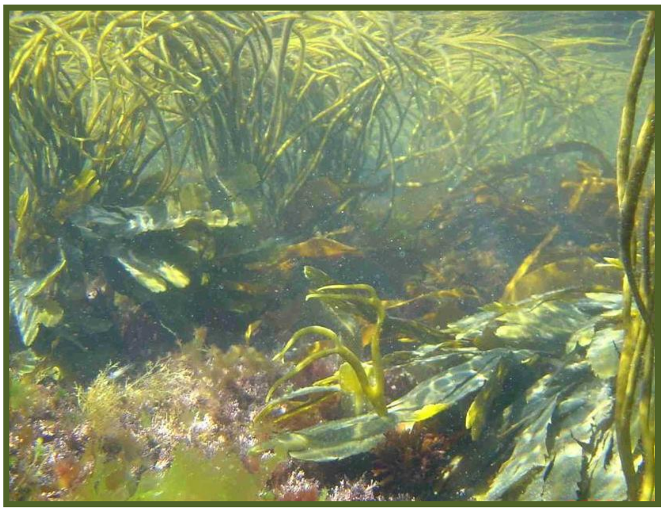
# The effect of sustainable agricultural practices and low-meat diets on nutrient export by European rivers to the coastal waters of the North Atlantic

*Olga Vasilishina*

**MSc Thesis in Environmental Sciences**

**March 2010**



**Supervised by: Carolien Kroeze**

ENVIRONMENTAL SCIENCES GROUP
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## Summary

Human activities are the main drivers of nutrients in rivers polluting coastal waters. Nutrients exported by rivers stem from agricultural sources, sewage and industrial sources. They cause eutrophication in many coastal ecosystems. This problem is pressing everywhere, but especially in the Baltic and the North Sea. In the past years, some improvements have been achieved through reducing contamination from point sources. However, agricultural diffuse sources remain difficult to be addressed. This study uses the Global *NEWS* model to analyze trends in nutrient export by rivers to the coastal waters in Europe. The model considers the river export of different dissolved and particulate nutrients (N, P and C).

The objective of this study is to analyze past and future trends in nutrient export to the European coastal waters of the North Atlantic Ocean and to assess the potential of low-meat diets and sustainable agricultural practices to reduce future nutrient exports. The North Sea and the Baltic Sea are emphasized. With regard to the objective this study answers six research questions. The first question addresses past trends in nutrient river export to the North Atlantic. The second question inquires in the validity of Global *NEWS* model for the selected region. The comparison of the measured and calculated nutrient export in the years 1970 and 2000 is performed here. The third question discusses future nutrient export trends in the selected region. The forth question reviews model inputs and parameters that reflect agricultural practices and meat consumption. Questions six and five are aimed at discovering alternative futures for the Baltic Sea and the North Sea. They discuss the potential of sustainable agricultural practices and low-meat diets to reduce future nutrient export to these seas.

First, past trends in nutrient export by European rivers to the coastal waters of the North Atlantic were analyzed on basis of Global *NEWS* simulations. Between 1970 and 2000 European nutrient export was stable with only slight decreases or increases for some nutrients. These trends were analyzed at the level of the ocean. The export of dissolved inorganic and organic nitrogen (DIN and DON) increased slightly between 1970 and 2000. Agricultural sources constitute an important share in the export of these nutrient forms in this period. The main sources of dissolved inorganic phosphorus (DIP) are point sources (sewage). A significant reduction of DIP export from these sources between 1970 and 2000 decreased DIP export to the coastal waters of the North Atlantic by one third. However, DIP export from agriculture remains stable and therefore, these sources increased their relative importance. The share of point sources in the river export of dissolved organic phosphorus (DOP) is less significant than in the export of DIP. Even though DOP river export from point sources decreased by almost one third, total river export of DOP remained stable between 1970 and 2000. This is because of constant DOP export from agricultural sources which played an important role here. The export of nutrients like dissolved organic carbon (DOC) and particulate nitrogen and phosphorus (PN and PP) have slightly increased over this period. However, these nutrients seem independent from agricultural sources.

In general, the analysis shows that river export of most nutrient forms (DIN, DIP, DON and DOP) resulting from agricultural activities remained constant in the past, while nutrient export from point sources was reduced.

The calculated nutrient exports by selected European rivers were then compared to measured nutrient exports in 1970 and 2000. This comparison indicated that the Global NEWS

model can reasonably simulate river export of DIN, DIP and TSS. For DON and DOC river export the model fit was lower. Measurements for only few (14 for DIN, 20 for DIP, 1 for DON and 17 for TSS) European river basins were available. For DOP river export no measurements were found for the selected river basins. This complicated the validation of Global *NEWS* model performance for the selected region.

Next, the future nutrient export by European rivers to the coastal waters of the North Atlantic was analyzed as projected by *NEWS* models for 2030 and 2050. These future trends are based on the four scenarios developed in the Millennium Ecosystem Assessment (MA), which were implemented in *NEWS* by the Global *NEWS* group. These scenarios are Global Orchestration (GO), Order from Strength (OS), TechnoGarden (TG) and Adapting Mosaic (AM) GO focuses on economical growth and technological development in a globalized world leaving a minor role to the environmental issues. In OS material wealth and security issues in different regional blocks are important and little attention is paid to the environmental problems. TG assumes globalization trends and technological development but unlike GO, environmental problems are addressed. AM pictures a world with regional blocks and an emphasis on solving environmental issues.

At the level of the ocean the river export of dissolved inorganic and organic N and P has mostly decreasing trends in the future. These trends are more or less profound depending on the scenario. As in the past, agriculture is rather important sources of nutrient export in the future. River export of PN, PP and DOC are stable between 2030 and 2050. The model projects the highest future nutrient export for the GO scenario compared to the other scenarios. This scenario was, therefore, chosen as a basis for the development and analysis of alternative scenarios in this study, which focuses on DIN, DON, DIP and DOP. This is because DOC and particulates do not depend on agricultural inputs. The *NEWS* model uses many input parameters for its calculations, such as those that reflect agricultural practices and meat consumption. Before analyzing the alternative scenarios, it was important to identify the sensitivity of the Global *NEWS* nutrient river export to the changes in the selected input parameters related to agriculture and meat consumption. A sensitivity analysis for these inputs was performed. This analysis indicated that the calculated river export of DIN is more sensitive to the changes in the input parameters than river export of DOP and DIP. River export of DON is the least sensitive to the changes in agricultural inputs.

Finally, the potential of sustainable agricultural practices and low-meat diets to reduce the nutrient river export to the Baltic and North Seas was analyzed by adjusting the relevant input parameters. Three alternative scenarios are analyzed: Scenario 1 includes a moderate shift to more sustainable practices; Scenario 2 assumes more profound shift; and Scenario 3 reduces meat consumption. These alternative scenarios are compared to the year 2050 in GO scenario, which is chosen as the baseline here. While at the ocean level the export of dissolved N and P decreases in the future in the baseline, at the sea level the trends are slightly different. DIN nutrient export to the Baltic Sea is projected to increase between 2000 and 2050 in GO scenario, the export of DIP shows decreasing trend in this period and DON and DOP exports to the Baltic Sea are stable. The export of nutrients to the North Sea either decreases (DIN and DOP) or stabilizes (DON and DOP) between the years 2000 and 2050 in the baseline scenario.

The results of the model runs with the alternative scenarios indicate that DIN river export to the Baltic Sea are reduced by about 7% in Scenario 1, 15% in Scenario 2 and by almost 30% in Scenario 3 in the year 2050 relative to the baseline scenario (GO). The increase of 13% in DIN export to the Baltic Sea that occurs between 2000 and 2050 can be slowed down by the measures in Scenario 1. In Scenario 2 the increase is avoided and in Scenario 3 DIN export to the Baltic Sea is reduced between 2000 and 2050. The reduction of DIP and DOP river export is less then 10% for all alternative scenarios relative to the current level and the level of GO 2050. However, in some river basins the export of these nutrients is half the GO 2050 level. DON river export is not affected by the measures implemented in all the alternative scenarios.

The results for the North Sea are slightly different than those for the Baltic Sea. Between the year 2000 and 2050 the already decreasing in the baseline scenario, DIN export to the North Sea can be reduced by 20%, by 30% and by 50% in Scenario 1, 2 and 3, respectively. Relative to the baseline scenario the reduction in DIN export is about 15% for Scenario 1, 25% for Scenario 2 and almost 45% for Scenario 3. The decrease in DIP and DOP river export is small in all scenarios, both relative to current level and the baseline scenario. The reduction in DON export is almost negligible. Some river basins draining into the North Sea show from 10 to 30% decrease in DIP and DOP export relative to the baseline, depending on the alternative scenario. In general, Scenario 3 has more potential to reduce nutrient river export to both the Baltic and the North Seas than the other scenarios.

The assumptions made in this study for the alternative scenarios lead to some uncertainties in the results. It was difficult to define the interrelationship between nutrient inputs from agriculture and to quantify their reduction in the alternative scenarios. The assumed reduction in most of agricultural inputs of nutrients involved in this study is based on quantitative findings of other studies. For a few inputs qualitative data was missing, so then assumptions were based on the qualitative information. Moreover, the validation of the model was hindered by the lack of measurements available for the selected river basins. Clearly, there are uncertainties related to the model performance at the scale of the selected region.

There are few other studies that discuss the effect of sustainable agriculture and low-meat diets on nutrient pollution using different models but their analysis is less complete as not all nutrient inputs are included in the analysis. On the one hand, the current study may be seen as a further step in defining the role of sustainable agriculture and low-meat diets to reduce nutrient export to the coastal waters. On the other hand, the assumptions made here may have increased an uncertainty. However, the results for both this study and the studies performed earlier show a large potential of sustainable agriculture and low-meat diets to mitigate nutrient pollution.

The results show, that sustainable agricultural practices as in Scenario 2 and the reduction of meat consumption as in Scenario 3 may help to reduce DIN river export to the coastal waters of the Baltic Sea and the North Sea and to a lesser extend the export of DIP and DOP. Concerning DIP and DOP river export, these measures have some potential to mitigate nutrient export by specific river basins. A moderate switch to more sustainable agricultural practices has only a small reduction potential. Sustainable agriculture and low-meat diets as in alternative scenarios were not effective in reducing DON river export. A greater focus on the river export of DON and measures that can reduce the export of this compound are required.

# 1 Introduction

## 1.1 Nutrients and their role for coastal water ecosystems

Many natural resources are degrading both in quantity and quality nowadays, and water is of no exception. Water not only supports all forms of life but economical, social and biological activities as well. However, both fresh and coastal waters are seriously contaminated. It is clear that human activities drive the rapid degradation of these waters and their habitats all over the world. Approximately 3 billion people, which constitutes about half of the world population, live within 200 km from coastal zones. This population could double by 2025 bringing more and more pressure to coastal waters (Creel, 2003).

Among the important factors associated with coastal waters degradation are elevated levels of nutrients. This is not only a result of human activities in the vicinity of coastal areas. The rivers that flow into the seas and oceans bring pollution to the coastal waters (Agardy *et al.*, 2005). Nutrient pollution of coastal ecosystems appears to be one of the most important global environmental issues (Rockstrom *et al.*, 2009). The excess of nutrients increases biomass production which builds up and facilitates microbial activity. This in its turn enhances the consumption of dissolved oxygen. The lack of oxygen causes a death of living organisms and destruction of the ecosystem. This phenomenon is called eutrophication. Some studies suggest that more than 60% of coastal waters in the USA are suffering from eutrophication (Howarth *et al.*, 2000). Severe eutrophication occurs in some European coastal waters. Many other regions of the world lack data on eutrophication state and trends. However the fast population growth, industrialization and change of land use, especially in countries in transition and developing countries, allow for the assumption that eutrophication is a pattern in these regions as well (Howarth *et al.*, 2000; Ærtebjerg *et al.*, 2001; Selman *et al.*, 2008).

The major nutrients causing eutrophication are nitrogen, phosphorous (P) and carbon (C). These nutrients are essential for all living organisms. However the amounts of the nutrients entering the environment exceed the needs of ecosystems in many regions. It is estimated that the amount of nitrogen, converted due to human activities into the reactive forms each year, exceeds total nitrogen that is converted into these forms naturally by terrestrial ecosystems (Rockstrom *et al.*, 2009). The phosphorus cycle is seriously altered by human activities as well. Due to mining, the rates of phosphorus, entering oceans, exceed natural background rates eight times (Rockstrom *et al.*, 2009). These levels introduce serious problems in aquatic ecosystems, such as eutrophication, stimulating the growth of harmful algae. The species feeding on algae cannot keep up with such a boost. This may lead to oxygen depletion, which has adverse effects on the ecosystem. Besides this, the growth of harmful species of algae may be directly toxic to the organisms in the water. Thus, it affects water quality and causes habitat loss (Tilman *et al.*, 2001; Allen *et al.*, 2006; Seitzinger *et al.*, in press, 2009).

Although all the nutrients mentioned above have adverse effects on coastal ecosystems nitrogen is particular concern on the global scale. Food production is one of the major sources of nutrients, as nitrogen and phosphorus are widely used in agriculture (Howarth *et al.*, 2000; Allen *et al.*, 2006).

To understand the sources of nutrient pollution in rivers and seas, its distribution and nutrient loads along the coastal waters the Global NEWS group has developed the Global NEWS model. About 6000 watersheds are included in the model. It is multi-element and multiform model as it considers several nutrients (N, P, and C) and their different forms (dissolved organic, dissolved inorganic and particulate) (Seitzinger *et al.*, 2005). Global NEWS can be run to calculate past trends in nutrient export to the coastal zones as well to estimate future trends (Mayorga *et al.*, submitted, 2009). To predict the future trends in nutrient pollution the inputs are derived from four scenarios that were developed in Millennium Ecosystem Assessment (Global Orchestration, Order from Strength, TechnoGarden and Adapting Mosaic). Under the Global Orchestration scenario the development of the world happens with the focus on globalization, material wealth and economical growth and little attention to the emerging environmental issues. Order from Strength also suggests economical growth but in more regionalized world where security issues are of the most concern. Globalization, high attention to environmental issues and technological development to address them are the brief characteristics of TechnoGarden scenario. Under Adapting Mosaic local and regional development, with strong focus on the state of environment prevail (Alcamo *et al.*, 2005; Mayorga *et al.*, submitted, 2009). More detailed description of the Global NEWS and its inputs are provided in section 1.3 of this chapter.

The current study will focus on European rivers, draining into the North Atlantic Ocean. This Ocean represents 5 sea basins, described by the Global News model: Baltic Sea, North Sea, the basin of Iberian-Biscay Plains, Hutton-Rockall Basin and Balearic basin. Selman *et al.* (2008) suggest that 65% of European Atlantic coast waters suffer the symptoms of eutrophication. The special accent in the research will be made on the North and Baltic Sea. Waterborne inputs of the nutrients are the most important pollution sources of their coastal waters. Today the measures are taken to reduce this pollution and some positive effects have been achieved. Helssinki Commission reports 40% reduction in nitrogen and phosphorus export to the Baltic Sea, although the target of the HELCOM Baltic Sea Action plan is still to be achieved. The reduction of 40% was possible due to active measures in regulating point source input of nutrients. Diffused sourced, being the most difficult to control did not get proper attention (HELCOM, 2007; Pawlak *et al.*, 2009). The situation with the pollution of the coastal waters of the North Sea is approximately the same. Since 1980's the input of phosphorus was cut down significantly, by about 50%, while nitrogen inputs, being more of a diffused origin, did not show such a stable decrease (OSPAR, 2000).

From the above it is clear that to tackle the problem of excessive nutrient export in the given areas it is important to pay the attention to agricultural practices where diffuse sources prevail. Agriculture accounts for about 50% of land use in Western Europe. Despite some measures directed to reduce adverse environmental impact from the sector, agriculture is still the major source of nutrient pollution of coastal waters of the North Sea (Koster, 2005; Kronvang *et al.*, 2005). Similarly, agriculture is responsible for 80% of total nutrient pollution from diffuse sources in Baltic Sea (Pawlak *et al.*, 2009). It should be pointed out that within agricultural sector, livestock and meat production are the largest contributors to eutrophication of fresh and coastal waters. This is especially true for the North Sea where number of countries have highly intensive livestock sector (Steinfeld *et al.*, 2006). Several studies, concerning nitrogen pollution, indicate that a shift from animal proteins to plant proteins in human diets may result in considerable reduction of dissolved inorganic nitrogen export. For example, assuming only a moderate reduction in meat consumption in Europe, resulted in a scenario with about 30% reduction in dissolved inorganic nitrogen export by European rivers to the North Atlantic Ocean (Kroeze *et al.*, 2001).

Hence, the current research aims at projecting future trends in nutrient pollution of coastal waters of Europe, and a positive effect of sustainable agricultural practices and low-meat diets in some European regions.

## 1.2 Purpose of study

### *1.2.1 Research objective*

The research objective is to analyze past, present and future trends in nutrient export to coastal waters, and to assess the potential of low-meat diets and sustainable agricultural practices to reduce future nutrient export by rivers draining from Europe into the North Atlantic Ocean. This will be done at the level of the ocean, with a special emphasis on the North Sea and the Baltic Sea.

### *1.2.2 Research questions*

**Exploring Global NEWS models**

1. What are the nutrient export rates by European rivers to the coastal waters of the North Atlantic calculated by NEWS models for 1970 and 2000?
2. How do calculated nutrient exports by these rivers compare to measured nutrient exports in 1970 and 2000?
3. What are nutrient export rates by European rivers to the coastal waters of the North Atlantic projected by NEWS models for 2030 and 2050?
4. What are the NEWS model inputs and parameters that reflect meat consumption and agricultural practices?

**Exploring alternative futures**

5. What is the potential of low-meat diets to reduce nutrient export by European rivers to the coastal waters of the North Sea and the Baltic Sea in 2030 and 2050?
6. What is the potential of sustainable agricultural practices to reduce nutrient export by European rivers to the coastal waters of the North Sea and the Baltic Sea in 2030 and 2050?

## 1.3 Methodology

In this research, the Global NEWS models, brought together in the GNE model, will be used to analyze past, future and current trends of global NEWS nutrient export to the coastal waters. The focus area of this study will be rivers in Europe draining into the North Atlantic. A review of relevant scientific literature will be carried out. The GNE model will be run with inputs and parameters that are consistent with scenarios to be developed to asses the potential of low-meat diets and sustainable agricultural practices. The methods being used to answer each research question are described in the following sections.

### *1.3.1 Global NEWS models (GNE)*

Global NEWS models simulate the global patterns in export of different forms of nutrients to the coastal waters (Seitzinger *et al.*, 2005). There are several individual models, each dealing with its own form and nutrient. The NEWS-DIN and NEWS-DON models simulate the export of dissolved inorganic and dissolved organic nitrogen respectively. The NEWS-DIP and –DOP models describe flows of the same forms of phosphorus. The NEWS-DOC model deals with dissolved organic carbon. And the particulate models explain the export of particulate forms of all these nutrients (Seitzinger *et al.*, 2005). Recently these models have been combined in the GNE interface (Mayorga *et al.*, submitted, 2009). This is the second improved version of Global NEWS model, referred to as NEWS-2. It includes two submodels: submodel of dissolved nutrient forms and submodel of particulates. The former describes dissolved nutrient export from point and diffused sources, and being based on the mass-balance approach, integrates inputs associated with land use, natural process in ecosystems and socio-economical factors. The latter is based on linear regression and describes the relationships between TSS and particulate nutrients (POC, PN PP), using the information on the land type (marginal grassland or wetland rice), dam properties, climate, lithology and relief of the basin area. The overview of all model inputs is provided in section 3.2. The model has been run for the years 1970, 2000, 2030 and 2050 and thus can be used for the analysis of past and future nutrient export trends. The future trends are described consistent with the Millennium Ecosystem Assessment (MEA) scenarios, which are briefly illustrated previously. Like the previous version of NEWS model, NEWS-2 uses resolution of 0.5 by 0.5 grid cell and can be applied in global, continental and regional levels (Mayorga *et al.*, submitted, 2009).

### *1.3.2 Exploring Global NEWS model*

The first four research questions are focused on exploring the Global NEWS model and will contribute to the understanding of the model operation. To answer questions 1 and 3 the results from NEWS-2 (GNE model) Run 5 for the region specified in the research objective, and for the years 1970, 2000 and 2030, 2050 will be analyzed. Besides the literature describing these results will be reviewed. The results will be discussed and conclusions will be drawn. As polluting nutrients are different and occur in different forms, the analysis will focus on the yields and loads of dissolved N and P as well as yields and loads of particulate N, P and C. For the years 2030 and 2050 the outputs are available for four MEA scenarios.

The Global NEWS models have been validated at the global level. This will provide necessary information for question 2. The data regarding model validation fro the selected region will be analyzed and the main issues will be brought up.

Question 4 will require study of the literature on the NEWS model. Besides the model itself will be studied in order to obtain user skills and comprehension of the model parameters and input data.

### *1.3.3 Exploring alternative futures*

Research questions 5 and 6 are aimed at exploring the alternative futures for the North and Baltic Seas and the role of low-meat diets and sustainable agriculture in them. First of all, one scenario out of four provided by MEA, will be chosen as a basis for the analysis and the assumptions underlying this scenario with respect to human diets and agricultural practices will be summarized. Second, for the answers on question 5 and 6 storylines with different assumptions for low-meat diets and sustainable agricultural practices will be developed on the basis of scientific literature review. Third, the parameters and input data which are associated with low-meat diets and agricultural practices (chosen in question 4) will be changed systematically, as in sensitivity analysis. The model with changed parameters and inputs will be run several times. The results of these runs will be analyzed and discussed. Then few illustrative scenarios will be developed, based on previous analysis, for the North and Baltic Seas. These scenarios will indicate the effects of changes in human diets and agricultural practices on the nutrient export rates by rivers, draining to coastal waters of the North and Baltic Seas.

# 2 Nutrient export to coastal waters

## 2.1 Introduction

This chapter addresses first four research questions.

- What are the nutrient export rates by European rivers to the coastal waters of the North Atlantic calculated by *NEWS* models for 1970 and 2000?
- What are nutrient export rates by European rivers to the coastal waters of the North Atlantic projected by *NEWS* models for 2030 and 2050?
- How do calculated nutrient exports by these rivers compare to measured nutrient exports in 1970 and 2000?
- What are the *NEWS* model inputs and parameters that reflect meat consumption and agricultural practices?

First, the chapter presents some general information about study area (2.2) and drivers of nutrient export (2.3). Next, past (1970 and 2000) and future (2030 and 2050) trends in nutrient export for the selected region are discussed (2.4). The analysis of these trends is based on the results from Global *NEWS* models. The major focus of the discussion is determined by the purpose of the study and thus, most attention is paid to the drivers and forms of nutrients attributed to agriculture. Besides the results for nutrient export, the chapter analyzes the results of the model calibration and validation for the selected area (2.5). In addition, model inputs and parameters reflecting human diets and agricultural practices are identified and discussed in order to proceed with the second part of the research where the assumptions for the alternative scenarios will be made (2.6).

## 2.2 Area of study

The study is focused on European rivers draining into the North Atlantic Ocean. These river basins were found and identified in Global *NEWS* model input data set. However the river basins that are smaller then 5 grid cells were excluded from the analysis, as the model is relatively uncertain for these basins. The area of study includes 67 river basins that drain into four sea basins (Baltic Sea, North Sea, the basin of Iberian-Biscay Plains and Hutton-Rockall Basin). Table 2-1 presents brief characteristics of the largest rivers in each sea basin. Together these rivers cover 70% of the total study area. The information on river basins is based on input data used in Global *NEWS* model for the year 2000.

Some rivers that drain into Iberian-Biscay Plains basin have agricultural areas that cover more than 50% of their area. Some intensive agriculture occurs in North and Baltic Sea as well. Rivers that drain into the North Sea have the highest natural runoff. Population and GDP are not evenly distributed among the river and sea basins.

**Table 2-1. General information on major river basins in Baltic Sea, North Sea, Iberian-Biscay Plains and Hutton-Rockall sea basins. Source: Global *NEWS* model input data for the selected European rivers.**

| Sea basin | Number of river basins | Largest river basins | Basin area(1) | Population density | | | GDP(2) | Runoff(3) | Agricultural land |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Total | Urban | Rural | | | |
| | | | ($km^2$) | ($inh/km^2$) | | | (US$/cap) | mm/year | % |
| Baltic Sea | 33 | Neva | 240726 | 28.3 | 22.3 | | 9669 | 256.2 | 2.3 |
| | | Wisla | 179883 | 135.4 | 92.0 | | 8625 | 126.1 | 50.9 |
| | | Odra | 118731 | 121.4 | 74.4 | | 10439 | 96.2 | 63.5 |
| | | Nemanus | 95531 | 46.2 | 28.1 | | 6529 | 173.3 | 37.6 |
| | | Daugava | 83315 | 30.5 | 19.5 | | 5846 | 194.2 | 20.7 |
| | | Narva | 54373 | 19.66 | 11.2 | | 7148 | 193.6 | 30.6 |
| | | Kemijoki | 51680 | 1.93 | 0 | | 22701 | 143.9 | 0 |
| North Sea | 19 | Rhine | 163750 | 300.3 | 261.9 | | 24504 | 357.2 | 46.0 |
| | | Elbe | 148118 | 166.6 | 132.3 | | 20069 | 114.6 | 53.7 |
| | | Gota | 44107 | 21.8 | 17.4 | | 23618 | 314.6 | 12.0 |
| | | Glama | 45654 | 28.5 | 25.4 | | 32228 | 392.7 | 0 |
| | | Weser | 45388 | 196.9 | 170.3 | | 23913 | 176.3 | 29.0 |
| | | Meuse | 43284 | 278.8 | 235.3 | | 24098 | 304.1 | 50.0 |
| The basin of Iberian-Biscay Plains | 13 | Loire | 117340 | 70.6 | 42.4 | | 23225 | 190.304 | 77.4 |
| | | Douro | 95455 | 55.7 | 33.1 | | 17790 | 181.290 | 65.5 |
| | | Seine | 72838 | 210.3 | 183.2 | | 23225 | 133.011 | 81.7 |
| | | Tejo | 72290 | 101.4 | 71.6 | | 17682 | 125.279 | 58.0 |
| | | Guadiana | 64195 | 26.4 | 1.7 | | 17770 | 100.878 | 80.1 |
| | | Garonne | 57858 | 62.9 | 38.1 | | 23033 | 273.810 | 53.6 |
| | | Guadalquivir | 53249 | 80.7 | 53.5 | | 18314 | 104.288 | 72.7 |
| Hutton-Rockall Basin | 2 | Shannon | 20830 | 33.8 | 10.4 | | 27612 | 504.4 | 32.1 |
| **Total** | 67 | - | 2645109 | 96.1 | 74.6 | | 19628.1 | 19348.3 | 35.2 |

(1) Land area in the river basin ("arealand" in Global *NEWS* model)
(2) GDP: Gross Domestic product at purchasing power parity
(3) Runoff: natural ("pristine" )runoff

## 2.3 Drivers of nutrient export

Here the discussion will focus on socio-economical, agricultural and other essential drivers of nutrient export by selected rivers. Past dynamic of the drivers is presented for the years 1970 and 2000 and their future trends are based on four MEA scenarios for the years 2030 and 2050.

### *2.3.1 Population and economy*

During past years (1970 and 2000) the population in the selected region slightly increased from 230 to 250 million inhabitants (Figure 2-1). The future trends in population growth highly depend on the scenarios. Thus, in GO scenario population growth stabilizes, while in other scenarios decreasing trends in demography occur. OS scenario has the fastest decrease between 2030 2050 reaching the value of 190 million inhabitants, which is 20% lower then in 1970. GO scenario has the highest value of 270 million inhabitants in 2050.

The economic trends show increase in almost all scenarios and years (Figure 2-2). Notably the increase in GDP in the future happens faster then in the past. GO scenario shows the highest GDP value in 2050, while in OS scenario GDP increased from almost 5000 to 8000 1995billions USD/year between 2000 and 2030 and stabilized in 2050.

In general, regionalized scenarios (OS and AM) show higher decreasing trends in demography then globalized scenarios. Similar to this, the future trends for GDP in regionalized scenarios differ from the ones in globalized scenarios. Regionalized scenarios have slower growth of GDP in the future. These trends demonstrate the characteristics of MEA scenarios for industrialized countries (Bouwman *et al.*, in press, 2009).

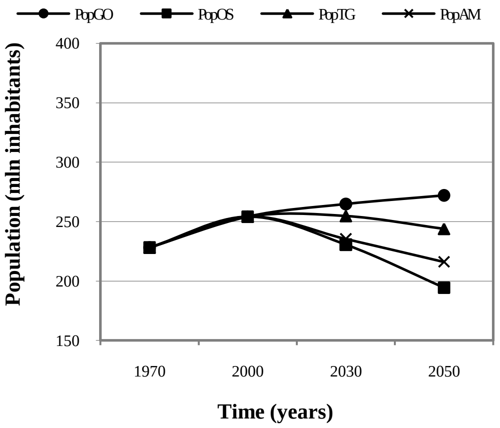


**Figure 2-1. Past and future population trends for the selected European river basins.** Pop GO = population trends in Global Orchestration scenario; Pop OS = population trends in Oder from Strength scenario; Pop TG = population trends in TechnoGarden scenario; Pop AM = population trends in Adapting Mosaic scenario. Source: Global *NEWS* model input data for the selected river basins.

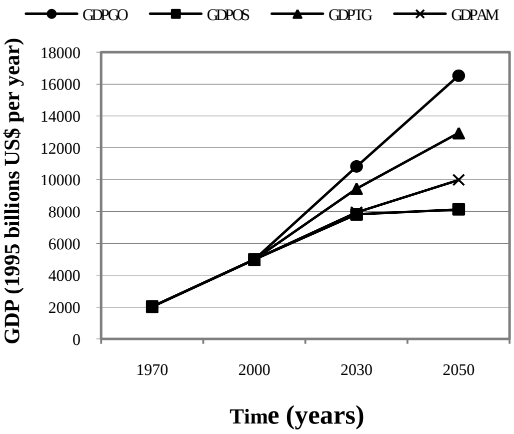


**Figure 2-2. GDP at purchasing power parity for the selected European river basins.** GDP GO = GDP tends in Global Orchestration scenario; GDP OS = GDP trends in Oder from Strength scenario; GDP TG = GDP trends in TechnoGarden scenario; GDP AM = GDP trends in Adapting Mosaic scenario. Source: Global *NEWS* model input data for the selected river basins.

### 2.3.2 Agricultural land use

Some changes occurred in agricultural land use during the period from 1970 to 2050 (Figure 2-3). In 1970 agricultural land constitutes about 42 % of the total selected region. This corresponds to 110 million ha. Between 1970 and 2000 the percentage of agricultural land decreased down to 35%. Between 2000 and 2030 it stays nearly constant in GO, TG and AM scenarios, while in OS scenario slight increase can be observed. After 2030 the percentage of agricultural land stabilizes in OS and AM scenarios and slightly increases in TG scenario. GO scenario shows a decreasing trend between 2030 and 2050. Despite the highest population number and economic growth, GO has the smallest agricultural land among all scenarios in 2050. This is possible due to fast technological progress in arable and livestock production systems assumed in this scenario. In OS this progress happens with the slowest rates compared to the other scenarios (Bouwman *et al.*, in press, 2009). This explains the highest agricultural land percentage occurring in this scenario in 2050.

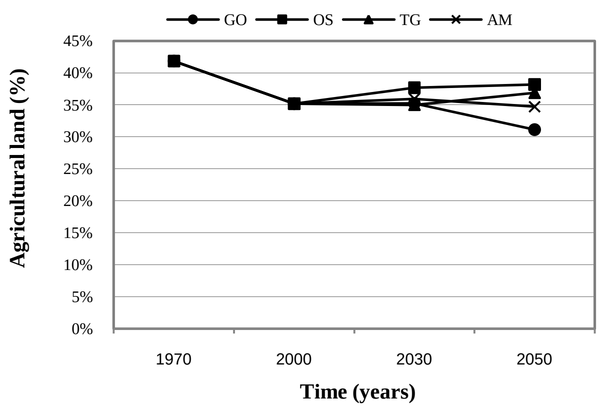


**Figure 2-3. Trends in agricultural land use for the selected European river basins.** GO=Global Orchestration scenario; OS=Oder from Strength scenario; TG=TechnoGarden scenario; AM=Adapting Mosaic scenario. Source: Global *NEWS* model input data for selected river basins.

### 2.3.3 Inputs of nutrients from agriculture

Agriculture contributes a significant share of nutrients due to synthetic and organic fertilizer use and $N_2$ fixation by crops (only for nitrogen). The following subchapter describes changes in past and future trends of nutrient inputs associated with agricultural land use.

According to Global *NEWS* model the input of N from agriculture incorporates N coming from manure and fertilizer application, biological N fixation by crops and deposition over agricultural land (in this study N deposition over natural land are not considered) as well as N withdrawn due to crop harvests and animal grazing. Similar approach is used to estimate P input from agriculture. It includes P added through fertilizer and manure application and P exported through crop harvesting (Mayorga *et al.*, submitted, 2009).

#### 2.3.3.1 Manure application

Global *NEWS* model predicts the decreasing trends of N and P inputs from manure application in all scenarios (Figure 2-4). In 2000 3.6 Tg N/year and 0.8 Tg P/year enters the system due to manure application. This is about 25 % less for both N and P then in 1970. In the future similar decreasing trends in N and P inputs continue in all scenarios. These trends can be explained by changes in demographic trends and meat consumption. Despite the assumption of increasing per capita meat consumption in the selected region, population trends slow down or even decrease, causing stabilization in livestock production. Besides it is assumed that in all scenarios the share of pork and poultry consumption will increase relative to red meat consumption. And as pork and poultry has more efficient feed conversion then ruminant animals, the amount of manure produced per product will decrease (Bouwman *et al.*, in press, 2009).

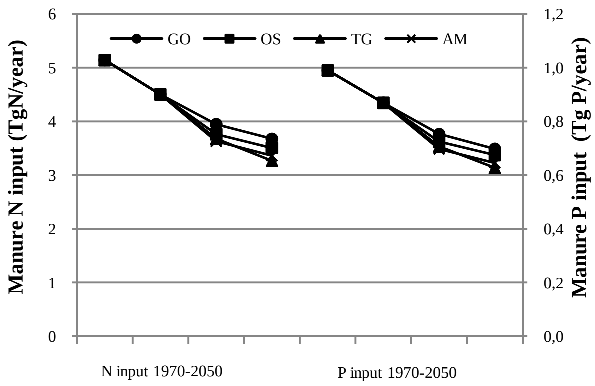


**Figure 2-4. Inputs of N and P from manure application for the selected European river basins.** GO=Global Orchestration scenario; OS=Oder from Strength scenario; TG=TechnoGarden scenario; AM=Adapting Mosaic scenario. Source: Global *NEWS* model input data for selected river basins.

#### *2.3.3.2 Fertilizer application*

Between 1970 and 2000 N input from fertilizer increased from 4.7 Tg N/year to 6 Tg N/year, while P input decreased from 1.5 Tg P/year to 0.7 Tg P/year (Figure 2-5). In the future N and P inputs from fertilizer slightly increase or decrease depending on the scenarios. In general GO and OS scenarios show higher values of inputs then TG and AM scenarios. It stipulated by the higher efficiency in fertilizer use, assumed in TG and AM scenarios in countries with nutrient surplus (Bouwman *et al.*, in press, 2009; Seitzinger *et al.*, in press, 2009).

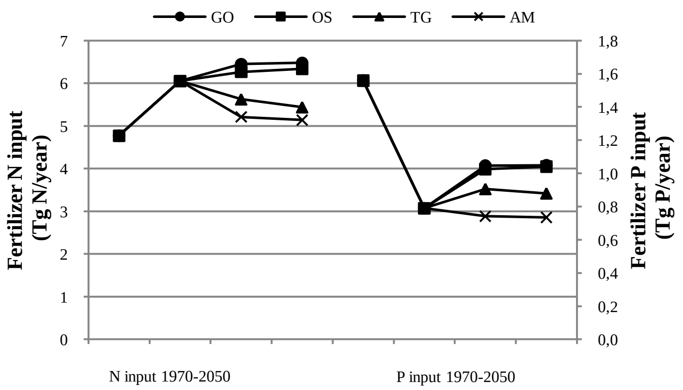


**Figure 2-5. N and P inputs from fertilizer application for the selected European river basins.** GO=Global Orchestration scenario; OS = Oder from Strength scenario; TG=TechnoGarden scenario; AM=Adapting Mosaic scenario. Source: Global *NEWS* model input data for selected river basins.

#### 2.3.3.3 *Deposition and crop fixation*

Estimated N deposition over agricultural land decreased between 1970 and 2000 from about 2 Tg N/year to about 1.5 Tg N/year (Figure 2-6). In OS scenario the trend stabilizes in the future while in GO scenario it stabilizes in 2030 and slightly decreases in 2050. For TG and AM scenario it continues to decrease over this period, with TG scenario showing greater reduction.

The fixation of N by crops represents the smallest share among all agricultural inputs of N (Figure 2-6). In 2000 about 0.67 Tg N/year is fixed by agricultural crops. This is slightly more then in the year 1970. Until 2030 slow increasing trends can be observed in all scenarios. In 2050 slight increase continues in all scenarios except GO. Global *NEWS* model estimates the fixation of N by agricultural crops by using total legume production and the area of grass- and cropland (Bouwman *et al.*, in press, 2009). And as the area of grass- and cropland is projected to decrease in the selected region, the slight increase in agricultural N fixation is caused by increasing legume production.

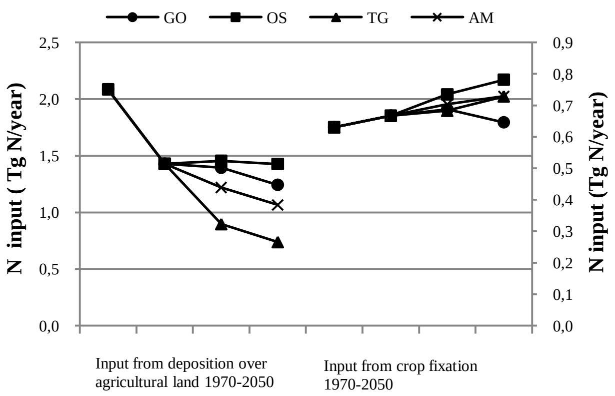


**Figure 2-6. N inputs from deposition over agricultural land and crop fixation for the selected European river basins.** GO=Global Orchestration scenario; OS=Oder from Strength scenario; TG=TechnoGarden scenario; AM=Adapting Mosaic scenario. Source: Global *NEWS* model input data for selected river basins.

#### 2.3.3.4 *Crop export*

The amount of N removed from the system due to harvest of crops increased between 1970 and 2000 from 5.7 to 6.7 Tg N/year (Figure 2-7). It implies higher yields and increasing efficiency in fertilizer uptake by crops in the region during this period. In the future N uptake by crops stabilizes in all scenarios.

P export by agricultural crops increased fast during the period of 1970 and 2000 and continues to increase in all scenarios until 2030 (Figure 2-7). After 2030 slight decrease is observed in all scenarios.

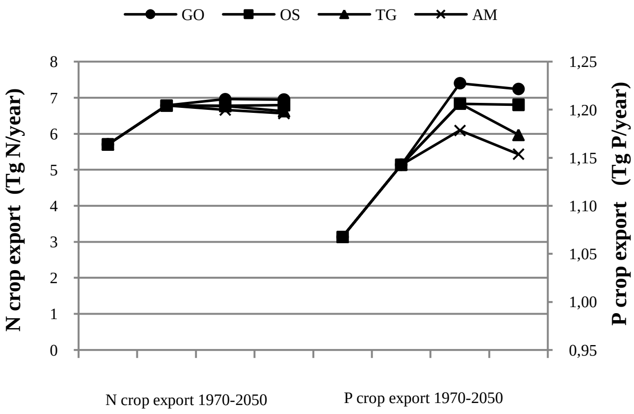


**Figure 2-7. The export of N and P with crop harvesting for the selected European river basins.** GO=Global Orchestration scenario; OS=Oder from Strength scenario; TG=TechnoGarden scenario; AM=Adapting Mosaic scenario. Source: Global *NEWS* model input data for selected river basins.

#### *2.3.3.5 Net total inputs of nutrient from agriculture*

Figure 2-8 presents the past and future trends in net total nitrogen input from agricultural areas (inputs from manure, fertilizer, fixation (for N) and deposition (for N) minus crop export). It shows decreasing trends in all scenarios. Between 1970 and 2000 the net agricultural input of N reduced from 7 Tg N/year to 6 Tg N/year. The decrease of net N input in GO and OS scenario for the years 2030 and 2050 is estimated to continue with approximately the same speed, while in TG and AM scenarios the reduction is more rapid.

P input associated with agricultural sources numbers more then 1.5 Tg P/year in 1970 (Figure 2-8). In 2000 it undergoes almost threefold decrease. Between 2030 and 2050 P net input stabilizes in GO and OS scenarios and continues to decrease in TG and AM scenarios, however with lower speed than between the period of 1970 and 2000.

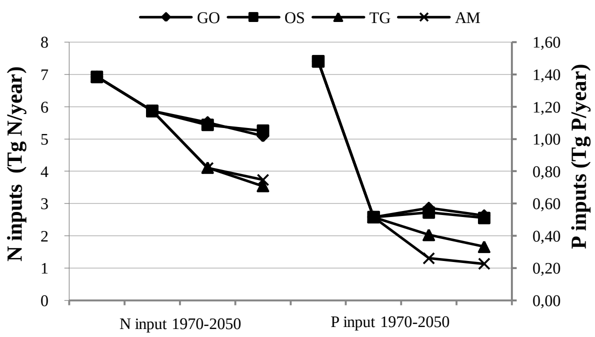


**Figure 2-8. Net total N and P inputs to agricultural areas for the selected European river basins.** GO=Global Orchestration scenario; OS =Oder from Strength scenario; TG=TechnoGarden scenario; AM=Adapting Mosaic scenario. Source: Global *NEWS* model input data for selected river basins.

### *2.3.4 Hydrology*

Changes in hydrology can influence the export of nutrients to the coastal waters. Some hydrological basin characteristics can change over time due to climate change and anthropogenic intervention (for example, consumptive water use, irrigation and others).

Higher runoff to watersheds can cause higher nutrient export to coastal waters. Global *NEWS* model distinguishes natural and actual runoff. Natural runoff reflects only climatic characteristics of the watersheds, while actual runoff takes into account the impact of anthropogenic land use (Fekete *et al.*, in press, 2009). In the selected region the alteration of runoff by human activities appears to be very small in all scenarios (Figure 2-9). This means that the anthropogenic influence in this respect can be neglected. Both natural and actual runoff show increase in the period of 1970 and 2000 (Figure 2-9). This caused by increased precipitation in the selected region during this period. In the future runoff remains stable in all scenarios.

Global *NEWS* model uses dam retention factor for dissolved inorganic nutrients (N and P) and sediments as one of the inputs. This factor represents the fraction of nutrients restrained behind the dam. Decrease of the fraction results in higher nutrient export to the coastal waters. In the selected region retention of nutrients in reservoirs in the selected region undergoes some changes over time (Figure 2-10).

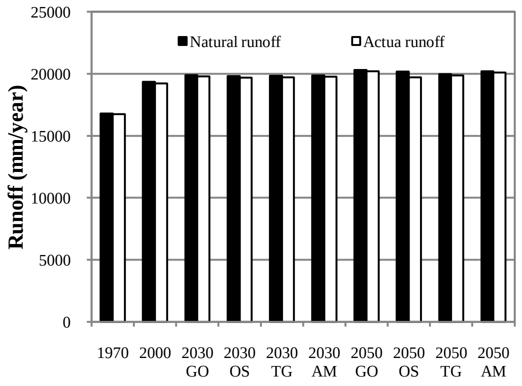


**Figure 2-9. Natural and actual runoff for the selected European river basins.** GO=Global Orchestration scenario; OS=Oder from Strength scenario; T=TechnoGarden scenario; AM=Adapting Mosaic scenario. Source: Global *NEWS* model input data for selected river basins.

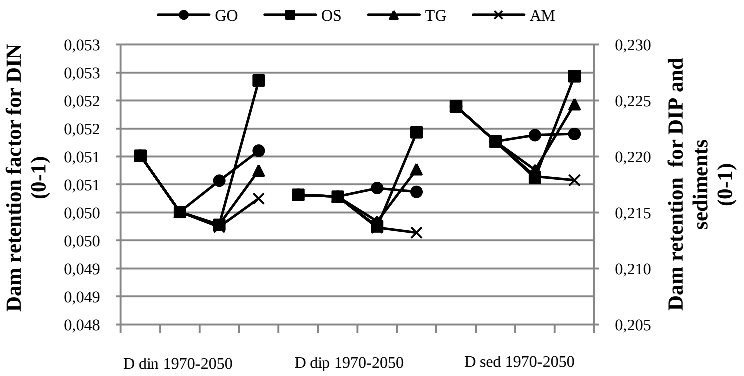


**Figure 2-10. Dam retention factor for dissolved inorganic N, P and sediments for the selected European river basins;** GO=Global Orchestration scenario; OS=Oder from Strength scenario; TG=TechnoGarden scenario; AM=Adapting Mosaic scenario; Ddin=dam retention factor for DIN, Ddip=dam retention factor for DIP, Dsed =dam retention factor for sediments. Source: Global *NEWS* model input data for selected river basins.

## 2.4 Past and future trends of Global NEWS nutrient export by selected European rivers

The present subchapter discusses past and future trends in nutrient export by selected European river basins to the coastal waters. The analysis starts with the dominating form of nutrients and then the export of nutrients is presented by their element and form.

### *2.4.1 Dominating forms of nutrients*

DIN has the largest share in total, exported to the North Atlantic from the selected region. It accounts for more than 60% in 1970 and 2000 (Figure 2-11). For the years 2030 and 2050 DIN accounts approximately the same share with slight variations in different scenarios. In P export DIP is an important form (Figure 2-12). It constituted almost 70% of total P export in 1970. Its share dropped to 50% in 2000 and remained close to this figure in all scenarios in 2030 and 2050. Among C forms DOC is of higher importance in all years and scenarios (Figure 2-13).

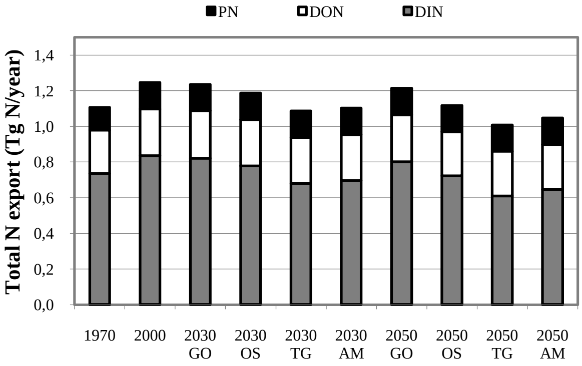


**Figure 2-11. Trends in total N export (by form) by the selected European river basins.** GO=Global Orchestration scenario; OS=Oder from Strength scenario; TG=TechnoGarden scenario; AM=Adapting Mosaic scenario. Source: Global *NEWS* model output data for selected river basins.

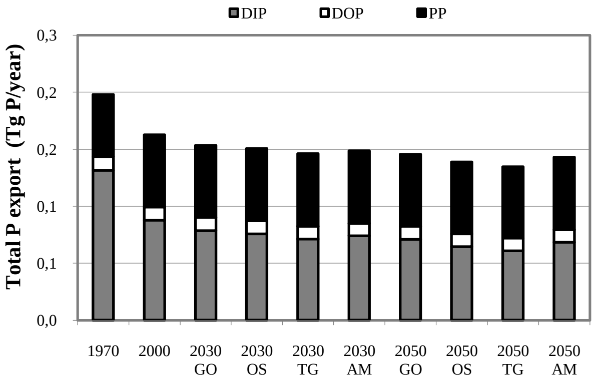


**Figure 2-12. Trends in total P export (by form) by the selected European river basins.** GO=Global Orchestration scenario; OS=Oder from Strength scenario; TG=TechnoGarden scenario; AM=Adapting Mosaic scenario. Source: Global *NEWS* model output data for selected river basins.

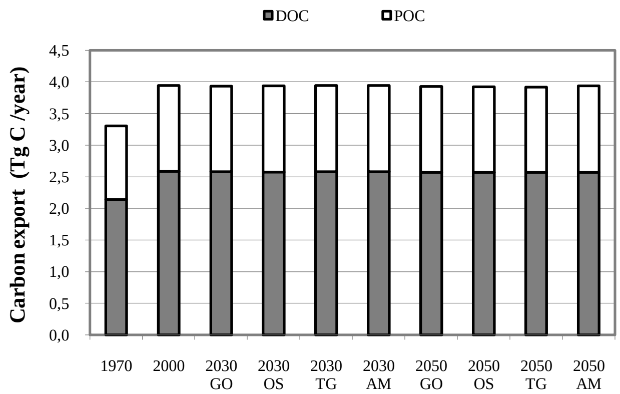


**Figure 2-13. Trends in total C export (by form) by the selected European river basins.** GO=Global Orchestration scenario; OS=Oder from Strength scenario; TG=TechnoGarden scenario; AM=Adapting Mosaic scenario. Source: Global *NEWS* model output data for selected river basins.

### 2.4.2 Nitrogen and phosphorus

#### 2.4.2.1 Dissolved inorganic nitrogen (DIN)

Global *NEWS* model estimates total DIN export of 0.73 Tg N/year for the year 1970 and 0.83 Tg N/year for the year 2000 (Figure 2-14). In the future DIN export is projected to decrease in all scenarios with GO scenario having the slightest decrease. The highest reduction happens in TG scenario.

Agriculture appears to be a dominant source of DIN export in all years and scenarios (Figure 2-15). Between 1970 and 2000 DIN export coming from agricultural sources (in particular from fertilizer application) increased (Figure 2-17) despite the decrease of net N input to agriculture (Figure 2-8). This can be attributed to higher runoff in the year 2000 relative to the year 1970 (Figure 2-9). Natural sources have important share in DIN export as well. The share of DIN exported from these sources increased between 1970 and 2000 (Figure 2-15). As the total export of DIN decreases in the future, so does the export of DIN coming from agricultural and natural sources. Contribution from point sources remains more or less stable over the whole period in all scenarios.

The yield of DIN differs greatly among the river basins, ranging from about 20 kg N/km$^2$/yr to about 3000 kg N/km$^2$/yr in 2000 (Figure 2-19). The rivers with the highest yields (more then 300 N/km$^2$/yr) drain into the North Sea, Hutton-Rockall basin and the basin of Iberian-Biscay plains. Some river basins draining to Baltic Sea show high yields as well. In all years and scenarios the highest yield occurs in the river, draining into the basin of Hutton-Rockall. It ranges from 2000 to almost 5000 N/km$^2$/yr depending on the year and scenario.

#### 2.4.2.2 Dissolved inorganic phosphorous (DIP)

Total DIP export is projected to decrease almost 50% between 1970 and 2000 (Figure 2-14). Although slowing down, the decreasing trend continues in the future in all scenarios. DIP export highly depends on the point sources in all years and scenarios (Figure 2-16). Their share of DIP export is decreasing over time with the most significant reduction between 1970 and 2000. Among agricultural sources fertilizer application has the highest contribution to DIP export in 1970 (Figure 2-18). In 2000 the share of fertilize contribution decreased and thus the manure contribution gains more importance. However in GO scenario the share DIP coming from fertilizer application slightly increases in 2030 and stabilizes in 2050.  For OS scenario this share is stable between 2030 and 2050 and for TG and AM it decreases during this period. The share of manure application decreases remains stable or decreases depending on the year and scenario.

The yields of DIP range from 1 to 600 kg P/km$^2$/yr in 2000 (Figure 2-20). For all years and scenarios the highest yields occur in the river basins draining into the North Sea. In general DIP yields decrease in most of the river basins in all years and scenarios.

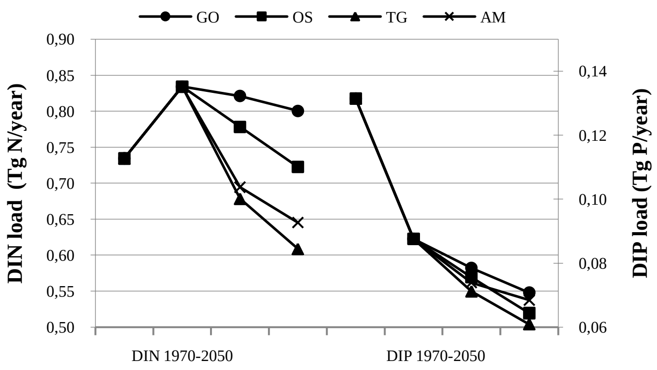


**Figure 2-14. Trends in export of dissolved inorganic N and P by selected European river basins.** GO=Global Orchestration scenario; OS=Oder from Strength scenario; TG=TechnoGarden scenario; AM=Adapting Mosaic scenario. Source: Global *NEWS* model output data for selected river basins.

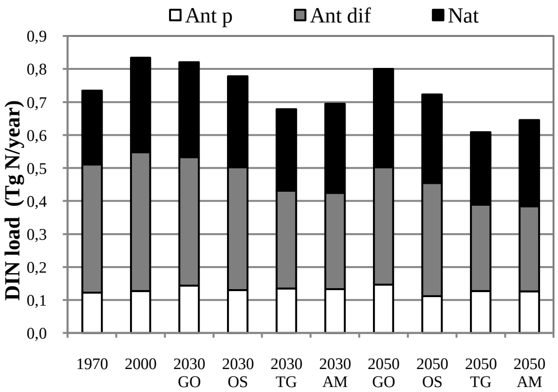


**Figure 2-15. Sources attribution of dissolved inorganic N export by selected European river basins.** Ant p=anthropogenic point sources; Ant dif=anthropogenic diffuse (agricultural) sources; Nat=natural sources; GO=Global Orchestration scenario; OS=Oder from Strength scenario; TG=TechnoGarden scenario; AM=Adapting Mosaic scenario. Source: Global *NEWS* model output data for selected river basins.

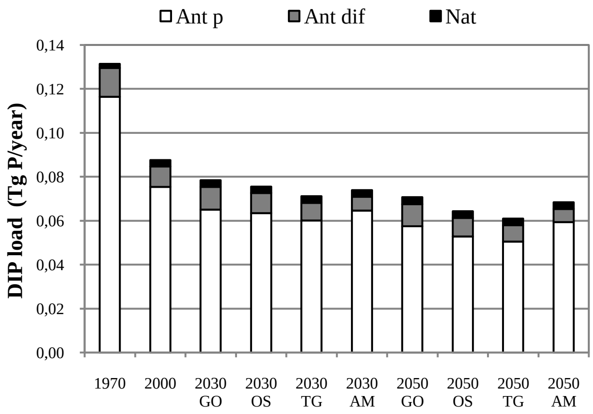


**Figure 2-16. Sources attribution of dissolved inorganic P export by selected European river basins.** Ant p=anthropogenic point sources; Ant dif=anthropogenic diffuse (agricultural) sources; Nat=natural sources; GO=Global Orchestration scenario; OS=Oder from Strength scenario; TG=TechnoGarden scenario; AM=Adapting Mosaic scenario. Source: Global *NEWS* model output data for selected river basins.

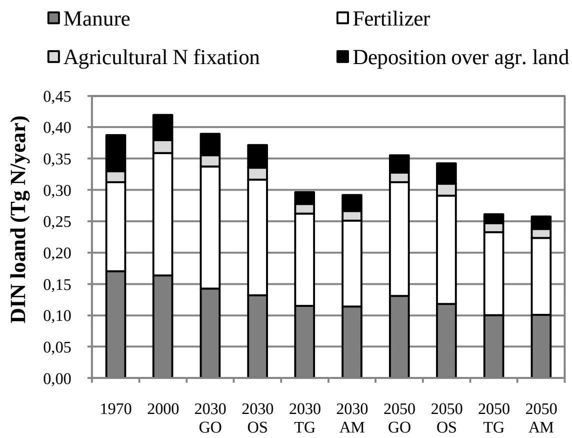


**Figure 2-17. Agricultural sources attribution of dissolved inorganic N export by selected European river basins.** GO=Global Orchestration scenario; OS=Oder from Strength scenario; TG=TechnoGarden scenario; AM=Adapting Mosaic scenario. Source: Global *NEWS* model output data for selected river basins.

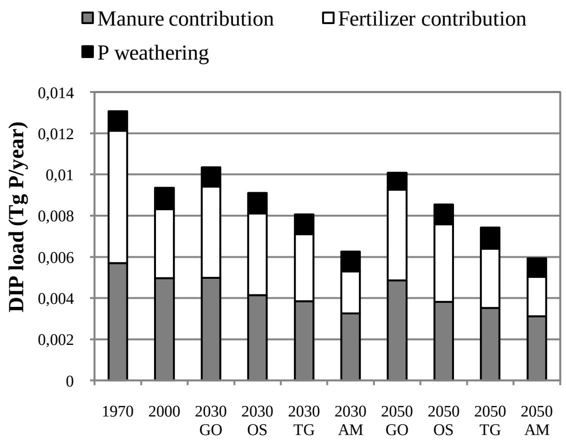


**Figure 2-18. Agricultural sources attribution of dissolved inorganic P export by selected European river basins.** GO=Global Orchestration scenario; OS=Oder from Strength scenario; TG=TechnoGarden scenario; AM=Adapting Mosaic scenario. Source: Global *NEWS* model output data for selected river basins.

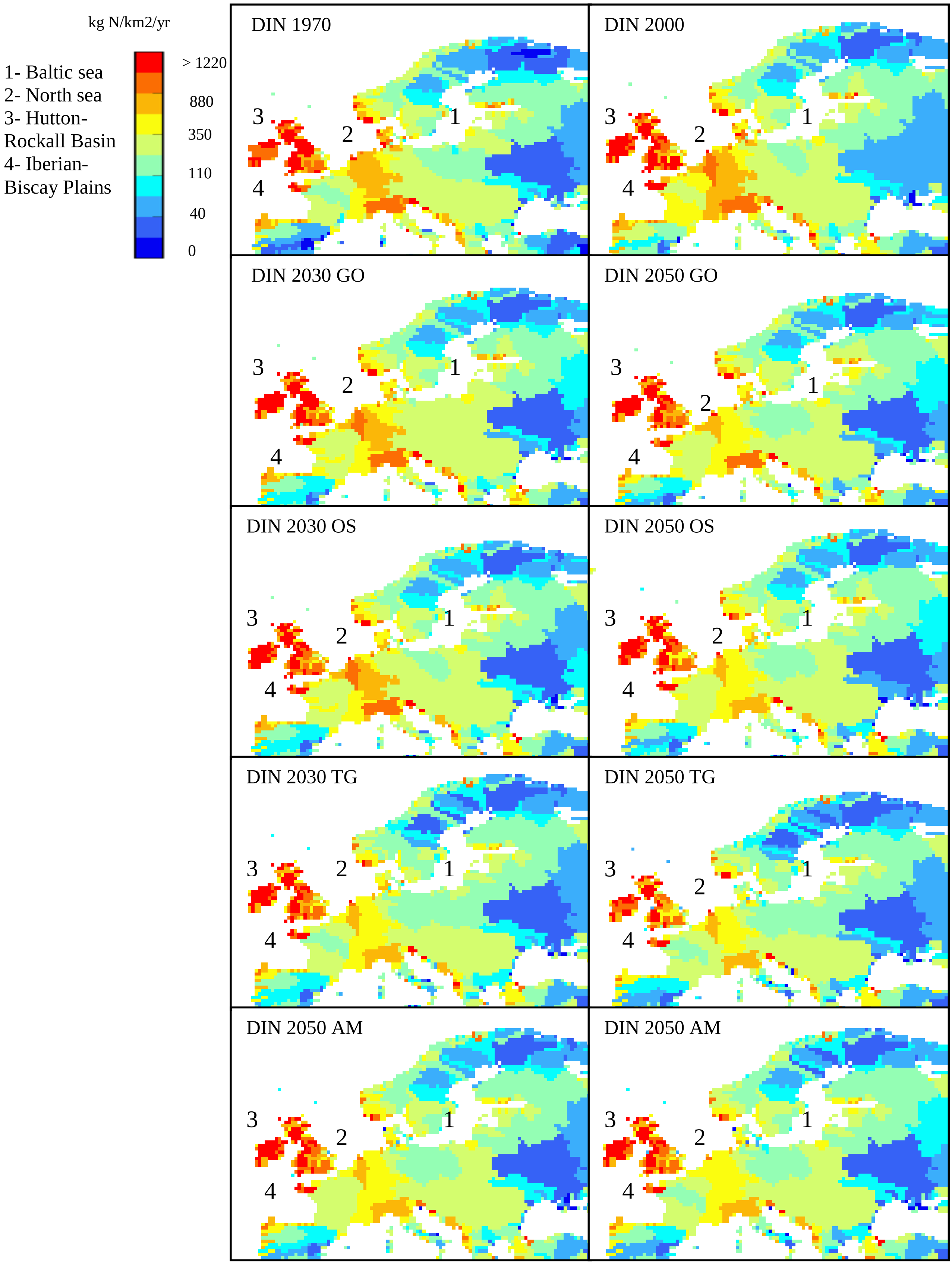


**Figure 2-19. Trends in DIN yields from the selected European river basins.** GO=Global Orchestration scenario; OS=Oder from Strength scenario; TG=TechnoGarden scenario; AM=Adapting Mosaic scenario. Source: Global *NEWS* model output data for selected river basins.

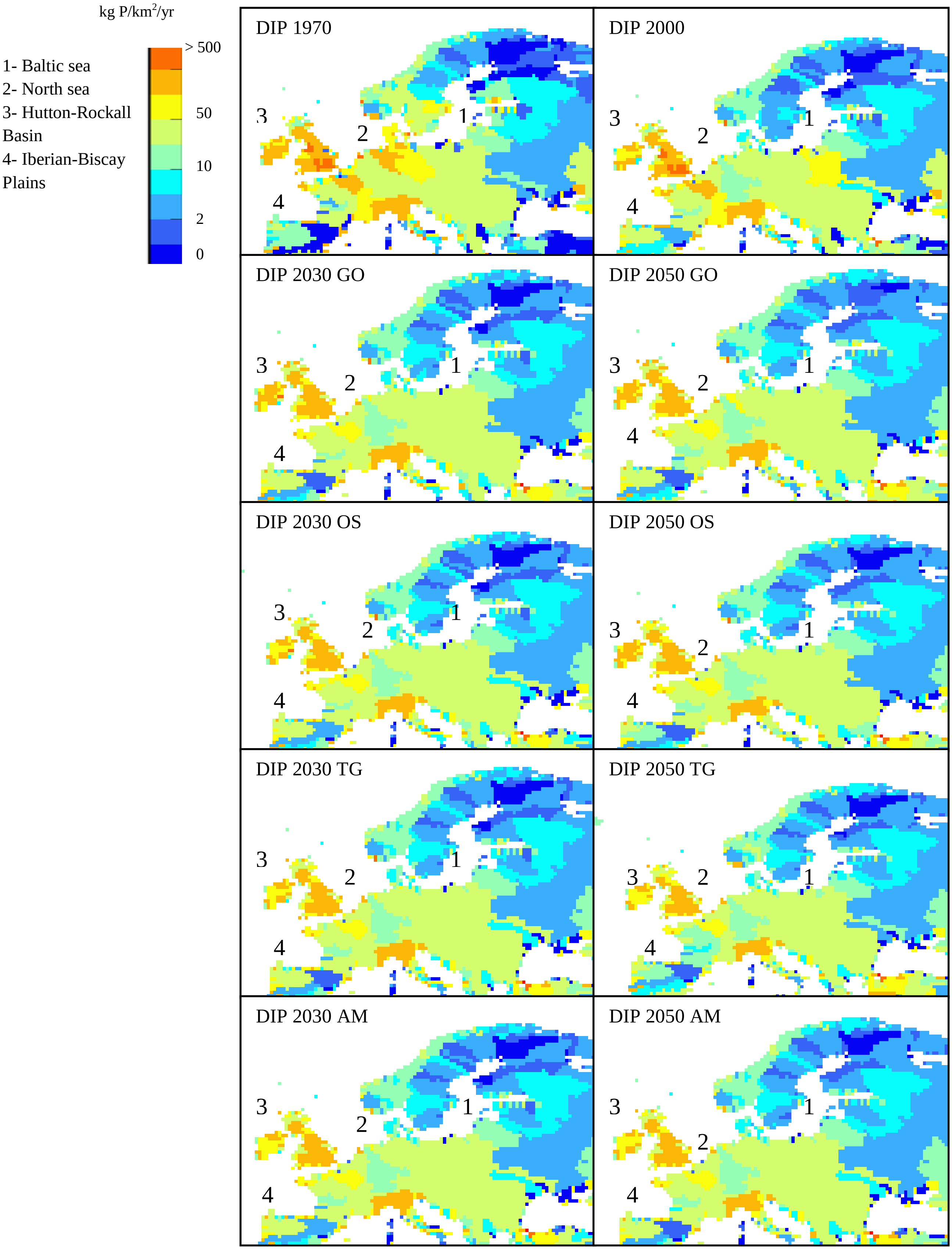


**Figure 2-20. Trends in DIP yields from the selected European river basins.** GO=Global Orchestration scenario; OS=Oder from Strength scenario; TG=TechnoGarden scenario; AM=Adapting Mosaic scenario. Source: Global *NEWS* model output data for selected river basins.

#### 2.4.2.3 Dissolved organic nitrogen (DON)

Future and past trends for dissolved organic N are similar to the ones of dissolved inorganic N. However the difference between scenarios is less pronounced then for DIN export. The total DON export accounted for 0,245 Tg N/year in 1970 (Figure 2-21). It increased up to 0,262 Tg N/year in 2000. In the future it decreases in all scenarios except GO where it continues slightly increasing trend until 2030 and then slightly decreases in 2050. In the past and future natural sources contribute the largest share of DON (Figure 2-22). However agricultural and point sources are important here as well. As the share of point sources decreased between 1970 and 2000, slight increase in the share of agricultural sources and more rapid increase in the share of natural sources cause the total DON export to increase. The increases in natural and agricultural sources contribution were caused by higher runoff in this period. Almost in all scenarios except GO the decrease in DON export caused by slight decrease in contribution from agricultural and point source as they together offset slight increase in export of DON from natural areas. In GO scenario different trend occur between 2000 and 2030 when the share of point sources together with natural sources increases causing slight increase in total DON export in this period. Among agricultural sources leaching takes the dominant place in DON export (Figure 2-24). It constitutes over 80% through all the years and scenarios.

The yields of DON range in the selected area, from 40 to 500 kg N/km$^2$/yr in 2000 (Figure 2-26).And as with DIN and DIP yields, the highest yields for DON (more then 100 kg N/km$^2$/yr) occur in river basins draining into the North Sea, Iberian-Biscay plains and Hutton-Rockall sea basins in all scenarios.

#### 2.4.2.4 Dissolved organic phosphorus (DOP)

In total the export of DOP a decrease is calculated for the past (Figure 2-21). In the future this trend continues for all scenarios. TG and AM scenarios show slightly higher decreasing rates then GO and OS. In 1970 agricultural sources have the highest contribution in DOP export. However since 2000 natural sources became more important (Figure 2-23). Over the time the contribution from natural sources increases in almost all scenarios while the share of DOP coming from agricultural and point sources decreases. This causes the reduction in total DOP export in all scenarios. Among agricultural sources leaching has the largest contribution to DOP export (Figure 2-25). The contribution of leaching remains more or less stable over the time. Thus, the reduction of DOP coming from agriculture is attributed to decreased contribution from manure and fertilizer.

DOP yields from the selected river basins range from about 2 to 30 kg P/km$^2$/yr in 2000(Figure 2-27). In the future only minor changes occur in yields exported to the coastal waters. In all scenarios the highest yields come from the rivers flowing into the North Sea and Hutton-Rockall sea basin.

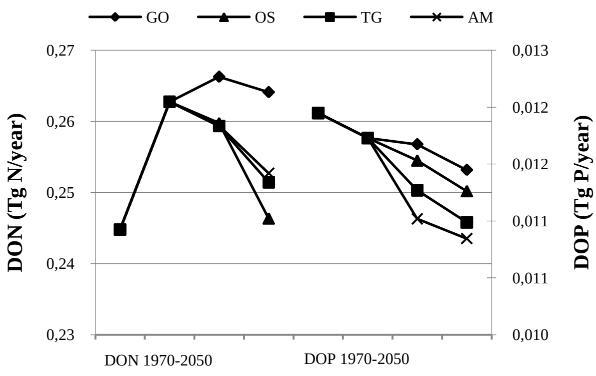


**Figure 2-21. Trends in export of dissolved organic N and P by selected European river basins.** GO=Global Orchestration scenario; OS=Oder from Strength scenario; TG=TechnoGarden scenario; AM=Adapting Mosaic scenario. Source: Global *NEWS* model output data for selected river basins.

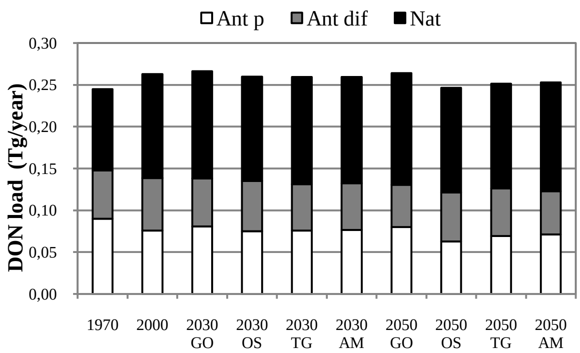


**Figure 2-22. Sources attribution of dissolved organic N export by selected European river basins.** Ant p=anthropogenic point sources; Ant dif=anthropogenic diffuse (agricultural) sources; Nat=natural sources; GO=Global Orchestration scenario; OS=Oder from Strength scenario; TG=TechnoGarden scenario; AM=Adapting Mosaic scenario. Source: Global *NEWS* model output data for selected river basins.

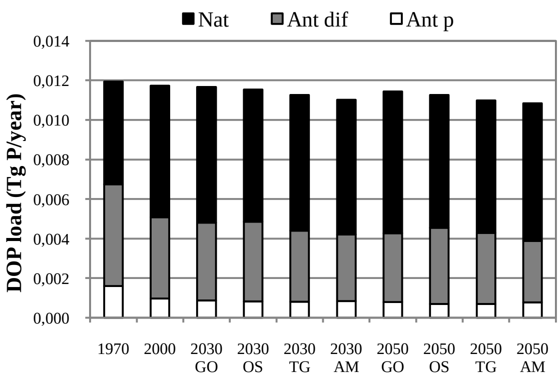


**Figure 2-23. Sources attribution of dissolved organic P export by selected European river basins.** Ant p=anthropogenic point sources; Ant dif=anthropogenic diffuse (agricultural) sources; Nat=natural sources; GO=Global Orchestration scenario; OS=Oder from Strength scenario; TG=TechnoGarden scenario; AM=Adapting Mosaic scenario. Source: Global *NEWS* model output data for selected river basins.

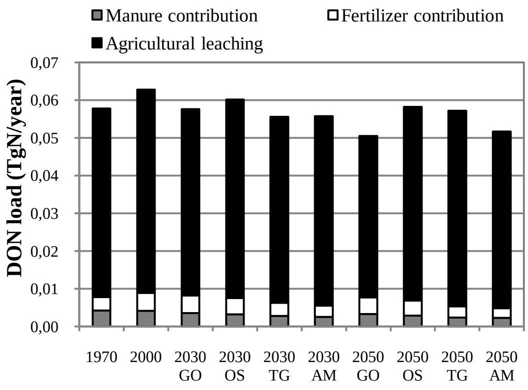


**Figure 2-24. Agricultural sources attribution of dissolved organic N export by selected European river basins.** GO=Global Orchestration scenario; OS=Oder from Strength scenario; TG=TechnoGarden scenario; AM=Adapting Mosaic scenario. Source: Global *NEWS* model output data for selected river basins.

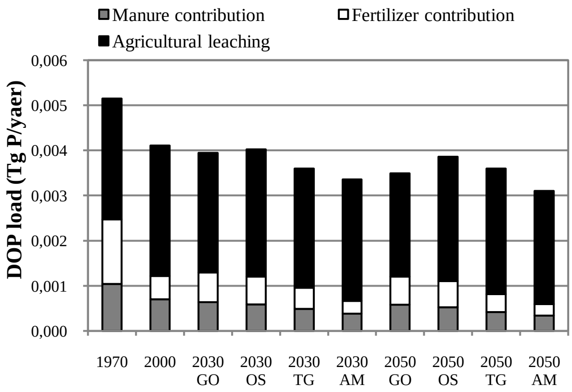


**Figure 2-25. Agricultural Sources attribution of dissolved organic P export by selected European river basins.** GO=Global Orchestration scenario; OS=Oder from Strength scenario; TG=TechnoGarden scenario; AM=Adapting Mosaic scenario. Source: Global *NEWS* model output data for selected river basins.

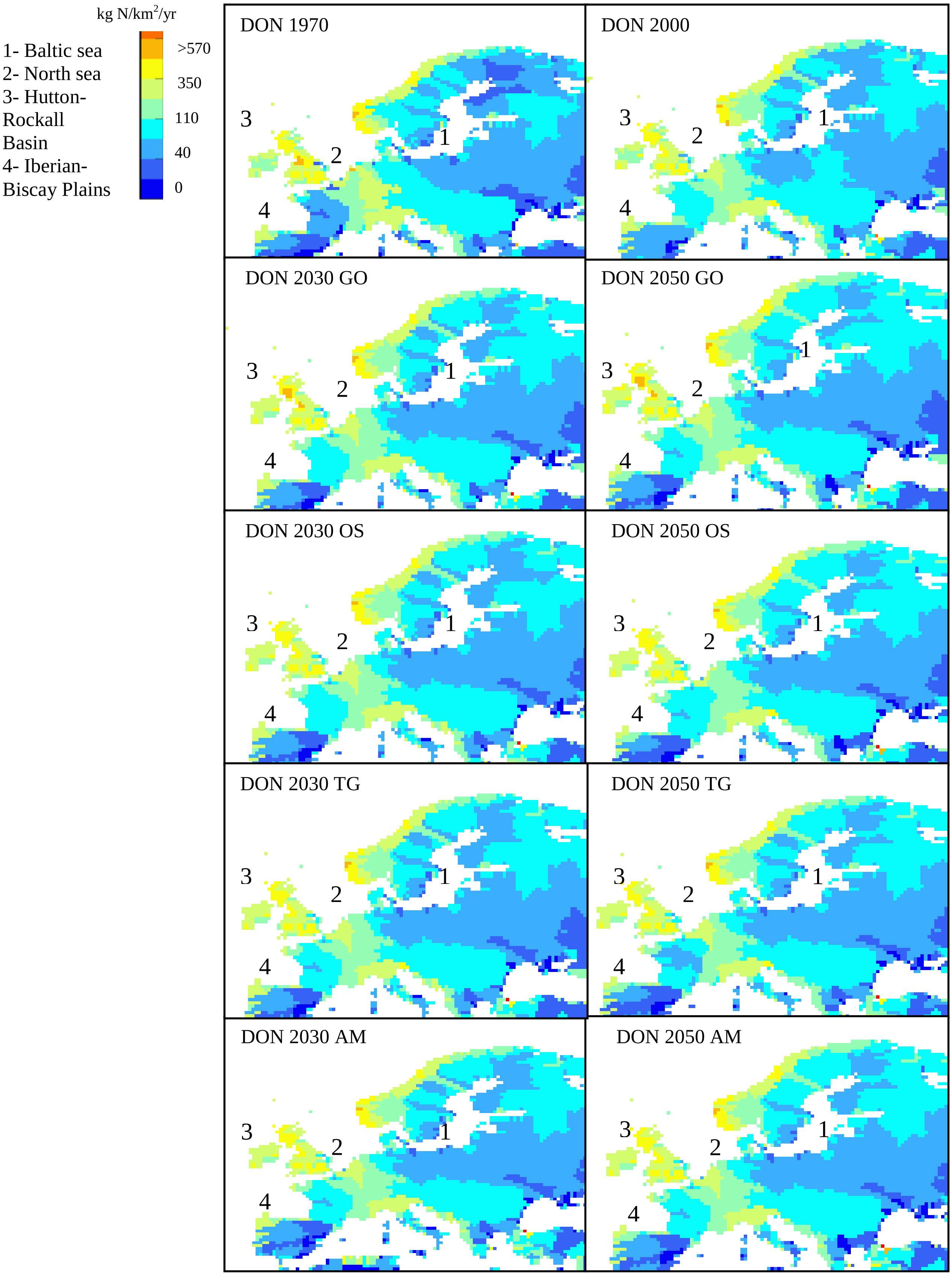


**Figure 2-26. Trends in DON yields from the selected European river basins.** GO=Global Orchestration scenario; OS=Oder from Strength scenario; TG=TechnoGarden scenario; AM=Adapting Mosaic scenario. Source: Global *NEWS* model output data for selected river basins.

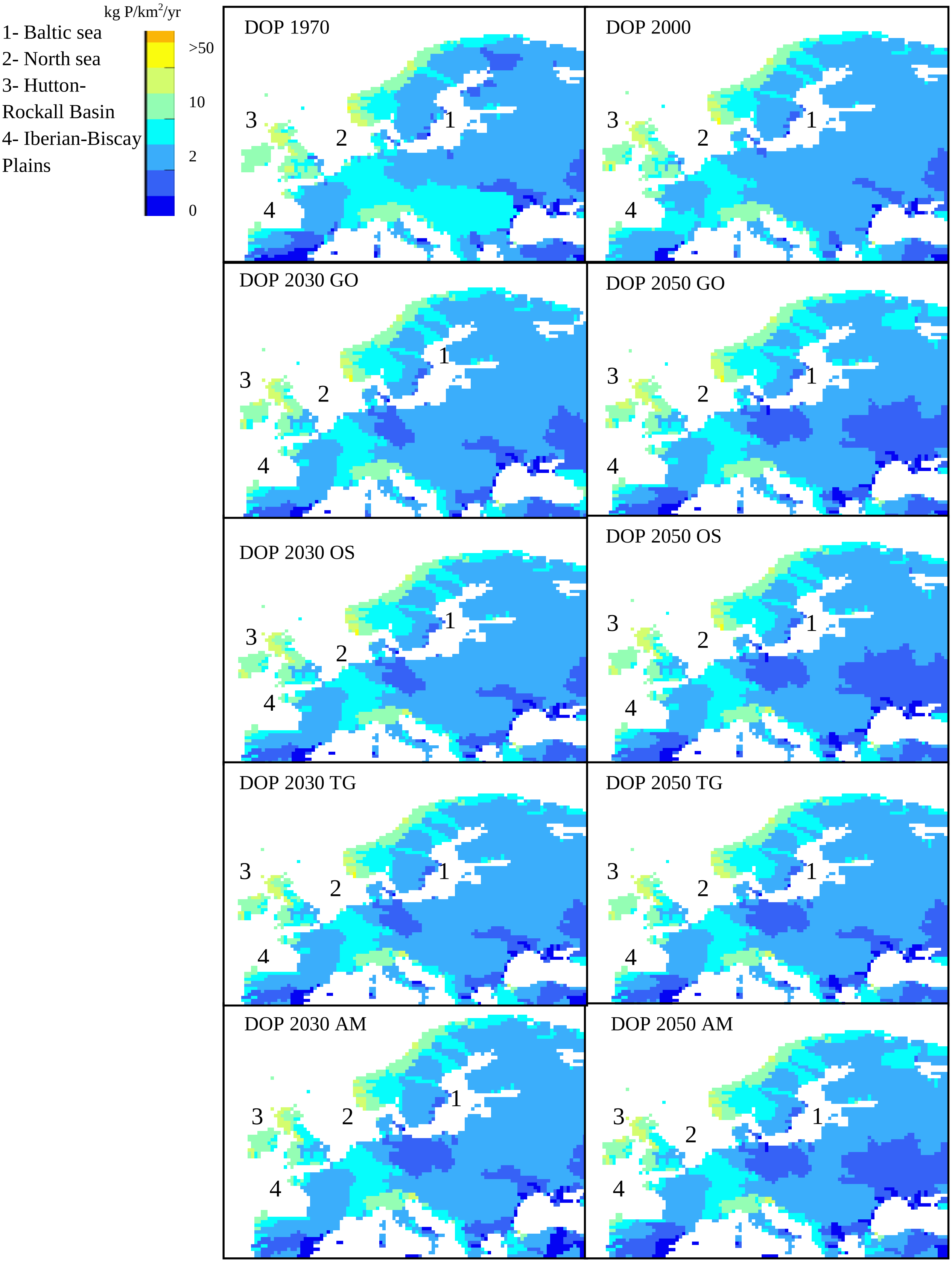


**Figure 2-27. Trends in DOP yields from the selected European river basins.** GO=Global Orchestration scenario; OS=Oder from Strength scenario; TG=TechnoGarden scenario; AM=Adapting Mosaic scenario. Source: Global *NEWS* model output data for selected river basins.

### 2.4.3 Carbon and particulate matter

In calculations of Global *NEWS* model DOC export highly depends on wetlands (Mayorga *et al.*, submitted, 2009). In the selected area no changes occurred in the percentage of wetland, and yet, DOC export increased over the period of 1970 and 2000 (Figure 2-28). This can be explained by increase in runoff in this period. In the future DOC export stabilizes having identical trends in all scenarios.

As with DOC export the increase in runoff between 1970 and 2000 caused higher export of particulate nutrients in 2000 relative to 1970 (Figure 2-29). Future trends of particulate matter stabilize with small differences among scenarios which can be partly attributed to changes in dam retention factor for sediments.

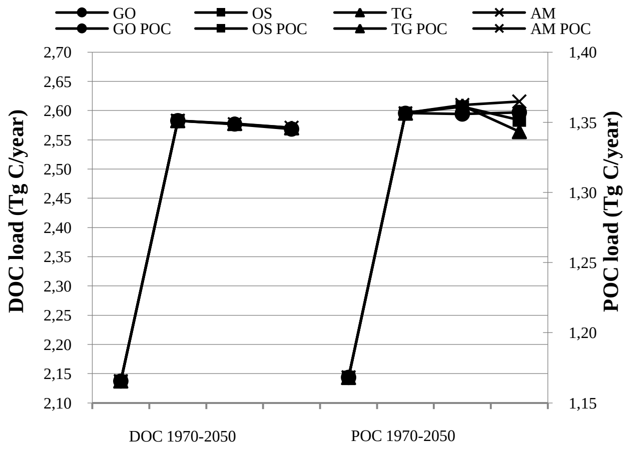


**Figure 2-28. Trends in export of dissolved organic and particulate C by selected European river basins.** GO=Global Orchestration scenario; OS=Oder from Strength scenario; TG=TechnoGarden scenario; AM=Adapting Mosaic scenario. Source: Global *NEWS* model output data for selected river basins.

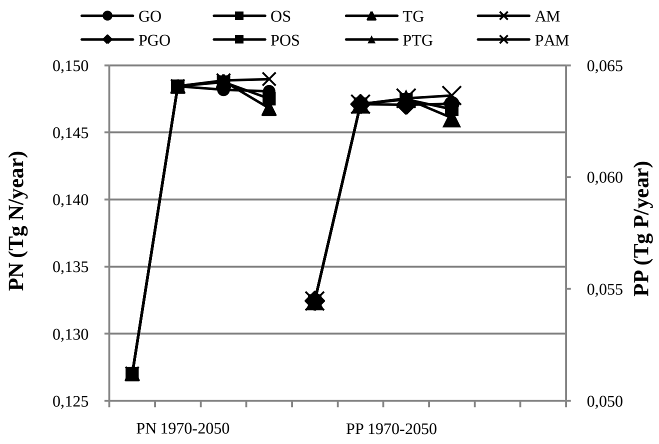


**Figure 2-29 Trends in export of particulate N and P by selected European river basins.** GO=Global Orchestration scenario; OS=Oder from Strength scenario; TG=TechnoGarden scenario; AM=Adapting Mosaic scenario. Source: Global *NEWS* model output data for selected river basins.

## 2.5 Measured and calculated nutrient export by selected European river basins

Global *NEWS* model was validate and calibrated at the global scale. A set of measurements of nutrient export was collected and compared to the values predicted by the model. At the global scale model fit ($R^2$) varies from about 0.5 to 0.9 (Mayorga *et al.*, submitted, 2009). With regard to the selected region measurements are available for only few rivers (for DIN, DIP, DON, DOC and TSS (total suspended solids) measurements are available for 14, 20, 1, 5 and 17 rivers, respectively, while for DOP no measurements for the selected river basins are present in the data sets for model calibration and validation) . Figure 2-30 compares modeled nutrient yields plotted against measured ones. Although it is not possible to perform a statistical analyses, it can be concluded, that for DIN, DIP and TSS model fit is reasonable, as almost for half of the rivers modeled values are consistent with observations. For DON and DOC model fit is very low. But it should be noted that for these forms even fewer measurements are available.

The study is based on the latest version of Global *NEWS* model (*NEWS*-2). In this version recalibration of DIN and DIP submodels was done as some input data and model components were modified. Thus, the data for comparison of measured and modeled DIN and DIP yield export by the selected European river basins is taken from the latest paper describing *NEWS*-2 by Mayorga *et al.* (submitted, 2009). DOC and particulate submodels were not recalibrated and the data sets for these forms were taken from earlier papers by Harrison *et al.* (2005) and Beusen *et al.* (2005).

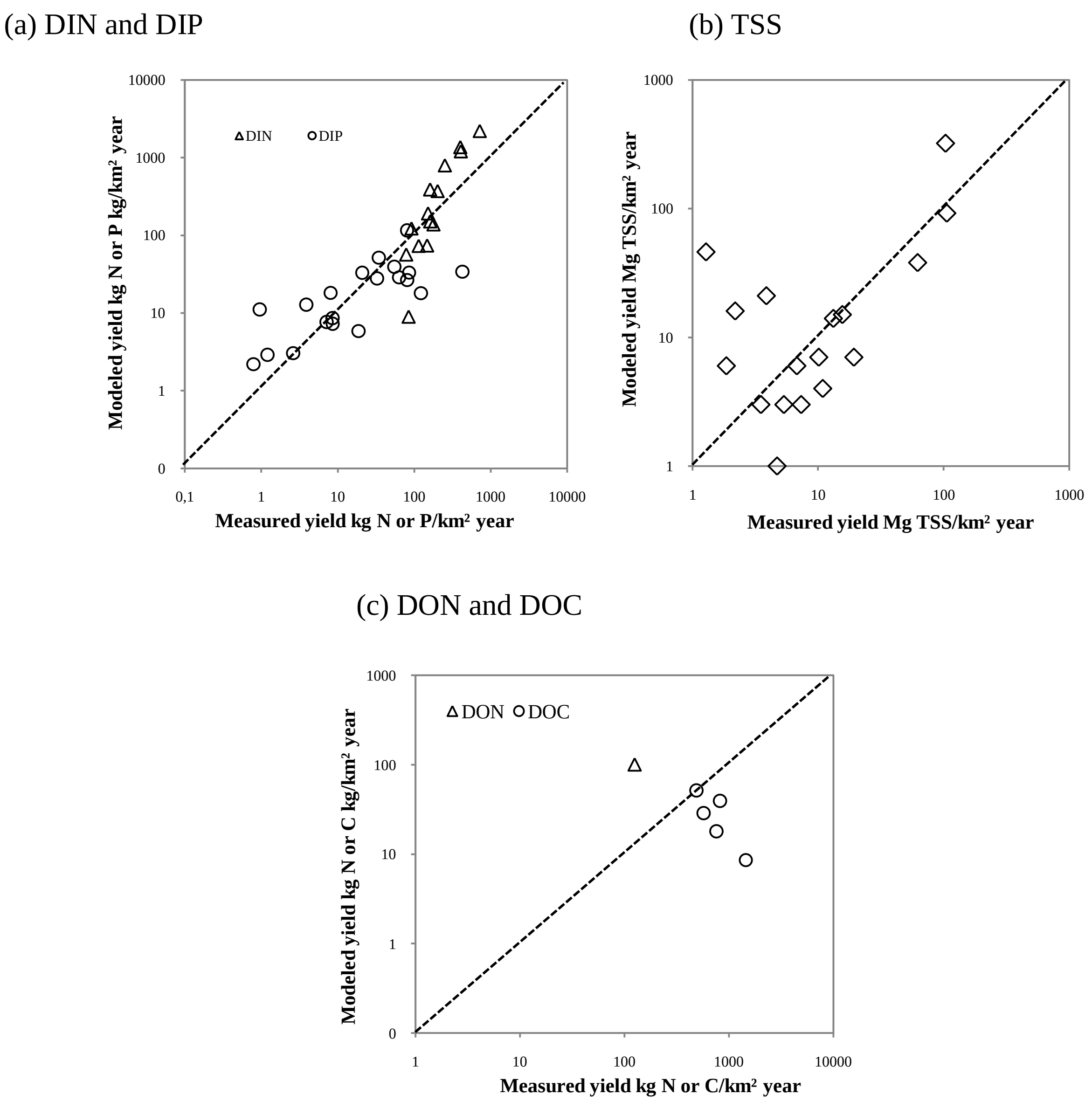


**Figure 2-30. Modeled versus measured yields of nutrients and TSS for the selected European river basins; a) yields of total suspended solids; b) yields of dissolved inorganic N and P; c) yields of dissolved N and C. Source: (Mayorga et al. 2009; Harrison et al. 2005; Beusen et al. 2005).**

## 2.6 Global NEWS model inputs reflecting meat consumption and agricultural practices

Global *NEWS* model contains different inputs related to hydrology of the watersheds, climate and human activities in order to calculate the export of nutrients to the coastal waters. Table 2-2 presents an overview of all inputs to the Global *NEWS* model that vary depending on time and scenario. Further analysis will focus on changes in agricultural land use and therefore the inputs that are associated with it and can be influenced by measures in agriculture are selected with a mark from the Table 2-2.

**Table 2-2. Input parameters used in Global *NEWS* model (parameters marked with + are chosen for further analysis)**

| **Inputs to Global *NEWS* models** | |
|---|---|
| Natural basin runoff | |
| Annual percipitation | |
| Fournier percipitation index | |
| Fraction removed through consumptive water use | |
| Dam retention factor for DIN | |
| Dam retention factor for DIP | |
| Dam retention factor for sediments | |
| Percentage of agricultural land | |
| Percentage of wetland under rice cultivation | |
| Percentage of marginal grassland | |
| N and P fertilizer inputs to watershed | + |
| N and P manure inputs to watershed | + |
| N and P export from watershed | + |
| $N_2$ agricultural fixation | + |
| $N_2$ natural fixation | + |
| N deposition over agricultural areas | + |
| N deposition over natural areas | + |
| N and P sewage emission to rivers from human waste (excrement) | |
| P sewage emission to rivers from detergents | |

In further analysis the assumptions for low-meat diets and increased sustainable agricultural practices in the selected region will be done in order to run Global *NEWS* model with these alternative scenarios. These assumptions will change the input parameters chosen previously and thus some changes will occur in the model results for nutrient export. The input parameter that reflects percentage of agricultural land was excluded from the analysis. This parameter is not used to calculate the export of nutrients but rather the source contribution and as it is extremely difficult to make an assumption of change in agricultural land area, including this parameter into the analysis would bring additional uncertainty. Moreover the model inputs that are chosen in the Table 2-2 are interconnected. Thus, the reduction in one parameter can cause an increase in the other. This is to be taken into account while assuming changes in input data.

## 2.7 Conclusion

From the analysis carried above it is clear that in the European river basins considered of nutrients from agricultural areas decrease in all scenarios between 2000 and 2050. However, agriculture remains an important source of most of the nutrient forms.

In general GO scenario has the highest nutrient river export. Higher economic growth and the number of population in this scenario relative to the other ones imply higher inputs of nutrients from anthropogenic sources which includes inputs from agriculture.

The loads of DIN have the largest differences among scenarios. The temporal changes in DIN loads can be attributed to the changes in N export from agricultural sources. DIP load decreased in the past due to decrease of P exported from point sources while in the future small difference can be observed among scenarios. DON and DOP river export shows little change over time. The increase in natural source contribution of this form of N and P can be observed in almost all scenarios while the share of agricultural and point sources decreases. The export of DOC and particulate nutrients has similar trends increasing in the past and stabilizing in the future. According to Global *NEWS* model their export highly depends on the presence of wetlands, runoff and damming of rivers (only for particulates). Therefore DOC and particulate nutrients can hardly be influenced by changes in chosen inputs parameters and are excluded from further analysis.

With regard to the yields of nutrients the highest export is calculated for the river basins draining into the North Sea, Hutton-Rockall and Iberian-Biscay plains sea basins in all years and scenarios. However, only small rivers drain into the Hutton-Rockall and Iberian-Biscay plains sea basins. Therefore they do not contribute much to the overall nutrient export. On the contrary North Sea and Baltic Sea have more and larger river basins. These river basins are responsible for the magnitude of the overall nutrient export causing the North and Baltic Seas suffer the most from nutrient pollution.

As it was already mentioned, further analysis will focus on the forms of nutrients that depend on agricultural land use such as DIN, DIP, DON and DOP. Comparison of the measured and calculated export of these forms showed, that model fit is acceptable only for DIN and DIP river export. For DOP comparison was not possible due to the lack of data and for DON a measurement for only one river basin was available. It is rather difficult to define a model performance with regard to the selected river basins as the available data set is too small for the statistical analysis.

Further scenario analysis will be carried out in order to determine whether sustainable agricultural practices or low-meat diets are able to decrease nutrient export by rivers in the selected region. Change in agricultural practices and meat consumption can influence inputs of nutrients to the soil with fertilizer, manure and deposition. Sustainable agriculture and low-meat diets can also bring change in composition of growing plants and their yields which in its turn has an effect on export of nutrients with harvest and $N_2$ fixation. Therefore, it was essential to identify the input parameters of Global NEWS model that correspond to these changes.

# 3 Alternative scenarios

## 3.1 Introduction

This chapter answers following research questions:

- What is the potential of low-meat diets to reduce nutrient export by European rivers to the coastal waters of the North Sea and the Baltic Sea in 2030 and 2050?
- What is the potential of sustainable agricultural practices to reduce nutrient export by European rivers to the coastal waters of the North Sea and the Baltic Sea in 2030 and 2050?

These questions are aiming at exploring alternative futures for the North and Baltic Seas and the role of low-meat diets and sustainable agriculture in them. In the paragraph 3.2 GO scenario with summarized assumptions underlying it is chosen as a basis for analysis. Before developing alternative scenarios sensitivity of model output to changes in the input parameters chosen in the previous chapter is performed (3.3). This is done in order to get a clear picture of management options that can best solve the problem of nutrient pollution coming from agriculture and to identify what forms of nutrients are the most sensitive to changes in input parameters. Next, storylines for three alternative scenarios are presented (3.4). These scenarios are developed for agricultural land use in the year 2050 as alternatives to GO 2050 scenario. The storylines describe alternative futures in which low-meat diets and sustainable agricultural practices are widespread in the region. Developed storylines are quantified with regard to input parameters of the Global *NEWS* model related to agricultural land use. The input parameters are in consistent with the alternative scenarios and the results of the model runs are described (3.5). The conclusion of this chapter is presented in the paragraph (3.6).

## 3.2 GO scenario as a baseline

The rationale for choosing the GO scenario as a basis for alternative scenario analysis lies in the current situation in the selected region. The GO scenario is closest to current trends in the development of the region as globalization and liberalization of the trade gain more importance and environmental problems increase. In order to use GO scenario in Global *NEWS* model several assumptions related to agricultural land use has been made.

GO scenario has the highest population and economic growth among four MEA scenarios resulting in the highest food demand. Thus crop and meat production is the highest in this scenario (Alcamo *et al.*, 2005). However, GO also assumes the largest technological progress in agricultural production systems. This brings higher yields and more productive livestock systems which help to meet food demand without area expansion (Bouwman *et al.*, in press, 2009). Besides, increased trade liberation is an important positive factor in meeting food demand. The net effect of this is that agricultural land area shows the fastest decrease in the GO scenario compared to the other MEA scenarios.

Due to the fast growth in food production (especially livestock production), manure and fertilizer inputs are relative in this scenario. Besides, it is assumed that in GO scenario the efficiency (kg of production per kg of fertilizer) is lower than in the other scenarios. This explains high fertilizer inputs (Bouwman *et al.*, in press, 2009).

Biological $N_2$ fixation is lower in GO scenario than in the others. Biological $N_2$ fixation rate depends on the production of leguminous and the grassland and crop land areas (Bouwman *et al.*, in press, 2009). In GO scenario as it was already mentioned the area of cropland and grassland is assumed to be smaller than in other scenarios and thus the amount of $N_2$ fixed by crops will be smaller.

Although agriculture contributes to N deposition from animal manure, the major source of it is industries. This explains N deposition over agricultural land in GO scenario being slightly lower than in OS and higher than in AM and TG. Higher economic growth in the GO scenario results in higher energy use and transportation. However in the OS scenario with the lowest economic growth, a lack of pollution control results in the highest $NO_x$ emissions and thus to the highest rates of deposition. In AM and TG measures to control air pollution caused the lowest rates of N deposition (Alcamo *et al.*, 2005; Bouwman *et al.*, in press, 2009).

The removal of N and P with harvested crops depends on the crop production and the content of N and P in this crop (Bouwman *et al.*, in press, 2009). As GO scenario is assumed to have the highest productivity among all scenarios, more nutrients are exported with crop harvest in this scenario than in the other three.

Knowing the assumptions underlying GO scenario which represent the baseline for the further analysis it will be now possible to develop alternative scenarios.

## 3.3 Sensitivity analysis

The purpose of a sensitivity analysis is to analyze how sensitive the output of the Global *NEWS* model is to changes in input parameters. This is important for the development of alternative scenarios that will be focused on changes in agricultural land use. The sensitivity analysis will help to identify management options that can best solve the problem of nutrient pollution of coastal waters in the selected region. The choice of the input parameters is discussed in section 2.6 of Chapter 2. The sensitivity analysis is performed for the GO scenario for the years 2030 and 2050. The input parameters are changed in a systematical way by reducing or increasing the values by 10%, 20%, 30%, 40% and 50%. The analysis of the model output is focused only on dissolved N and P since the export of other forms and nutrients are hardly dependent on the chosen input parameters.

### *3.3.1 DIN export*

DIN export modeled by Global *NEWS* depends on several input parameters related to land use, such as N fertilizer and manure inputs, N inputs from deposition and fixation and N export by crop harvesting and grazing. The calculated DIN export by rivers is rather sensitive to changes in N exported through harvest and grazing (Figure 3-1 and Figure 3-2). A reduction in this input parameter results in an increased load of DIN export by river. 20% reduction in N exported from the system results in about 10% increase in DIN load in the Baltic and North Seas. Among other parameters fertilizer input can largely influence calculated river export of DIN. With 20% fertilizer input reduction DIN export to the Baltic and North Seas can be decreased by about 9%. Changes in manure input are slightly less influential. N inputs from deposition and natural fixation are less important here as it is difficult to reach large reduction in these inputs by changes in agriculture. For N inputs from $N_2$ crop fixation sensitivity analysis is performed with increasing values (+10%, +20%, etc.). The reason for that is that increased crop fixation may be used as one of the management options (e.g. applying legumes as “green” fertilizer) in alternative scenarios. An increase in this input parameter result only in a very slight increase in calculated river export of DIN. This means that “green” fertilizer can to some extent substitute synthetic fertilizer without causing elevated nutrient export to coastal waters.

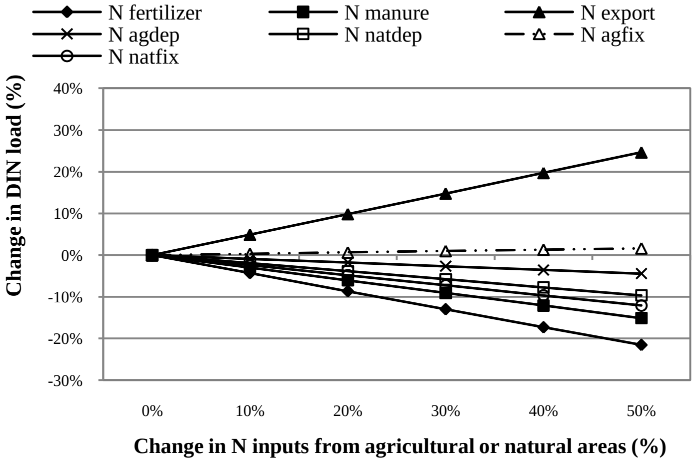


**Figure 3-1. Change in DIN export from the river basins draining into the North and Baltic Seas in 2030. Solid lines = change in DIN export caused by reduction of N inputs; dashed line =change in DIN export caused by increase of N inputs; N fertilizer = inputs from fertilizer application; N manure = inputs from animal manure; N export = N exported from the system due to crop harvest or grazing; N agdep = N inputs from deposition over agricultural land; N natdep = N inputs from deposition over natural land; N agfix = N inputs from N crop fixation; N natfix = N inputs from N fixation by natural areas.**

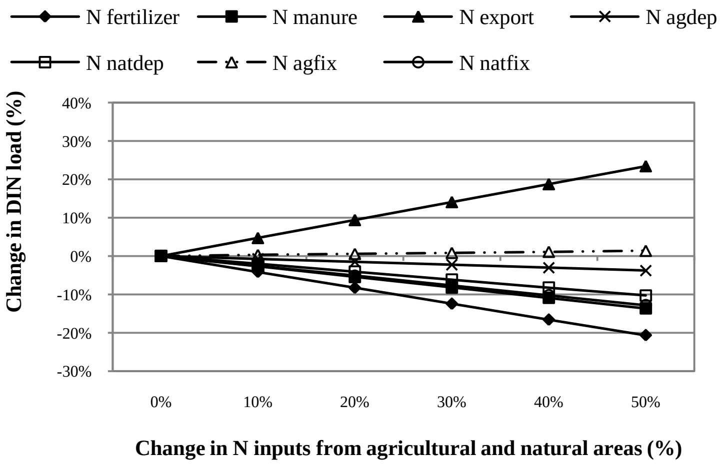


**Figure 3-2. As figure 3-1, but for 2050.**

### *3.3.2 DON export*

Among land use related input parameters only three influence the calculated DON export. These are N inputs from fertilizer, manure and N export with crop harvest and grazing. Unlike DIN, DON export is hardly sensitive to changes in inputs from agriculture as 50% reduction in any of the input parameters results in 2% or less change in calculated DON river export to the Baltic and North Sea for both 2030 and 2050 (Figure 3-3). This means that the export of DON is hardly influenced by changes in agricultural land use.

(a) (b)

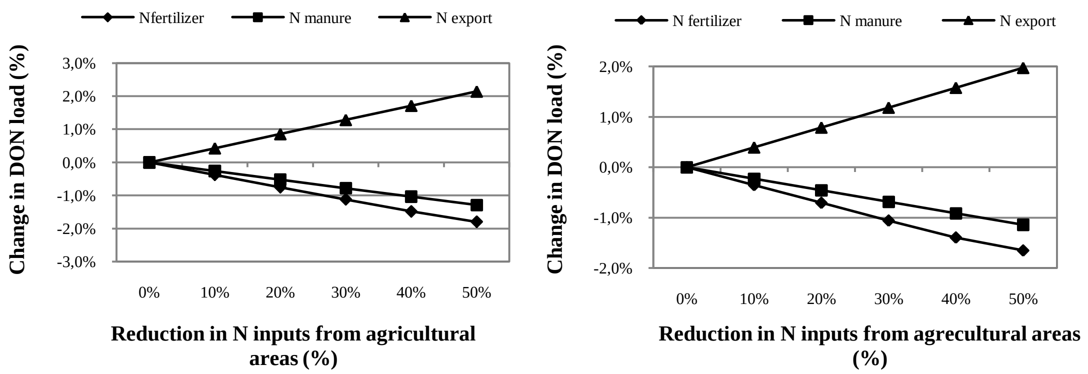


**Figure 3-3. Change in DON export from the river basins draining into the North and Baltic Seas in a) 2030 and b) 2050. N fertilizer = inputs from fertilizer application; N manure = inputs from animal manure; N export = N exported from the system due to crop harvest or grazing.**

### *3.3.3 DIP export*

The calculated DIP river export is slightly more sensitive to the changes in inputs related to agriculture than DON export is. Among the input parameters related to land use P export by crop harvesting and grazing is the most influential both in 2030 and 2050 (Figure 3-4). River export of DIP is equally sensitive to the reductions in fertilizer and manure inputs.

(a) (b)

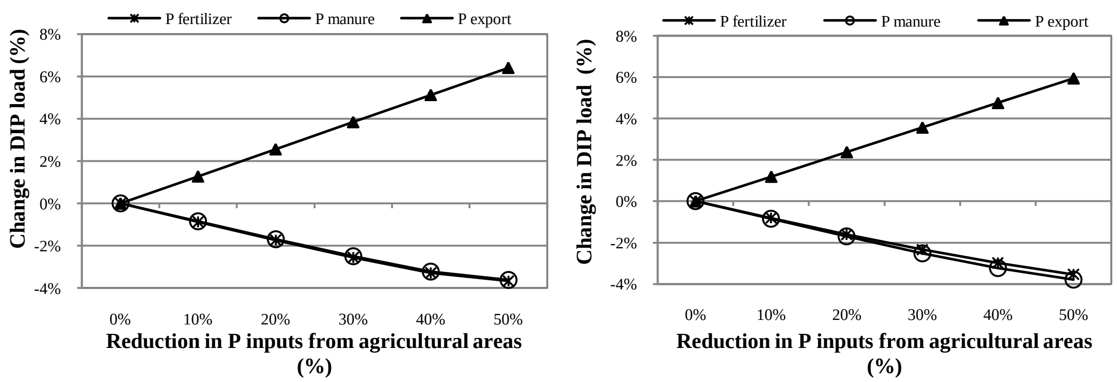


**Figure 3-4. Change in DIP export from the river basins draining into the North and Baltic Seas in a) 2030 and b) in 2050. P fertilizer = inputs from fertilizer application; P manure = inputs from animal manure; P export = P exported from the system due to crop harvest or grazing.**

## 3.4 Alternative scenarios

In this section three alternative scenarios for selected European rivers draining into Baltic and North Seas are presented. The scenarios consider moderate and extreme cases of more sustainable agricultural practices and a case of low-meat diets. Sustainable agricultural practices should be interpreted here as practices that involve pollution prevention measures and increased use of organic fertilizers. The alternative scenarios are first designed qualitatively and then interpreted for model inputs related to agricultural land use applying the GO scenario as a baseline. All assumptions underlying the GO scenario other than assumptions related to agricultural land use remain intact. The scenarios developed here are not intended to predict the future but rather to explore possible consequence of changed agricultural land use on nutrient export to coastal waters of Baltic and North Seas. The scenarios differ considerably from current situation and therefore are developed for the remote future. In the following three scenarios are described: Scenario 1 (Sustainable agriculture: moderate case, Scenario 2 (Sustainable agriculture: extreme case) and Scenario 3 (Low-meat diets).

### *3.4.1 Scenario 1: Sustainable agriculture (moderate case)*

Scenario 1 assumes that the environmental problems caused by intensive agriculture are recognized and some measures aiming at reducing this impact are taken. Motivated by the policies, farmers choose more sustainable practices and in a few cases even change to organic farming. Strategies to increase the efficiency of nutrient use are adopted to a moderate extent. These strategies include advanced fertilizer application techniques and more precise matching of nutrient supply with crop demand. Due to these measures fertilizer use is lower than in the GO 2050. The yields stay almost constant and there is no need to substitute N fertilizer with $N_2$ fixing crops. With constant yields the expansion of the agricultural land area does not occur. Due to this the $N_2$ fixation by crops and $N_2$ fixation by natural vegetation stays at the GO 2050 level. The total amount of manure available in the selected region stays at the GO 2050 level as well, as no changes occur in livestock numbers. Some moderate improvements in livestock management and manure storage, in line with Nitrates Directive of the EU, result in a reduction in N volatizing to the atmosphere, and thus have some positive effect on the N entering the system through atmospheric depositions. However, the amount of nutrients excreted by animals stays unaffected by the measures taken in this scenario. Moreover, with no changes in crop production and animal stock nutrients exported with crop harvest and animal grazing stay at the level of GO 2050 level.

#### *3.4.1.1 Quantitative interpretation of Scenario1*

To quantify the model inputs consistent with the storyline developed for Scenario 1, many assumptions have to be made. In this scenario it is assumed that 20% reduction in synthetic fertilizer input can be achieved without yield reduction. This is based on studies suggesting that with more efficient fertilizer use in high-N input regions it is possible to decrease N fertilizer input by 20-30% (Kroeze and Mosier, 2000; Howarth *et al.*, 2002). Fertilizers are assumed to have a fixed N:P ratio and with the decrease in N fertilizer input, P fertilizer application is assumed to decrease proportionally.

The scenario storyline supposes some improvements in manure and livestock management and this clearly has an effect on N inputs from atmospheric depositions. These depositions consist of $NO_x$ and $NH_3$, where $NO_x$ is attributed mostly to industrial and $NH_3$ to agricultural activities. Here it is assumed that $NH_3$ represents 50% of all N depositions in Europe (Dentener *et al.*, 2006). This assumption is the same for all scenarios. Full implementation of the Nitrates Directive in EU-27 which implies moderate changes in agricultural activities can decrease $NH_3$ emissions from agricultural systems. The results from the MITERRA-EUROPE model developed to assess the effects of policy measures on nutrient losses from agriculture shows that full implementation of the Nitrates Directive in EU-27 can reduce $NH_3$ emissions by 4% relative to a baseline scenario for the year 2020 (Oenema *et al.*, 2007). The model GAINS dealing with greenhouse gas emission and air pollution in Europe calculates a 9% reduction in $NH_3$ emissions with full implementation of the Nitrates Directive in 2020 (Amann *et al.*, 2008). By reference to these studies it is assumed that measures taken in Scenario 1 can reduce $NH_3$ emissions and thus depositions by 7%, which implies a 3.5% reduction in total N deposition.

Other inputs to the Global *NEWS* model related to agricultural activities remain unaffected by measures implemented in Scenario 1. The quantitative changes of model inputs for Scenario 1 are presented in Table 3-1.

**Table 3-1. Changes in Global *NEWS* model inputs for Scenario 1.**

| Input parameter | % change relative to GO 2050 |
|---|---|
| Fertilizer N and P inputs | -20 |
| Manure N and P inputs | 0 |
| Atmospheric N deposition inputs over agricultural areas | -3.5 |
| Atmospheric N deposition inputs over natural areas | -3.5 |
| $N_2$ fixation over agricultural areas | 0 |
| $N_2$ fixation over natural areas | 0 |
| N and P crop export (grazing and harvesting) | 0 |

### *3.4.2 Scenario 2: Sustainable agriculture (extreme case)*

In this scenario environmental problems caused by agriculture are recognized and measures are taken as well. However, these measures are more drastic than in Scenario 1. Relatively large numbers of farms switch from conventional to organic farming. Conventional farms are using the same technologies as described in Scenario 1, but to a much larger extent. Thus nutrient inputs from synthetic fertilizers drop down significantly. Synthetic fertilizers are partly replaced by $N_2$ fixing crops gain more importance and their use as “green manure” gets widespread. $N_2$ fixation rate by agricultural crops increases, as well as the area needed to grow these crops. Despite “green manure” application, the yields are lower then in GO 2005. This causes a reduction in export of agricultural products from the region in order to meet the local demand for food. Due to agricultural land extension a decrease in natural $N_2$ fixation occurs.

The changes in agricultural land use influence the livestock sector as well. Besides some improvements in the management of cattle and manure storage that decrease losses of nutrients from livestock production, increased organic farming results in decreasing in animal numbers as it requires more space than conventional farming. This causes a reduction in the total amount of manure available in the region. As in Scenario 1 management of manure and livestock improves but to a larger extent which not only reduces N volatilization from manure, but also nutrients excreted by animals. This results in larger reduction in N deposition from agriculture than in Scenario 1. Moreover, with reduced livestock and crop production export of nutrients removed from the system through animal grazing and crop harvest decreases.

#### *3.4.2.1 Quantitative interpretation of Scenario 2*

The storyline of Scenario 2 describes a more extreme case than the storyline of Scenario 1. In scenario 2 it is assumed that the reduction of fertilizer input twice is 40%.

Improved livestock management reducing nutrient excretion together with a slight decrease in animal numbers causes a reduction in nutrients entering the system with manure and deposition. Results from the MITERRA-EUROPE model indicate that with an optimal package of measures to reduce N pollution from agriculture it is possible to achieve an 8% reduction in N excreted by animals and a 20% reduction in $NH_3$ emissions in EU-27 in 2020 relative to the baseline scenario (Oenema *et al.*, 2007). However, the scenarios for MITERRA –EUROPE do not include changes in animal numbers, while in Scenario 2 of this study such changes take place. For this reason slightly larger reduction percentages are assumed in Scenario 2 with regard to nutrient excretion and $NH_3$ emissions: 10% and 25% respectively. This is translated to a 10% decrease in nutrients from manure inputs and 12.5% decrease in N depositions. As it was mentioned before N and P are supposed to have the same ratio for manure and fertilizer inputs thus they decreasing proportionally and $NH_3$ is assumed to constitute half of all N depositions.

It is assumed that fertilizer is partly substituted with N from crop fixation and application of “green” manure. This creates more $N_2$ fixed by crops. Granstedt (2000) in his study compared supply, export and surplus of nutrients on several farms in Sweden. This comparison showed that an organic combined (arable and livestock) farm has about 60% more $N_2$ fixed by crops than a conventional combined farm. In Scenario 2 large numbers of farm in the selected region switch to organic. Thus we assume about 25% increase in $N_2$ fixation by agricultural crops.

Slight increases in agricultural land area cause a decrease in $N_2$ fixation over natural areas. It is very difficult to quantify this decrease and as the increase in agricultural area is only a slight one it is assumed that $N_2$ fixation over natural areas decrease only by 5%.

The same assumption is made with nutrient export through harvest and grazing. The calculation of this input parameter involves many factors such as crop yields, crop uptake, number of animals and so on and as these factors do not change largely in Scenario 2, it is assumed that nutrient export reduces by 10%.

The quantitative changes of model inputs for Scenario 2 are presented in Table 3-2.

Table 3-2. Changes in Global *NEWS* model inputs for Scenario 2.

| Input parameter | % change relative to GO 2050 |
|---|---|
| Fertilizer N and P inputs | -40 |
| Manure N and P inputs | -10 |
| Atmospheric N deposition inputs over agricultural areas | -12.5 |
| Atmospheric N deposition inputs over natural areas | -12.5 |
| $N_2$ fixation over agricultural areas | +25 |
| $N_2$ fixation over natural areas | -5 |
| N and P crop export | -10 |

### 3.4.3 Scenario 3: Low-meat diets

This scenario assumes that different strategies are used to tackle environmental problems caused by intensive agriculture. Changes in human diets occur in the region with a moderate shift to lower animal protein consumption. Instead of typical Europe and Baltic States 2003 diet, the diet similar to Italy 1963 or Turkey 1993 is adopted (Table 3-3). Due to these changes in diets livestock production drops down and so do fertilizer and manure inputs. As humans rely more on vegetables and cereals the area formerly used for livestock feed production is used for crop production. However crop production is less intensive than livestock thus agricultural land and total crop and grass production decrease. While less fodder is grown and fewer animals graze nutrient export with harvests and grazing reduces as well. N deposition coming from agriculture decreases with decreasing manure inputs. Some changes occur in N fixation in natural and agricultural areas. With reduced total crop and grass production and decreased agricultural area N fixation by crops slightly goes down, while N fixation by natural areas goes up.

Table 3-3. Description of diets for Europe and Baltic States 2003, Turkey 1963 and Italy 1963.

| Diet name | Average protein supply (g/per/day) | | | Source |
|---|---|---|---|---|
| | Total | Animal | Vegetal | |
| **Europe&Baltic States 2003** | 105 | 61 | 44 | (FAO, 2009) |
| **Turkey 1993** | 101 | 26 | 75 | (Bleken, 1997) |
| **Italy 1963** | 85 | 32 | 63 | (Bleken, 1997) |

#### 3.4.3.1 Quantitative interpretation of Scenario 3

The assumptions for quantifying the Global *NEWS* model inputs for Scenario 3 are made on the basis of study made by Bleken (1997). In her analysis it is stated that total N supply to soils can be reduced by almost half with the switch from a high animal protein diets (similar to Europe and Baltic States 2003 diet) to lower animal protein diets (equivalent to the Turkish 1993 and

Italian 1963) (Table 3-3). Therefore, a net reduction of 45% is assumed in total N supply to soil from manure, fertilizer, agricultural $N_2$ fixation and atmospheric N deposition inputs in Scenario 3. It is difficult to estimate the associated increase in natural $N_2$ fixation and decrease in N and P export by harvest and grazing. The changes in these parameters are assumed to be minor, thus natural $N_2$ fixation increases by 10% and nutrient export by 15%. As in Scenarios 1 and 2 P inputs and export reduce proportionally to the ones of N. The changes in Global *NEWS* model are quantitatively specified in Table 3-4.

**Table 3-4. Changes in Global *NEWS* model inputs for Scenario 3.**

| Input parameter | % change relative to GO 2050 |
|---|---|
| Fertilizer N and P inputs | -45 |
| Manure N and P inputs | -45 |
| Atmospheric N deposition inputs over agricultural areas | -45 |
| Atmospheric N deposition inputs over natural areas | -45 |
| $N_2$ fixation over agricultural areas | -45 |
| $N_2$ fixation over natural areas | +10 |
| N and P crop export | -15 |

## 3.5 Results of the model run

### *3.5.1 Baltic Sea*

The Global *NEWS* model was run, using the alternative inputs summarized in Table 3-1, Table 3-2 and Table 3-3. First the results for Baltic Sea are presented. The export of DIN by rivers to the Baltic Sea is increasing with time (from 1970 to GO 2050). All alternative scenarios show a decrease in DIN export relative to GO 2050 (Figure 3-5). In GO the DIN export to the Baltic Sea increases by about 13% between 2000 and 2050. The *NEWS* model results suggest that with management options assumed in Scenario 1 this can be reduce to a 5% increase. In Scenario 2 the DIN export to Baltic Sea in the year 2050 is back at the level of 1970. Scenario 3 shows the largest decrease among all alternative scenarios. The calculated DIN export to the Baltic Sea in this scenario is almost 15% lower than in the year 1970. Figure 3-7 shows reduction in nutrient export to Baltic Sea relative to GO 2050. It includes the average and the range of reduction for 33 river basins draining into the Baltic Sea. The calculated average decrease in DIN export by rivers is 7%, 15% and 26% for Scenario 1, Scenario 2 and Scenario 3, respectively. For some river basins the decrease goes down to 60% in Scenario 3.

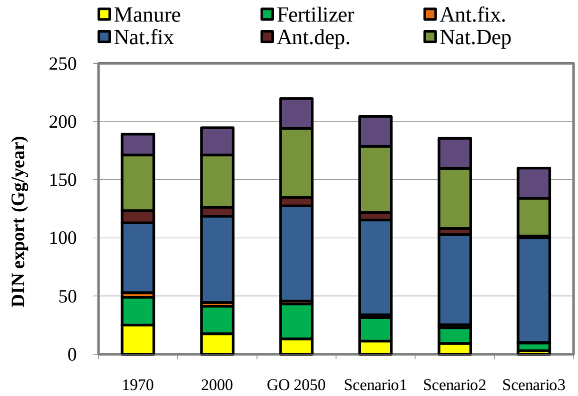


**Figure 3-5. Source specified DIN export to Baltic Sea for 1970, 2000, GO 2050 and alternative scenarios.**

The results for DIP, DON and DOP show that export to the Baltic Sea in the alternative scenarios is slightly lower than in GO 2050. This is due to agricultural sources representing rather small part of the export of these forms of nutrients (Figure 3-6). However on Figure 3-7 it can be observed that while the average export reduction is insignificant, for some river basins where agricultural sources are important the change in dissolved nutrient export (especially in DIP and DOP) is considerable. The reduction in DIP export ranges from 0 to 10, 15 and 40% for Scenario 1, Scenario 2 and Scenario 3, respectively. For DOP export the range is comparable while for DON it is less than 10% for all basins.

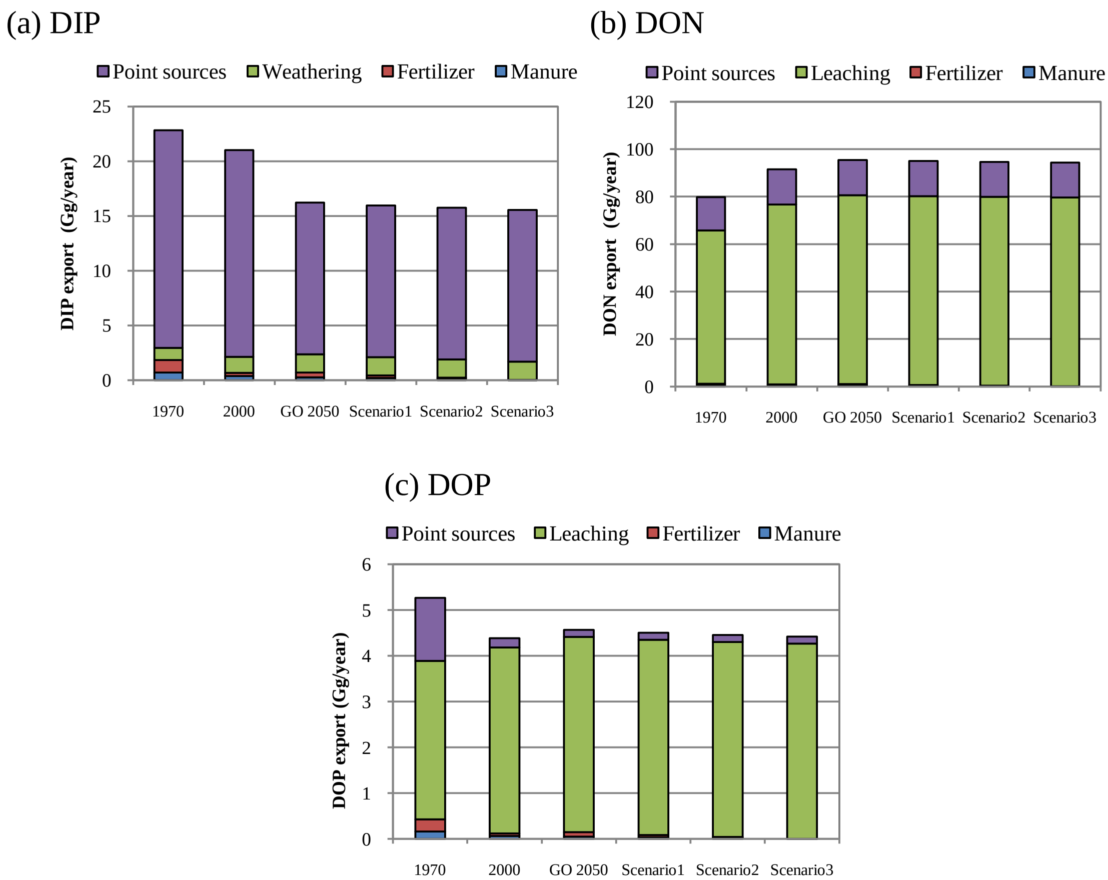


**Figure 3-6. Source specified nutrient export to Baltic Sea for 1970, 2000 GO 2050 and alternative scenarios; a) DIP export to Baltic Sea; b) DON export to Baltic Sea; c) DOP export to Baltic Sea.**

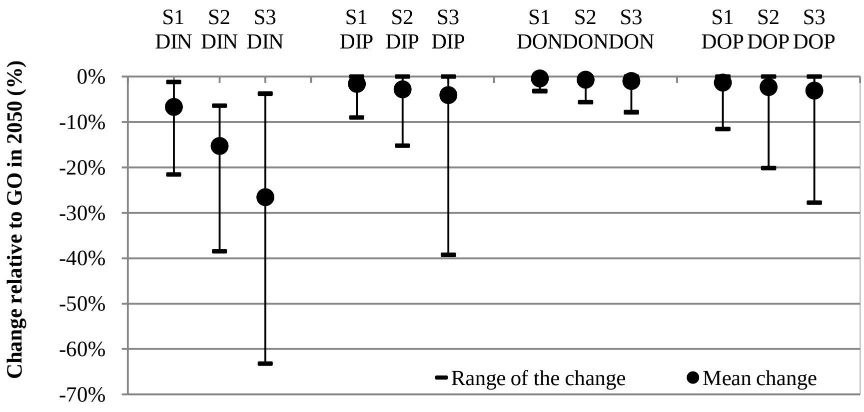


**Figure 3-7. Change in dissolved N and P export to Baltic Sea in 2050 for alternative scenarios relative to GO scenario; S1=Scenario 1; S2=Scenario 2; S3=Scenario 3.**

The reduction of nutrient export to the Baltic Sea varies greatly among the river basins especially for DIN in all alternative scenarios and for DIP and DOP for Scenario 2 and 3. Therefore, more detailed overview of the change in nutrient export to the Baltic Sea for some large river basins is presented in Table 3-5. The percentage of reduction is high in those river basins where agricultural land occupies a considerable amount of area. The size of the river basin can have an effect on the reduction values as well. Pregolya and Odra have similar percentage of agricultural land; however the alternative scenarios have more considerable effect on the reduction of export of DIN and DIP from Pregoyla. As smaller river basins with intensive agriculture have higher pollution levels then bigger ones with similar agricultural intensity, they respond faster on the measures taken to reduce pollution from agricultural activities.

**Table 3-5. Detailed overview of the change of nutrient export to the Baltic Sea for alternative scenarios relative to GO 2050 at the river basin level.**

| Baltic Sea | | | | | | | |
|---|---|---|---|---|---|---|---|
| River basin | Change in nutrient load relative to GO 2050 (%) | | | | Basin area (km2) | Agricultural land (%) | Population density, projected for GO 2050 (inh/km2) |
| | DIN | DIP | DON | DOP | | | |
| **Scenario 1** | | | | | | | |
| Neva | -1 | 0 | 0 | 0 | 240726 | 2 | 25 |
| Wisla | -14 | -2 | -2 | -7 | 179883 | 51 | 127 |
| Odra | -13 | -1 | -1 | -7 | 118731 | 64 | 116 |
| Nemanus | -9 | -3 | -1 | -3 | 95531 | 38 | 40 |
| Daugava | -3 | -1 | 0 | 0 | 83315 | 21 | 25 |
| Narva | -5 | -3 | 0 | -1 | 54373 | 31 | 15 |
| Kemijoki | -2 | 0 | 0 | 0 | 51680 | 0 | 2 |
| Pregolya | -20 | -9 | -3 | -8 | 16988 | 64 | 50 |
| **Scenario 2** | | | | | | | |
| Neva | -7 | 0 | 0 | 0 | 240726 | 2 | 25 |
| Wisla | -26 | -3 | -3 | -12 | 179883 | 51 | 127 |
| Odra | -23 | -1 | -2 | -12 | 118731 | 64 | 116 |
| Nemanus | -19 | -4 | -1 | -4 | 95531 | 38 | 40 |
| Daugava | -10 | -2 | 0 | -1 | 83315 | 21 | 25 |
| Narva | -13 | -6 | -1 | -1 | 54373 | 31 | 15 |
| Kemijoki | -9 | 0 | 0 | 0 | 51680 | 0 | 2 |
| Pregolya | -34 | -15 | -5 | -14 | 16988 | 64 | 50 |
| **Scenario 3** | | | | | | | |
| Neva | -9 | 0 | 0 | 0 | 240726 | 2 | 25 |
| Wisla | -44 | -4 | -4 | -16 | 179883 | 51 | 127 |
| Odra | -40 | -1 | -3 | -14 | 118731 | 64 | 116 |
| Nemanus | -34 | -6 | -2 | -6 | 95531 | 38 | 40 |
| Daugava | -22 | -3 | 0 | -1 | 83315 | 21 | 25 |
| Narva | -27 | -9 | -1 | -2 | 54373 | 31 | 15 |
| Kemijoki | -20 | 0 | 0 | 0 | 51680 | 0 | 2 |
| Pregolya | -61 | -19 | -6 | -18 | 16988 | 64 | 50 |

### 3.5.2 North Sea

Under all alternative scenarios Global *NEWS* model projects a decrease in DIN export to the North Sea (Figure 3-8). Unlike with Baltic Sea the reduction in DIN export can already be observed since 1970. In GO 2050 DIN export decreases 10% relative to the year 2000. Alternative scenarios can provide even larger reduction. Under Scenario 1 DIN river export can go down by 20% in 2050 relative to the current (2000) level and by 30% and even 50% under Scenario 2 and 3, respectively. Quite significant average reduction in DIN river export is projected under the alternative scenarios relative to GO 2050 (Figure 3-10). The range of the reduction is high as well.

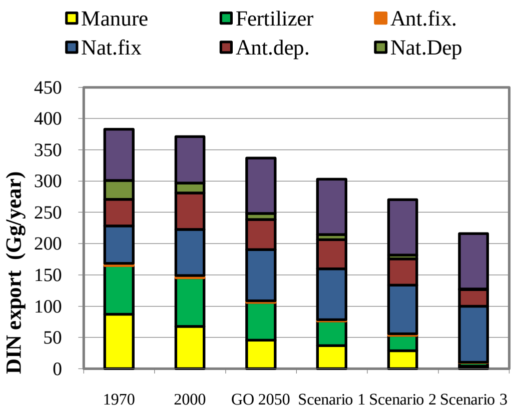


**Figure 3-8. Source specified DIN export to North Sea for 1970, 2000, GO 2050 and alternative scenarios.**

As with the Baltic Sea the export of DIP, DON and DOP to the North Sea under the alternative scenarios is slightly lower compared to GO 2050 although the reduction in nutrients coming from agricultural sources can be seen (Figure 3-9). However while change in DON export is insignificant for all river basins, change in DIP and DOP export can be 20 or even 30% depending on the alternative scenario.

A considerable difference in the effect of the alternative scenarios among river basins draining into the North Sea makes it important to address the issue at the river basin level (Table 3-6). The river basins with intensive agriculture such as Rhine, Elbe and Meuse show high percentage of change in nutrient export, especially in Scenario 2 and 3. Interestingly, DIN and DIP export by river Gota changes considerably as well while this river basin has only 12 % of agricultural land. This can be attributed to the low population density in the basin area which causes agricultural sources become more important and thus the measures in alternative scenarios show higher effectiveness.

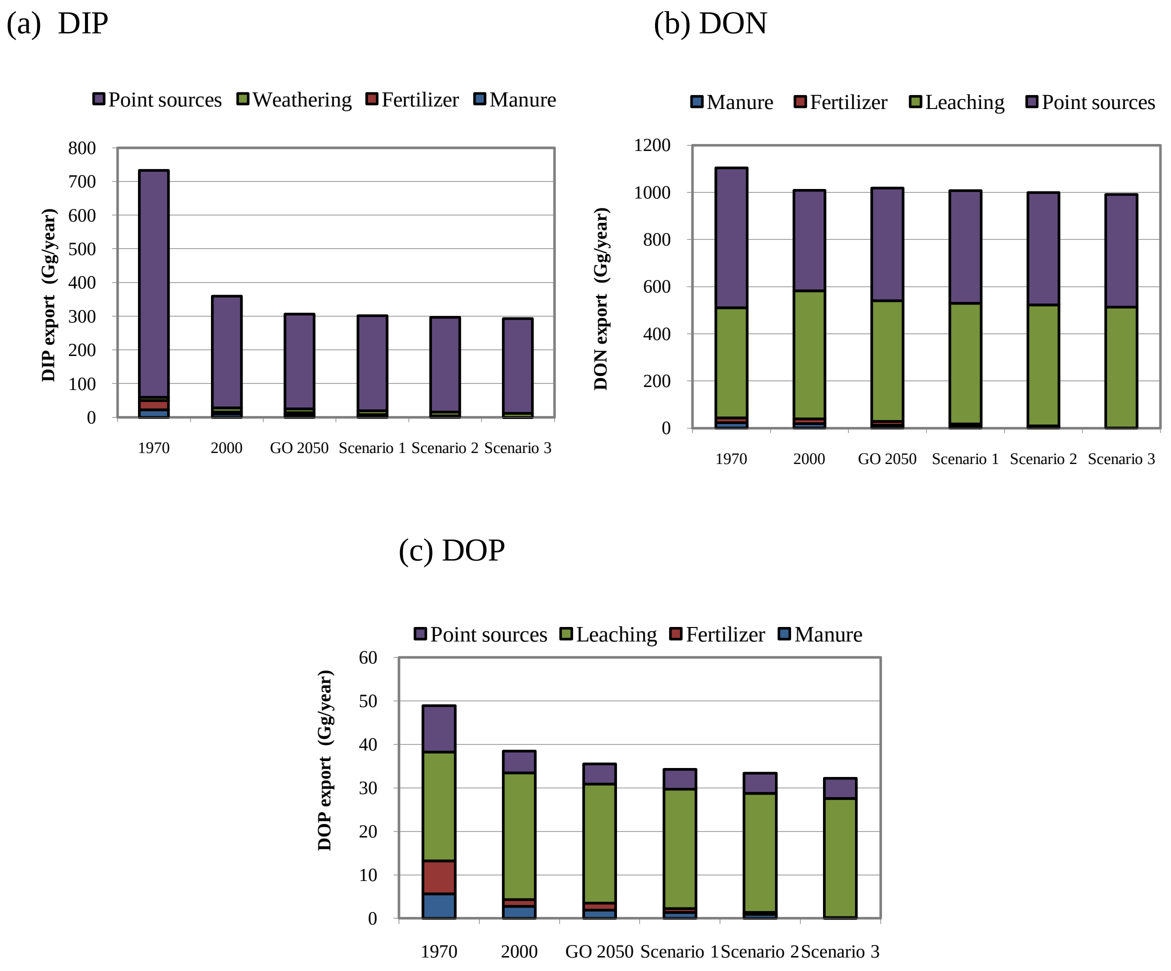


**Figure 3-9. Source specified nutrient export to North Sea for 1970, 2000, GO 2050 and alternative scenarios; a) DIP export; b) DON export; c) DOP export.**

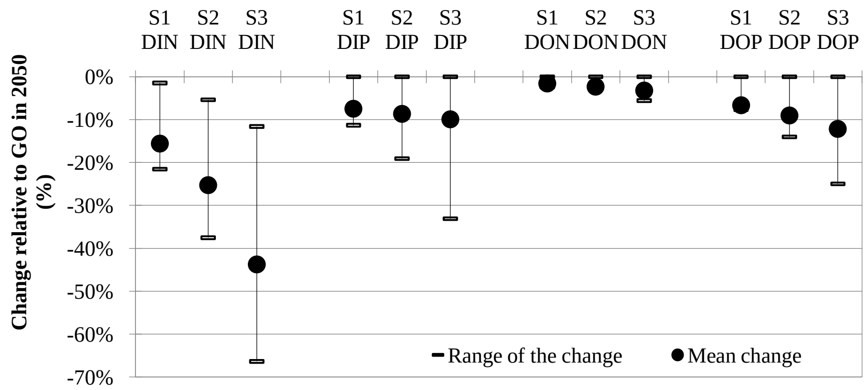


**Figure 3-10. Change in dissolved N and P export to North Sea for alternative scenarios relative to Go 2050; S1=Scenario 1; S2=Scenario 3; S3=Scenario 3.**

Table 3-6. As Table 3-5, but for the North Sea.

| North Sea | | | | | | | |
|---|---|---|---|---|---|---|---|
| River basin | Change in nutrient load relative to GO 2050 (%) | | | | Basin area | Agricultural land (%) | Population density, projected for GO 2050 (inh/km2) |
| | DIN | DIP | DON | DOP | | | |
| **Scenario 1** | | | | | | | |
| Rhine | -14 | -4 | -1 | -5 | 163750 | 46 | 325 |
| Elbe | -13 | 0 | -1 | -4 | 148118 | 54 | 175 |
| Gota | -8 | -10 | 0 | -1 | 44107 | 12 | 24 |
| Glama | -1 | 0 | 0 | 0 | 45654 | 0 | 35 |
| Weser | -11 | -1 | -1 | -4 | 45388 | 29 | 215 |
| Meuse | -11 | -3 | -1 | -6 | 43284 | 50 | 317 |
| **Scenario 2** | | | | | | | |
| Rhine | -25 | -7 | -3 | -9 | 163750 | 46 | 325 |
| Elbe | -23 | 0 | -2 | -4 | 148118 | 54 | 175 |
| Gota | -17 | -17 | -1 | -2 | 44107 | 12 | 24 |
| Glama | -7 | 0 | 0 | 0 | 45654 | 0 | 35 |
| Weser | -20 | -1 | -2 | -5 | 45388 | 29 | 215 |
| Meuse | -22 | -5 | -3 | -11 | 43284 | 50 | 317 |
| **Scenario 3** | | | | | | | |
| Rhine | -50 | -9 | -4 | -12 | 163750 | 46 | 325 |
| Elbe | -41 | 0 | -2 | -4 | 148118 | 54 | 175 |
| Gota | -26 | -18 | -1 | -2 | 44107 | 12 | 24 |
| Glama | -10 | 0 | 0 | 0 | 45654 | 0 | 35 |
| Weser | -38 | -1 | -2 | -5 | 45388 | 29 | 215 |
| Meuse | -51 | -12 | -5 | -26 | 43284 | 50 | 317 |

## 3.6 Conclusion

The scenario analysis showed that all of the developed scenarios show a decrease in dissolved nutrient export to the Baltic and North Seas. Under Scenario 1 where moderate transition to more sustainable practices is assumed the reduction of nutrient pollution is the smallest among all three alternative scenarios. The largest reduction of nutrient pollution is calculated for Scenario 3 where shift to low meat-diets is assumed. In general, the effect of alternative scenarios is considerable only for DIN river export for both Baltic and North Seas while export of other forms of nutrients is not affected largely at the sea level.

For the Baltic Sea the alternative scenarios can help to slow down or avoid the increase in DIN export that is projected by the Global *NEWS* model for the year 2050. Even a moderate switch towards more sustainable practices in agriculture can reduce the increase in DIN river export from 13% between 2000 and GO 2050 to 5% between 2000 and Scenario1. In more extreme case (Scenario 2) DIN export to the Baltic Sea in the year 2050 can be at the level of

1970. And, shift to low-meat diets in the region of Baltic Sea (Scenario 3) can keep the level of DIN river export even lower than one in 1970.

Concerning the North Sea where reduction of DIN river export is projected in GO 2050 relative to the years1970 and 2000 alternative scenarios can provide even higher reduction of pollution. Moderate measures in Scenario 1 resulted in moderate decrease in DIN river export to the North Sea reducing 20%, relative to the current (2000) level in stead of 10% that it predicted for GO 2050. Scenario 2 and Scenario 3 have more profound effect on the river export of DIN to the North Sea. The reduction in these scenarios compared to the GO 2005 is 30 and 50% for Scenario 2 and Scenario 3, respectively.

The change in DIP, DON and DOP river export at the sea level relative to GO scenario in 2050 is very small and in the case of DON almost negligible. This result was already predictable since sensitivity analysis showed that these forms of nutrient are hardly sensitive to changes in model input parameters related to agriculture. However, it should be noted that for some river basins the change in DIP and DOP export to both seas is rather large down to 60% in some cases. It means that alternative scenarios were not so effective in decreasing the export of some nutrient forms in the regions as a whole but for some river basins rather large reduction of pollution was reached.

# 4 Conclusions and recommendations

## 4.1 Introduction

This chapter draws conclusions with regard to the purpose of study: to analyze past, present and future trends in nutrient export to coastal waters, and to assess the potential of low-meat diets and sustainable agricultural practices to reduce future nutrient export by rivers draining from Europe into the North Atlantic Ocean. This will be done at the level of the ocean as well as its sea basins, with a special emphasis on the North and Baltic seas.

The past trends of nutrient export to the coastal waters of North Atlantic analyzed at the level of the ocean were stable with slight variations for some nutrients. It is projected that in the future the decreasing trend will take over. The results of the model runs with alternative scenarios showed that sustainable agriculture implemented to an extreme extent and low-meat diets (Scenario 2 and 3) provided a decrease in the overall river export of DIN to both, the Baltic and North Seas, while moderate spread of sustainable agricultural practices (Scenario 3) resulted in less profound decrease. The reduction in DON river export is negligible in all scenarios and therefore it may be concluded that measures assumed in Scenario 1, 2 and 3 are not suitable for reducing DON river export. With regard to the other dissolved nutrient forms (DIP and DOP) sustainable agriculture and low-meat diets are only effective in certain river basins, where agricultural sources of pollution have higher importance. In general, a shift to low-meat diets has higher potential to reduce nutrient pollution of coastal waters in the future than sustainable agricultural practices. These conclusions were drawn from the answers to the six research questions of this study. The first research question deals with the past export by European rivers to the coastal waters of the North Atlantic. The second question considers validation of the Global *NEWS* model for the selected region, comparing calculated nutrient export by selected rivers to export that was measured. The third question analyzes future trends in nutrient river export in the selected region. The forth question inquires in the inputs to the model that reflect agricultural practices and meat consumption. The fifth and sixth research questions discover alternative futures for the Baltic Sea and the North Sea. These questions are aimed at analyzing the potential of sustainable agriculture and low-meat diets to reduce nutrient export to the Baltic Sea and the North Sea.

In the following, these six questions are addressed (4.2 and 4.3) and the results are critically discussed together with recommendations for further studies (4.4). Besides, the implementation of these results in the policymaking is considered.

## 4.2 Past and future trends in nutrient export to the coastal waters of the North Atlantic

River export of nutrients that pollute coastal waters is mostly associated with socio-economical drivers, agricultural land use and hydrology. These drivers define the tendency in nutrient export by the selected rivers to the coastal waters of the North Atlantic Ocean. In the past population trends were quite stable and the inputs from agricultural areas decrease. However, hydrological factors such as run off increased from 1970 and 2000 due to more intensive precipitation in the selected area. The net effect of these trends for the river export of nutrients is a slight increase in the export of some forms of nutrients between 1970 and 2000.

Between 2030 and 2050 the nutrient export to the coastal waters of the North Atlantic is projected to stabilize or decrease for dissolved nitrogen, carbon and particulate nutrients depending on the scenario. Dissolved phosphorus has decreasing trends in all scenarios. Agricultural inputs to the watersheds of the selected area remain important drivers of the nutrient pollution. For this reason the issue of nutrient pollution coming form agricultural sources is addressed in the alternative scenarios.

In general, nutrient pollution of coastal waters of the North Atlantic is projected to be higher in the GO scenario than in other scenarios. Therefore, this scenario has been chosen for the analysis with alternative scenarios where more sustainable agricultural practices and decreased meat consumption are assumed.

Concerning the yields of the nutrients in the coastal waters of the selected area, the Hutton-Rockall and Iberian-Biscay sea basins have the highest pollution per $km^2$ in the past and future. However, only small rivers drain into these sea basins, so that they do not contribute much to the overall nutrient pollution of the North Atlantic Ocean. The North and Baltic Seas with large river basins are more important here and therefore, deserve more attention. The analysis of alternative scenarios focuses on dissolved N and P (DIN, DON, DIP and DOP). This is because DOC and particulates are not dependent on the inputs from agriculture.

Before the alternative scenarios could be developed and the Global *NEWS* model could be run, it was necessary to identify the input parameters of the model that reflect agricultural practices and meat consumption. Among these are fertilizer and manure inputs, export of nutrients with crop harvest and grazing, biological $N_2$ fixation in natural and agricultural areas and N deposition over natural and agricultural areas. These input parameters represent diffuse sources of nutrient pollution and are of anthropogenic as well as natural origin. However, changes in the anthropogenic diffuse source can influence the pollution coming from natural ones and therefore both sources are treated together in the alternative scenarios.

One of the constraints that has been faced while developing the alternative scenarios for the selected area is validation of the model for this area. As the Global *NEWS* model is a global model and its validation was performed at the global scale, measurements of nutrient river export were available for only few river basins in the selected area. These were used for a comparison of measured and modeled nutrient export. For DIN, DIP and TSS the model fit was rather reasonable, and better than for other nutrient forms (DON and DOC). However, it should be noted that the data set was too small for statistical analysis and therefore no firm conclusions can be drawn about the model performance in the selected area.

## 4.3 Alternative Scenarios

Under the GO scenario used in the Global *NEWS* model the inputs of nutrients to river basins and the associated river export is higher than for the other MEA scenarios. This GO scenario represents closest the recent trends in the development of the region. For this reason it was selected as a baseline for the development of alternative scenarios. Prior to the scenario development a sensitivity analysis has been performed in order to determine how nutrient river export responds to changes in certain input parameters of the model. This helped to identify best management options related to sustainable agricultural practices and meat consumption. The sensitivity analysis showed that DIN export can be influenced easier with changes in input parameters related to agriculture than DON, DIP and DOP. Among all the nutrient forms DON is the least sensitive to the reduction of the nutrient inputs from agricultural sources.

Three alternative scenarios were developed for the European river basins draining into the Baltic and North Seas. These scenarios project the future for the year 2050. Scenario 1 considers moderate change in agricultural practices towards more sustainable ones. This scenario was based on the current trends of environmental policies in agriculture. Scenario 2 assumes more extreme spread of sustainable practices in agriculture. And, Scenario 3 projects a shift from high animal protein diets, which is prevail in the selected region to lower meat consumption. Selected model input parameters that reflected agricultural practices were quantified according to the illustrative storylines.

In the past, nutrient export to the Baltic Sea decreased by only few percent (less then 5% for DIN) to 20% (DOP). For DON river export, a 10% increase is calculated between 1970 and 2000 for the Baltic Sea. In the future, nutrient export to the Baltic Sea for some forms is stable (DON and DOP) or decreases by 10% (DIP), while for DIN about 10% increase is calculated between 2000 and 2050 in the GO scenario. Sustainable agricultural practices applied in a moderate way (Scenario 1) have the potential to slow down this increase to 5 % relative to the year 2000. With more extreme implementation of these sustainable practices in agriculture (Scenario 2) it is possible to avoid the decrease in DIN river export to the Baltic Sea and stabilize it at the level close to the current. And, the shift to low-meat diets (Scenario 3) has a potential to decrease DIN export by 20% relative to the current year.  Changes in the river export of DIP, DOP and DON are relatively small. However, some river basins experience large reductions in the export of DIP and DOP. The change in DON export to the Baltic Sea in alternative scenarios is negligible at the sea level as well as at the level of separate river basins.

Past trends of nutrient river export to the North Sea vary, depending on the compound, from stabilizing to decreasing by half (DIP). In the future, between 2000 and 2050 for the GO scenario, nutrient river export to the North Sea stabilizes or decreases by few percent. Under alternative Scenario 1 a more profound reduction by 20% in DIN river export is reached between 2000 and 2050. In Scenario 2 and 3 DIN river export is reduced by one third and half, respectively, compared to the level of the year 2000. The reduction in DIP, DOP and DON river export is rather small for the North Sea as well as for the Baltic with DIP and DOP export reduction being significant in some river basins.

With regard to the individual river basins the results are similar for both the Baltic and North Seas. The reduction export by rivers draining to the Baltic and North Seas relative to GO 2050 of DIN ranges from almost 0% to 20% for Scenario 1, to 40% for Scenario 3 and to more than 60%

for Scenario 3. For DIP and DOP river export these results are slightly less profound in Scenario 1 and 2. However, in Scenario 3 DIP and DOP export by some river basins decreases to 1/3d or even 1/4$^{th}$ of their GO 2050 level, depending on the compound and the sea basin the river is draining to.

In general, measures in Scenario 3 are more effective in nutrient pollution reduction than ones in Scenario 1 and 2.

## 4.4 Discussion and recommendation

This study has several limitations that have to be mentioned. First, in order to quantify alternative scenarios for the selected region many assumptions had to be made. Changes in some input parameters like fertilizer and manure inputs were based on sound reasons. However, a lack of data on the relationship between assumed changes in agricultural land use and some nutrient inputs to the soil made it a very difficult task to quantify input parameters such as biological $N_2$ fixation or nutrient export with harvest and grazing. This brings some uncertainty to the results of the study. Moreover, the Global *NEWS* model is a global model and it is quite complicated to check the model performance in the regional scale. Some uncertainties existing in the model certainly reflected on the results of this study.

In spite of all shortcomings created by assumptions and the model itself this study has a value because of its novelty. This study can be considered as the first attempt to assess the potential of more sustainable agricultural practices and low-meat diets to reduce nutrient pollution of the coastal waters of the Baltic and the North Seas using Global *NEWS* model. This study can bring the attention of scientists and policymakers to relation between pollution caused by agricultural activities and people preferences in diets.

A similar study performed by Kroeze *et al.* (2001) also shows that low-meat diets have a positive influence on the pollution of coastal waters. In that study a scenario that assumes lower meat consumption was developed (low N diet Scenario).  Moderate reduction in meat consumption in industrialized regions including North America and Europe was assumed so that N inputs to soil do not exceed 40 kg N/person. Reaching this aim, Kroeze *et al.* (2001) calculated necessary reduction in fertilizer use. The inputs of manure were assumed to stay at the level of 1990 while other N inputs remained at the level of baseline scenario. Calculated reduction of fertilizer use necessary to reduce N inputs down to 40 kg N/person was 16% worldwide. In North America and Europe this calculated reduction was 80% and 60% of fertilizer use, respectively. The results of the study showed that in low N diet Scenario the calculated DIN river export to the North Atlantic and European Seas in the year 2050 decreases by one third, relative to the baseline. In contrast, the current study focuses on a smaller region in Europe, and is performed with an updated model that calculates not only DIN export but also other forms and nutrients such as DON and dissolved phosphorus (DIP and DOP). It also uses another baseline. Moreover, the current study involves more inputs of nutrients related to agricultural activities. On the one hand it can be considered as more complete analysis. But on the other, including more nutrient inputs require more assumptions that can result in increased uncertainties. Nevertheless, the results of both the current study and the study of Kroeze *et al.* (2001) showed that low-meat diets have large potential to reduce nutrient pollution of the coastal waters. The calculated decrease in DIN river export in diet scenario in this study for the Baltic Sea (26%) is comparable to the 30% calculated by Kroeze *et al.* (2001) for Europe as a whole. However, for the North Sea the reduction calculated here is larger (more then 40%).

Howarth *et al.* (2002) discuss human diets and more sustainable agricultural practices, for the case of North America with a different model. They conclude that in the year 2030 inorganic fertilizer use can be reduced by 37% relative to the baseline scenario if a Swedish diet is adopted in North America (50% decrease in meat consumption) and by 65% if a Mediterranean diet (70% decrease in meat consumption) is assumed. However, they evaluate only the impact of reduced meat consumption and more sustainable agricultural practices on the use of fertilizers. N river export is predicted for the year 2030 only for business-as-usual scenario. Therefore the current study can be considered as novel.

For further research it can be recommended to focus on the identification of measures that can also influence the export of other pollutants, such as DON and phosphorus. It is also important to get more thorough understanding of why measures to reduce nutrient pollution proposed in this study are more effective for some river basins than for others. Moreover, developing and applying a model that is more suitable for the regional scale can make the results of the study sounder and more substantiate.

It is obvious that more research is needed in this direction; however at this stage it can be noted that this study confirmed the conclusion of studies performed earlier. Low-meat meat diets and sustainable agricultural practices have the potential to reduce nutrient pollution to the coastal waters. These potential varies depending on the extent of their application and the forms of nutrients involved. Thus, sustainable practices, applied to a moderate extent, as assumed in Scenario 1can provide only a few percent reduction in DIN, DIP and DOP export to the Baltic Sea and the North Sea. More extreme application of sustainable agricultural practices (Scenario 2) has larger effect on the reduction of DIN river export, while for DIP and DOP export the change is considerable only for individual river basins. Low-meat diets (Scenario 3) have the largest potential to reduce DIN river export and are recommended as the best policy option out of the three proposed by this study to handle DIN pollution of coastal waters of the Baltic and North Seas. It may be seen as a controversial measure. However this study does not propose totally vegetarian diets, but the diets, where the share of meat proteins is reduced and substituted by the plant proteins. These diets can help not only to solve environmental problems in the region, but also to resolve or avoid health issues that arise from increased meat consumption. With regard to DIP and DOP export sustainable agricultural practices applied to extreme extent and low-meat diets are only effective at the level of certain basins. Therefore, these measures can be applied when local pollution is targeted. When focusing on reduction of DON export other solutions should be taken into consideration.

## References


Ærtebjerg, G., Carstensen, J., Dahl, K., Hansen, J., Nygaard, K., Rygg, B., Sørensen, K., Severinsen, G., Casartelli, S., Schrimpf, W., Schiller, C., Druon, J.N., 2001. Eutrophication in European Waters. European Environmental Agency, Denmark, pp. 1-86.

Agardy, T., Alder, J., Dayton, P., S., C., Kitchingman, A., Wilson, M., Catenazzi, A., Restrepo, J., Birkeland, C., Blaber, S., Saifullah, S., Branch, G., Boersma, D., Nixon, S., Dugan, P., Davidson, N., Vorosmarty, C., 2005. Millenium Ecosystem Assessment. In: Baker, J., Casasola, P.M., Lugo, A., Rodrı´guez, A.S., Ling Tang, L.D. (Eds.), Ecosystems and Human well being, Washington DC, pp. 513-549.

Alcamo, J., Vuuren, D.v., Cramer, W., Alder, J., Bennett, E., Carpenter, S., Christensen, V., Foley, J., Maerker, M., Masui, T., Morita, T., O'Neill, B., Peterson, G., Ringler, C., Rosegrant, M., Schulze, K., Bouwman, L., Eickhout, B., Floerke, M., Lal, R., Takahashi, K., 2005. Millenium Ecosystem Assessment. In: Sinh, B.T., Hammond, A., Field, C. (Eds.), Ecosystem and Human well-being, Washington DC, pp. 297-393.

Allen, J.I., Anderson, D., Burford, M., Dyhrman, S., Flynn, K., Glibert, P.M., Granéli, E., Heil, C., Sellner, K., Smayda, T., Zhou, M., 2006. GEOHAB, Harmful Algal Blooms in Eutrophic Systems. In: Glibert, P.M. (Ed.), Paris and Baltimore, pp. 1-76.

Amann, M., Bertok, I., Cofala, J., Heyes, C., Klimont, Z., Rafaj, P., Sch pp, W., Wagner, F., 2008. National Emission Ceilings for 2020 based on the 2008 Climate & Energy Package. International Institute for Applied Systems Analysis.

Beusen, A., Dekkers, A., Bouwman, A., Ludwig, W., Harrison, J., 2005. Estimation of global river transport of sediments and associated particulate C, N, and P. Global Biogeochem. Cycles 19.

Bleken, M., 1997. Food consumption and nitrogen losses from agriculture. In: Lag, J. (Ed.), Some geomedical consiquences of nitrogen circulation processes. Proceedings of an international simposium. Norwegian Academy of Sciences and Letters, Oslo, pp. 19-31.

Bouwman, A.F., Beusen, A.H.W., Billen, G., in press, 2009. Human alteration of the global nitrogen and phosphorus soil balances for the period 1970-2050. Global Biogeochemical Cycles.

Creel, L., 2003. Ripple Effects: Population and Coastal Regions. Population Reference Bureau, Washington DC, pp. 1-8.

Dentener, F., Stevenson, D., Ellingsen, K., Van Noije, T., Schultz, M., Amann, M., Atherton, C., Bell, N., Bergmann, D., Bey, I., 2006. The global atmospheric environment for the next generation. Environ. Sci. Technol 40, 3586-3594.

FAO, 2009. FAOSTAT Food balance sheet. Available at http://faostat.fao.org/site/368/default.aspx#ancor, November 27 2009.

Fekete, B.M., Wisser, D., Kroeze, C., Mayorga, E., Bouwman, A.F., Wollheim, W.M., Vörösmarty, C.J., in press, 2009. Millennium Ecosystem Assessment Scenario drivers (1970-2050): Climate and hydrological alterations. Global Biogeochemical Cycles.

Granstedt, A., 2000. Increasing the efficiency of plant nutrient recycling within the agricultural system as a way of reducing the load to the environment—experience from Sweden and Finland. Agriculture, Ecosystems and Environment 80, 169-185.

Harrison, J., Caraco, N., Seitzinger, S., 2005. Global patterns and sources of dissolved organic matter export to the coastal zone: Results from a spatially explicit, global model. Global Biogeochem. Cycles 19, 1-16.

HELCOM, 2007. The Baltic Sea Action Plan: A new environmental strategy for the Baltic Sea region. Helsinki Commision, Baltic Marine Environment Protection Commision, Krakow, pp. 1-12.

Howarth, R., Anderson, D., Cloern, J., Elfring, C., Hopkinson, C., Lapointe, B., Malone, T., Marcus, N., McGlathery, K., Sharpley, A., 2000. Nutrient pollution of coastal rivers, bays, and seas. Issues in Ecology.

Howarth, R., Boyer, E., Pabich, W., Galloway, J., 2002. Nitrogen use in the United States from 1961–2000 and potential future trends. AMBIO: A Journal of the Human Environment 31, 88-96.

Koster, E., 2005. The physical geography of Western Europe. Oxford University Press Oxford.

Kroeze, C., Mosier, A., 2000. New estimates for emissions of nitrous oxide. In: Ham, J.v., Baede, A., Meyer, L., Ybema, R. (Eds.). Kluwer Academic Pub, pp. 45-62.

Kroeze, C., Seitzinger, K., Domingues, R., 2001. Future trends in worldwide river nitrogen transport and related nitrous oxide emissions: A scenario analysis. The Scientific World 1, 328-335.

Kronvang, B., Jeppesen, E., Conley, D., Søndergaard, M., Larsen, S., Ovesen, N., Carstensen, J., 2005. Nutrient pressures and ecological responses to nutrient loading reductions in Danish streams, lakes and coastal waters. Journal of Hydrology 304, 274-288.

Mayorga, E., Seitzinger, S.P., Harrison, J.A., Dumont, E., Beusen, A.H.W., Bouwman, A.F., Fekete, B., Kroeze, C., Drecht, G.v., submitted, 2009. Global Nutrient Export from WaterSheds 2 (NEWS 2): Model development and Implementation" Environmental Modelling and Software

Oenema, O., Oudendag, D., Velthof, G., 2007. Nutrient losses from manure management in the European Union. Livestock Science 112, 261-272.

OSPAR, 2000. Quality status report 2000 for the North-East Atlantic. Regional QSR II: Greater North Sea. OSPAR Commision, London, pp. 36-57.

Pawlak, J.F., Laamanen, M., Andersen, J.H., 2009. Eutrophication in the Baltic Sea: An integrated thematic assessement of the effects of nutrient enrichment in the Baltic Sea region. Executive Summary. HELCOM: Baltic Marine Environment Protection Commision, Helsinki, pp. 1-19.

Rockstrom, J., Steffen, W., Noone, K., Persson, A., Chapin, F.S., Lambin, E.F., Lenton, T.M., Scheffer, M., Folke, C., Schellnhuber, H.J., Nykvist, B., de Wit, C.A., Hughes, T., van der Leeuw, S., Rodhe, H., Sorlin, S., Snyder, P.K., Costanza, R., Svedin, U., Falkenmark, M., Karlberg, L., Corell, R.W., Fabry, V.J., Hansen, J., Walker, B., Liverman, D., Richardson, K., Crutzen, P., Foley, J.A., 2009. A safe operating space for humanity. Nature 461, 472-475.

Seitzinger, S., Harrison, J., Dumont, E., Beusen, A., Bouwman, A., 2005. Sources and delivery of carbon, nitrogen, and phosphorus to the coastal zone: An overview of Global Nutrient Export from Watersheds (NEWS) models and their application. Global Biogeochem. Cycles 19.

Seitzinger, S., Mayorga, E., Bouwman, A.F., Kroeze, C., Beusen, A.H.W., Billen, G., Drecht, G.v., Dumont, E., Fekete, B.M., Garnier, J., Harrison, J., in press, 2009. Global River Nutrient Export: A Scenario Analysis of Past and Future Trends. Global Biogeochemical Cycles.

Selman, M., Sugg, Z., Greenhalgh, S., Diaz, R., 2008. Eutrophication and hypoxia in coastal areas: a global assessment of the state of knowledge. World Resources Institute.

Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M., De Haan, C., 2006. Livestock's long shadow. FAO Rome.

Tilman, D., Fargione, J., Wolff, B., D'Antonio, C., Dobson, A., Howarth, R., Schindler, D., Schlesinger, W., Simberloff, D., Swackhamer, D., 2001. Forecasting agriculturally driven global environmental change. Science 292, 281-284.