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Excessive nitrogen and phosphorus in European rivers: 2000–2050

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ABSTRACT

Rivers export nutrients to coastal waters. Excess nutrient export may result in harmful algal blooms and hypoxia, affecting biodiversity, fisheries, and recreation. The purpose of this study is to quantify for European rivers (1) the extent to which N and P loads exceed levels that minimize the risk of harmful algal blooms and (2) the relative shares of sources of N and P in rivers. This may help to identify effective management strategies to reduce coastal eutrophication. We focus on 48 rivers in 27 countries of the European Union (EU27). We used the Global Nutrient Export from Watersheds (*NEWS*) model to analyze nutrient export by rivers and the associated potentials for coastal eutrophication as reflected by Indicator for Coastal Eutrophication Potential (ICEP). In 2000, 38 of the 48 EU rivers indicated in our study had an ICEP > 0, indicating a relatively high potential for harmful algal blooms. These 38 rivers cover 60% of EU27 land area. Between 2000 and 2050 nutrient export by European rivers is projected to decrease. However, by 2050 still 34 EU rivers, covering 48% of the land area, have an ICEP > 0. This indicates that in these scenarios little progress is made in terms of environmental improvement. About one-third of the rivers with ICEP > 0 are N limited, and about two-thirds P limited. In N-limited rivers reducing N loads is a more effective way to reduce the risk for coastal eutrophication than reducing P, and vice versa. For N-limited rivers agriculture or sewage are the dominant sources of nutrients in river water. In P-limited rivers, sewage is found to be the dominant source of P, except for rivers draining into the Atlantic Ocean, where agriculture can also be dominant. A basin-specific approach is needed to effectively reduce N and P loads.

1. Introduction

1.1. Background

Eutrophication of coastal waters results from an increase in the supply of nutrients, which mostly is related to nutrient enrichment enhancing the primary production. Eutrophication can unbalance ecosystems in coastal waters (Romero et al., 2013). These problems are caused by increased transport of nitrogen (N) and phosphorus (P) from land to sea. Nutrients are from natural and anthropogenic sources. Natural sources include woods and wetlands, and are diffuse sources. Anthropogenic sources include urban, industrial and agricultural areas. Cities and industries can cause point source emissions of nutrients to rivers. Agriculture is among others a diffuse source of N and P in rivers, through leaching or runoff of fertilizers.

Increased N and P in coastal waters may lead to algal blooms, which in turn may disturb ecosystems in coastal waters. Algal blooms can be harmful when they lead to hypoxia or release for toxins. Eutrophication may thus result in changes in marine ecosystems and reduced biodiversity. It may also lead to reduced natural resources of fish and income in fish industry and affect the attractiveness of coastlines for tourism. Finally, algal toxins may lead to toxicity problems in ecosystems and for humans (EEA, 2001).

Harmful algal blooms have been observed worldwide (Diaz and Rosenberg, 2008; Scheffer, 2010; Seitzinger et al., 2010). The algal blooms indicate that river export of nutrients has been increasing in many world regions. Algal blooms can be observed by satellite observations (Sutton et al., 2011). Some coastal waters are more sensitive to eutrophication and algal blooms than others. In Europe, most algal blooms occur in the coastal waters of the North Atlantic Ocean and the Baltic Sea. In the North West region of the Black Sea also severe algal blooms have been observed, as well as in the Mediterranean Sea.

European rivers are polluted with nutrients, as a result of human activities on land (Seitzinger et al., 2005). Both point and diffuse sources contribute to this pollution (Howarth et al., 2011; Mayorga et al., 2010). Urban and industrial waste is generally treated by

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water treatment plants, but not all nutrients are removed and discharged to rivers with the effluent. In Europe, also food production is an important source of nutrients in rivers. Both synthetic fertilizers and manure used as fertilizer are partly exported to the coastal waters. Although European policies are expected to reduce N and P loads in rivers to some extent, the risk for coastal eutrophication will be considerable during the coming decades (Seitzinger et al., 2010).

In this study, we focus on rivers of 27 European countries that discharge into the coastal waters of the Atlantic Ocean, the Baltic Sea, the Black Sea and the Mediterranean Sea. Several studies exist on nutrient export by European rivers (Kroeze et al., 2002; Kroeze and Seitzinger, 1998). However, no systematic analysis has been published of the relative shares of anthropogenic sources in the excess nutrient export by rivers in Europe, and how these can develop over time. A comprehensive overview of sources of pollution by rivers would help to prioritize policies aimed at reducing coastal eutrophication.

The purpose of this study is to quantify for European rivers (1) the extent to which N and P loads exceed levels with no risks of harmful algal blooms and (2) the relative shares of sources of N and P in rivers. This may help to identify effective management strategies to reduce coastal eutrophication. We focus on 48 rivers in 27 countries of the European Union (EU27). We use the Global Nutrient Export from Watersheds (*NEWS*) model to analyze nutrient export by rivers and the associated potentials for coastal eutrophication as reflected by ICEP (Indicator for Coastal Eutrophication Potential). When ICEP values are <0 this is an indication that the risks of eutrophication are low. We identify the causes of ICEP values that exceed 0, indicating that there is a risk for harmful algal blooms. The results of our analysis may help to identify effective manage strategies to reduce the risk of algae blooms. We focus on 48 rivers in 27 European countries, in line with earlier studies (Blaas and Kroeze, 2014; Van Wijnen et al., 2015). We used the Global *NEWS* model for our analyses.

1.2. Global NEWS

Global Nutrient Export from Watersheds (*NEWS*) is a global, spatially explicit computer model of the exports of nutrients to coastal waters by more than 6000 exoreic rivers (Mayorga et al., 2010; Seitzinger et al., 2010). In 2002, the model has been developed by an international, interdisciplinary, scientific taskforce by an assignment of UNESCO. After the first development in the year 2005 the model was updated in 2009 and published as Global *NEWS* 2. In this new release all the submodels were combined in one integrated interface.

Global *NEWS* can be used to model river export of nitrogen (N), phosphorus (P), carbon (C) and silica (Si) in different forms, as a function of human activities on land, hydrology and basin characteristics. The model consists of two sub models: for point sources and diffuse source. Point sources include nutrient inputs to rivers from sewage. Diffuse sources include both natural and anthropogenic flows from land to rivers.

Point sources of nutrients include sewage treatment plants. Diffuse sources can be natural or anthropogenic (Mayorga et al., 2010; Van Drecht et al., 2009). Natural sources include N and P leaching and runoff from soils. Anthropogenic diffuse sources include leaching and runoff from soils with increased N and P levels from, for instance, agriculture and atmospheric N-deposition. Anthropogenic point sources include sewage systems. Waste water treatment can reduce part of nutrients from sewage. In Global *NEWS* this is simulated using a retention factor. The amount of nutrients transported by rivers to coastal waters depends on retention of nutrient in terrestrial systems, rivers and reservoirs. These different types of retention are also included in Global *NEWS* (Tysmans et al., 2012). River export of nutrient is expressed in yields (kg/km^2/yr) or loads at the river mouth (Mg/yr).

Table 1
Nutrients that are included in the Global *NEWS* model (Seitzinger et al., 2010; Mayorga et al., 2010).

Nutrient	Form	Abbreviation
Nitrogen	Dissolved and organic	DON
Nitrogen	Dissolved and inorganic	DIN
Nitrogen	Particulate	PN
Phosphorus	Dissolved and organic	DOP
Phosphorus	Dissolved and inorganic	DIP
Phosphorus	Particulate	P
Carbon	Dissolved and organic	DOC
Carbon	Particulate	PC
Silica	Dissolved	DSi

The hydrology is from the WBMplus model, and watersheds are delineated on a grid of 0.5° × 0.5° latitude by longitude based on the STN-30p river system (Vörösmarty et al., 2000). The input databases are generated by the IMAGE model (Bouwman et al., 2009; Van Drecht et al., 2009) and the Water Balance Plus model (Feteke et al., 2010) The model calculates export of nutrients in different forms (Table 1). The model has been implemented to calculate export of nutrients for the years 1970, 2000, 2030 and 2050.

The Global *NEWS* model has been validated in several ways. It was developed and validated at the global scale (Seitzinger et al., 2010; Mayorga et al., 2010). In addition, it was validated for several continents or regions (Qu and Kroeze, 2010; Sattar et al., 2014; van der Struijk and Kroeze, 2010; Yasin et al., 2010). Also for Europe it has been validated (Kroeze et al., 2002; Strokal and Kroeze, 2013; Thieu et al., 2010). At the global scale the model performance is assessed through comparing modeled versus measured values, to calculate Nash–Sutcliffe efficiencies (R^2). These efficiencies typically range between 0.5 and 0.9, indicating that the model can explain the observed variability reasonably well. Validations at the continental scale typically result in similar efficiencies. These different validations build trust in the model, indicating that it cannot only be applied at the global, but also at the continental scale.

The exports of the rivers for the years 2030 and 2050 are predictions based on the Millennium Ecosystems Assessment Scenarios (MA). For a description of the scenarios see below. In this study we use the scenario Global Orchestration (GO) for 2050 as a baseline to analyze the additional inputs of N, P and Si to rivers by using the Global *NEWS* model. A summary of the main equations used in the Global *NEWS* model is shown in Table 2.

Global *NEWS* furthermore includes an Indicator for Coastal Eutrophication (ICEP) (see Section 2.2). In this study we use Global *NEWS* to calculate river exports of N, P in excess over levels that would ensure a low risk for coastal eutrophication (i.e. ICEP = 0). We will identify the sources of these nutrients (point sources and diffuse sources) in the watersheds of the rivers.

1.3. Millennium ecosystem assessment scenarios

There is a strong relationship between ecosystems and human wellbeing. To survive humanity needs the services of the ecosystems. Services are among others water, fishery, wood, soil and air. The knowledge about ecosystems and their relationships with social systems is increasing. The Millennium Ecosystem Assessment (MA) scenarios have been developed to explore the future of ecosystems as affected by social systems. In the year 2000 the United Nations Secretary-General Kofi Annan sent the MA report “We the People: The Role of the United Nations in the 21st Century” to the UN General Assembly. Worldwide nearly 1360 experts from 95 countries contributed to the MA, including scenarios for the year 2050. The MA reports are available online at www.maweb.org.