilience in lakes, estuaries and coastal marine ecosystems can greatly influence ecological improvements being either accelerated or dampened following nutrient reductions, depending on the biological structure and sediment–water interactions (Jeppesen et al., 1999). Finally, changes in nutrient emissions will influence N/P-ratios in streams, rivers, lakes and estuaries in such a manner that a new nutrient limitation situation may occur in the water bodies Conley, 1999). Knowledge of such ecosystem responses is vital to catchment managers in Europe who are challenged with the task of implementing the WFD.

This paper describes and documents the effects of four Danish Action Plans adopted since the 1980s on N