OSPAR COMMISSION

Atmospheric Nitrogen in the OSPAR Convention Area in 1990 - 2004

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The Convention for the Protection of the Marine Environment of the North-East Atlantic (the "OSPAR Convention") was opened for signature at the Ministerial Meeting of the former Oslo and Paris Commissions in Paris on 22 September 1992. The Convention entered into force on 25 March 1998. It has been ratified by Belgium, Denmark, Finland, France, Germany, Iceland, Ireland, Luxembourg, Netherlands, Norway, Portugal, Sweden, Switzerland and the United Kingdom and approved by the European Community and Spain.

La Convention pour la protection du milieu marin de l'Atlantique du Nord-Est, dite Convention OSPAR, a été ouverte à la signature à la réunion ministérielle des anciennes Commissions d'Oslo et de Paris, à Paris le 22 septembre 1992. La Convention est entrée en vigueur le 25 mars 1998. La Convention a été ratifiée par l'Allemagne, la Belgique, le Danemark, la Finlande, la France, l'Irlande, l'Islande, le Luxembourg, la Norvège, les Pays-Bas, le Portugal, le Royaume-Uni de Grande Bretagne et d'Irlande du Nord, la Suède et la Suisse et approuvée par la Communauté européenne et l'Espagne.

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Executive Summary

This report presents estimates of atmospheric emissions of nitrogen and model-based calculations of atmospheric nitrogen deposition in the OSPAR maritime area for the period 1990 – 2004, prepared by the Co-operative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe (EMEP). It updates information on nitrogen emission and deposition in the OSPAR maritime area prepared by EMEP in 2004 (Bartnicki and Fagerli, 2003, 2004) with new information for the years 2002 – 2004 and updated shipping emissions data. The report supplements information collection by OSPAR under the Comprehensive Atmospheric Monitoring Programme (CAMP) and includes information on:

- Annual emissions of nitrogen oxides and ammonia from OSPAR Contracting Parties, ship emissions on the North Sea and Atlantic Ocean and selected large outside contributors to nitrogen deposition in the OSPAR maritime area;
- Modelled annual deposition of nitrogen in the main OSPAR regions;
- Modelled annual deposition of nitrogen in 13 sub-regions of the Greater North Sea;
- Comparison of model results and measurements from coastal monitoring stations within OSPAR;
- Remarks on uncertainties;
- Comparison of computed atmospheric inputs with waterborne inputs.

The EMEP Unified Eulerian model system has been used for all nitrogen computations presented here. This system has undergone a major overhaul during the last few years, where the previous EMEP models (Lagrangian as well as Eulerian) have been merged and the code re-written in order to produce the EMEP Unified Eulerian model. It has been verified against measurement data at EMEP stations for 13 different years (1980, 1985, 1990, 1995-2004) (EMEP Status Report 1/2003, Part II, EMEP Status Report 1/2004, EMEP Status Report 1/2005, EMEP Status Report 1/2006). A comparison of computed and measured nitrogen wet deposition at the OSPAR coastal monitoring stations for 1990, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003 and 2004 is described in the present report and shows that although the wet depositions in general are somewhat underestimated, the model is able to reproduce the year to year variations in the monitoring data.

According to emission guidelines, EMEP countries are reporting nitrogen oxides emissions (NO_x) as nitrogen dioxide (NO_2). For most of the OSPAR Contracting Parties a reduction of nitrogen oxides emissions has been reported for the period 1990 – 2004. Out of 18 countries relevant for OSPAR, annual emissions were declining in 15 countries. United Kingdom, Germany, Spain and France were the largest emitters of nitrogen oxides among the OSPAR Parties in 2004 with 493 kt N a^{-1}, 473 kt N a^{-1}, 432 kt N a^{-1} and 371 kt N a^{-1} respectively. In Germany, United Kingdom and France, emissions were significantly lower in 2004 than in 1990 by 46%, 45% and 37%, respectively. In Spain, nitrogen oxides emissions increased by 22% from 1990 to 2004. The three largest contributors to nitrogen deposition to the OSPAR Convention waters from outside OSPAR Parties were Poland, Italy and the part of the Russian Federation included in the EMEP area. Annual emissions in 2004 from these countries were reported to be lower than in 1990 by 49%, 14% and 36%, respectively. Thus, with some guardedness of the uncertainty associated with the reporting of emissions, there seems to be evidence for nitrogen oxides (NO_2) emissions going down in the countries relevant for the OSPAR maritime area (Table 1 and Figure 5). Nitrogen oxides emissions from national ship traffic in the costal zone are included in the national total emissions.

International ship traffic on the OSPAR Convention Waters is the largest single source of NO_2 emissions in the area of interest. There are large uncertainties in the estimate for ship traffic emissions. In 2006, international ship emissions and their spatial distribution have been updated based on new emission estimates derived by ENTEC for the year 2000 (ENTEC, 2006), resulting in higher depositions in sea areas than estimated in the previous report (Bartnicki and Fagerli, 2004). Ship emissions for 1990, 1995 and 2004 were deduced by applying an increase factor of 2.5 % per year on cargo vessel traffic and 3.9 % per year on passenger vessel traffic. The factors are the same as used by ENTEC for predicting emissions of nitrogen in 2010 based on the emission estimates for 2000 (ENTEC, 2006). Emission factors were assumed to be constant over time. This resulted in an increase of ship emissions of about 2.6 % per year, consistent with the increase of international shipping emissions from 1995 to 2000 proposed by Endresen et al., (2003). The same emission factors were applied for the entire considered period 1990 – 2004.

Annual emissions of ammonia (NH_3) were lower in 2004 than in 1990 for most of the OSPAR Contracting Parties and two out of three selected additional countries outside OSPAR. Out of 18 countries relevant for OSPAR, annual emissions in 14 countries were lower in 2004 than in 1990, sometimes significantly e.g.

49%, 46% and 45% emission reduction in Poland, Germany and in the United Kingdom, respectively (Tables 2 and Figure 6).

Annual 2004 emissions of nitrogen oxides (NO_2) as a sum of emissions from all OSPAR Contracting Parties and selected additional three countries outside OSPAR were 10% higher than the corresponding annual 2004 emissions of ammonia (NH_3), in terms of nitrogen emitted (Tables 1 and 2).

A typical uncertainty in total annual emissions from the OSPAR countries is approximately 20 %.

Annual nitrogen deposition in the entire area of the OSPAR Convention waters (Figure 13) was calculated for the years 1990, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003 and 2004. Modelled depositions of oxidized, reduced and total (oxidized + reduced) nitrogen were going down from 1990 to 1995. There is a clear maximum for all three types of nitrogen deposition in the year 1996 and then decreasing trend until 1999. From 1999 to 2003, depositions of oxidized, reduced and total nitrogen were going slightly up, reaching a second local maximum in 2003. The absolute minimum for these depositions can be observed in 2004. Modelled depositions of oxidized, reduced and total nitrogen were lower in 2004 than in 1990 by 20%, 12% and 17%, respectively.

For oxidized nitrogen, annual modelled depositions in the main OSPAR regions were lower in 2004 than in 1990 in all main OSPAR Regions, by 24 %, 22 %, 23 %, 1 % and 21 % for Arctic Waters, Greater North Sea, Celtic Seas, Bay of Biscay and Wider Atlantic, respectively (Table 3). For reduced nitrogen, annual modelled depositions in four main OSPAR Regions were lower in 2004 than in 1990, by 16%, 8%, 2% and 25% for Arctic Waters, Greater North Sea, Celtic Seas and Wider Atlantic, respectively. Depositions in the Bay of Biscay region were 10% higher in 2004 than in 1990 (Table 4). Depositions of total nitrogen in the Bay of Biscay region were 3% higher in 2004 than in 1990, whereas depositions of total nitrogen in Arctic Waters, Greater North Sea, Celtic Seas and Wider Atlantic were lower by 22%, 16%, 13% and 22%, respectively (Table 5).

For both oxidized and reduced nitrogen, a clear gradient of the modelled deposition towards the open sea can be noticed with maxima of the deposition in OSPAR Region II (Greater North Sea) for the year 1990 as well as 2004 (Figures 7-10).

In 2004, the maximum deposition of oxidized nitrogen (513 mg N m^{-2}) was slightly lower than the maximum deposition of reduced nitrogen (522 mg N m^{-2}). However, total deposition of oxidized nitrogen is much (64%) higher than the total deposition of reduced nitrogen to the OSPAR Convention Waters. This means that the nitrogen emitted from mobile sources contributed more to the deposition than the nitrogen emitted mainly from sources related to agriculture. Higher deposition of oxidized than reduced nitrogen can also be noticed for all other years of the considered period.

It should be stressed that calculated nitrogen depositions do not follow proportionally nitrogen emissions and are strongly dependent on meteorological conditions for individual years. There is a large inter-annual variability in modelled nitrogen deposition, caused by the different meteorological conditions in the different years (Bartnicki and van Loon, 2005; EMEP Status Report., 2005).

Annual modelled depositions of oxidized nitrogen in all sub-regions of the Greater North Sea except sub-regions 2 and 4 were lower in 2004 than in 1990 by 2% to 29%. (Table 6 and Figure 23).

Annual modelled depositions of reduced nitrogen in 2004 were higher than in 1990 in 3 out of 13 sub-regions of the Greater North Sea. For sub-region 13, the largest deposition increase was 15%. Lower depositions in 2004 than in 1990 can be especially noticed in the sub-regions 12 and 9 with 26 % and 20 % reduction, respectively (Table 7 and Figure 24).

Compared to 1990, annual modelled deposition of total nitrogen in 2004 was higher only in one out of 13 sub-regions, namely in the sub-region 13 (Channel) with 5% increase (Table 8 and Figure 25).

Measured and computed wet annual depositions of oxidized, reduced and total nitrogen were compared for the years 1990, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003 and 2004 for the stations located in the main OSPAR regions and in the sub-regions of OSPAR Region II (Greater North Sea). For the majority of the stations, the modelled and measured concentrations agree well. In general, modelled wet deposition for stations situated in the sub-regions of the Greater North Sea follow observations better than modelled wet deposition for stations located in the main OSPAR regions (Figures 26-31).

Concerning computed concentrations and depositions of nitrogen, a typical value of uncertainty is 30 %, but in some cases differences between measured and computed values can be much larger.

Récapitulatif

Le présent rapport comporte des estimations des émissions atmosphériques d'azote ainsi que des calculs des retombées atmosphériques d'azote à partir de modèles dans la zone maritime OSPAR de 1990 à 2004. Il a été préparé par le Programme coopératif de surveillance continue et d'évaluation de la transmission des polluants atmosphériques à longue distance en Europe, (EMEP). Il constitue une mise à jour des informations sur les émissions et les retombées d'azote dans la zone maritime OSPAR qui avaient été préparées par l'EMEP en 2004 (Bartnicki et Fagerli, 2003, 2004). Il comporte de nouvelles informations pour 2002 à 2004 ainsi que des données actualisées sur les émissions provenant de la navigation. Le présent rapport complémente les informations recueillies par OSPAR dans le cadre du Programme exhaustif de surveillance de l'atmosphère (CAMP). Il comporte notamment des informations sur:

- Les émissions annuelles d'oxydes d'azote et d'ammoniac des Parties contractantes OSPAR, les émissions provenant de la navigation dans la mer du Nord et l'océan atlantique et une sélection de contributeurs importants aux retombées d'azote dans la zone maritime OSPAR;
- Les retombées annuelles modélisées d'azote dans les principales régions d'OSPAR;
- Les retombées annuelles modélisées d'azote dans treize sous-régions de la mer du Nord au sens large;
- Une comparaison des résultats obtenus à partir de modèles ainsi que des analyses effectuées dans les stations côtières de surveillance dans le cadre d'OSPAR;
- Des observations sur les incertitudes;
- Une comparaison des apports atmosphériques et des apports aquatiques calculés.

On utilise ici pour tous les calculs le système de modèles eulériens unifiés de l'EMEP. Ce système a subi des révisions importantes au cours des quelques dernières années. Les modèles précédents de l'EMEP (lagrangiens aussi bien que eulériens) ont été fusionnés et de nouvelles instructions ont été rédigées. On est ainsi parvenu au modèle eulérien unifié de l'EMEP. Il a été vérifié par rapport aux données provenant des stations de l'EMEP pour treize années distinctes (1980, 1985, 1990, 1995 à 2004) (Rapport d'avancement de l'EMEP 1/2003, Partie II, Rapport d'avancement de l'EMEP 1/2004, Rapport d'avancement de l'EMEP 1/2005, Rapport d'avancement de l'EMEP 1/2006). On établit dans le présent rapport une comparaison entre les calculs et les relevés des retombées humides d'azote dans les stations côtières de surveillance OSPAR pour les années 1990, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003 et 2004. Cette comparaison révèle que le modèle est capable de reproduire les variations d'une année à l'autre pour les données provenant de la surveillance, bien que dans l'ensemble les retombées humides soient quelque peu sous-estimées.

Selon les lignes directrices pour les émissions, les pays de l'EMEP notifient les émissions d'oxydes d'azote (NO_x) en tant que dioxyde d'azote (NO_2). La plupart des Parties contractantes OSPAR notifient une réduction des émissions d'oxydes d'azote entre 1990 et 2004. Les émissions annuelles sont en baisse dans quinze des dix-huit pays pertinents à OSPAR. Le Royaume-Uni, l'Allemagne, l'Espagne et la France ont émis les plus grandes quantités d'oxydes d'azote parmi les Parties contractantes OSPAR en 2004, respectivement 493 kt N a^{-1}, 473 kt N a^{-1}, 432 kt N a^{-1} et 371 kt N a^{-1}. En 2004, les émissions sont nettement en baisse par rapport à 1990 en Allemagne, au Royaume-Uni et en France, respectivement de 46%, 45% et 37%. En Espagne les émissions d'oxydes d'azote ont augmenté de 22% entre 1990 et 2004. La Pologne, l'Italie et la partie de la Fédération de Russie qui appartient à la zone EMEP sont les trois principaux responsables des retombées d'azote dans les eaux de la Convention OSPAR, qui ne sont pas des Parties contractantes OSPAR. En 2004 les émissions annuelles notifiées par ces pays sont inférieures à celles de 1990, respectivement de 49%, 14% et 36%. Il semble donc que les émissions d'oxydes d'azote soient en baisse dans les pays pertinents à la zone maritime OSPAR. Il faut cependant faire preuve de prudence car la notification des émissions comporte des incertitudes (Tableau 1 et

figure 5). Les émissions d'oxydes d'azote provenant de la navigation nationale dans la zone côtière sont incluses dans les émissions nationales totales.

La navigation internationale dans les eaux de la Convention OSPAR est la source la plus importante d'émissions de NO_2 dans la zone qui nous intéresse. Les estimations d'émissions provenant de la navigation comportent des incertitudes importantes. En 2006, les émissions provenant de la navigation internationale ainsi que leur distribution spatiale ont été actualisées à partir de nouvelles estimations d'émission dérivées par ENTEC pour l'année 2000 (ENTEC, 2006). On a ainsi obtenu des retombées dans des zones marines qui sont supérieures à celles estimées dans le rapport précédent (Bartnicki et Fagerli, 2004). On a déduit les émissions provenant de la navigation pour 1990, 1995 et 2004 en appliquant pour chaque année un pourcentage d'augmentation de 2,5% pour le transport de fret et de 3,9 % pour le transport de passagers. Ces facteurs d'augmentation sont identiques à ceux utilisés par ENTEC pour la prédiction des émissions d'azote en 2010 à partir des estimations d'émissions pour 2000 (ENTEC, 2006). On présume que les facteurs d'émissions sont constants dans le temps. On obtient donc une augmentation d'environ 2,6 % par an des émissions provenant de la navigation, ce qui correspond aux émissions provenant de la navigation internationale de 1995 à 2000 proposées par Endresen et al., (2003). On a appliqué les mêmes facteurs d'émission pour toute la période étudiée (1990 à 2004.

Les émissions annuelles d'ammoniac (NH_3) en 2004 sont inférieures à celles de 1990 pour la plupart des Parties contractantes OSPAR et deux des trois pays supplémentaires sélectionnés qui se situent en dehors de la zone OSPAR. En 2004, les émissions annuelles dans quatorze des dix-huit pays pertinents à OSPAR sont inférieures à celle de 1990. Ces réductions sont quelquefois importantes, par exemple 49%, 46% et 45% respectivement en Pologne, en Allemagne et au Royaume-Uni, (Tableau 2 et figure 6).

Les émissions annuelles d'oxydes d'azote en 2004, qui représentent la somme des émissions de toutes les Parties contractantes OSPAR et des trois pays supplémentaires sélectionnés qui se situent en dehors de la zone OSPAR, sont supérieures de 10% à celles d'ammoniac pour la même année en ce qui concerne l'azote émis (Tableaux 1 et 2).

L'incertitude typique des émissions totales annuelles provenant des pays OSPAR est d'environ 20%.

On a calculé les retombées annuelles d'azote dans la totalité de la zone des eaux de la Convention OSPAR (Figure 13) pour les années 1990, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003 et 2004. Les retombées modélisées d'azote oxydé, réduit et total (oxydé + réduit) sont en baisse entre 1990 et 1995. Les retombées d'azote, sous ses trois formes, sont clairement à leur maximum en 1996 et présentent une tendance à la baisse jusqu'en 1999. Entre 1999 et 2003, ces retombées augmentent légèrement pour parvenir à un deuxième maximum local en 2003. On observe les retombées les plus faibles en 2004. Les retombées modélisées d'azote oxydé, réduit et total sont plus faibles en 2004 qu'en 1990, respectivement de 20%, 12% et 17%.

Les retombées annuelles modélisées d'azote oxydé sont plus faibles en 2004 qu'en 1990 dans les principales régions OSPAR, de 24 %, 22 %, 23 %, 1 % et 21 % respectivement pour les eaux arctiques, la mer du Nord au sens large, les mers celtiques, le golfe de Gascogne et l'Atlantique au large (Tableau 3). Les retombées annuelles modélisées d'azote réduit sont plus faibles en 2004 qu'en 1990 dans quatre régions principales d'OSPAR, de 16%, 8%, 2% et 25% respectivement pour les eaux arctiques, la mer du Nord au sens large, les mers celtiques et l'Atlantique au large. En 2004, les retombées dans la région du golfe de Gascogne sont supérieures de 10% à celle de 1990 (Tableau 4). En 2004, les retombées d'azote total dans la région du golfe de Gascogne sont supérieures de 3% à celles de 1990, alors que celles dans les eaux arctiques, la mer du Nord au sens large, les mers celtiques et Atlantique au large sont inférieures de 22%, 16%, 13% et 22%, respectivement (Tableau 5).

On observe une nette déclivité des retombées d'azote oxydé et d'azote réduit en allant vers la pleine mer, les retombées maximales se trouvant dans la Région II d'OSPAR (Mer du Nord au sens large) aussi bien en 1990 qu'en 2004 (Figures 7 à 10).

En 2004, les retombées maximales d'azote oxydé (513 mg N m^{-2}) sont légèrement inférieures aux retombées maximales d'azote réduit (522 mg N m^{-2}). Les retombées totales d'azote oxydé sont cependant bien supérieures (64%) à celles d'azote réduit dans les eaux de la Convention OSPAR. Ceci signifie que l'azote provenant de sources mobiles contribue plus aux retombées que l'azote provenant essentiellement de sources liées à l'agriculture. On observe également des retombées d'azote oxydé plus importantes que celles d'azote réduit pour toutes les autres années de la période étudiée.

On doit souligner que les retombées d'azote calculées ne correspondent pas proportionnellement aux émissions d'azote et sont grandement influencées par les conditions météorologiques propres à chaque année. Les diverses conditions météorologiques de chaque année entraînent une variabilité importante des retombées modélisées d'azote d'une année à l'autre (Bartnicki et van Loon, 2005; Rapport d'avancement EMEP, 2005).

En 2004, les retombées annuelles modélisées d'azote oxydé dans toutes les sous-régions de la mer du Nord au sens large, à l'exception des sous-régions 2 et 4, sont inférieures à celles de 1990 de 2% à 29%. (Tableau 6 et figure 23).

En 2004 les retombées annuelles modélisées d'azote réduit sont supérieures à celles de 1990 dans trois des treize sous-régions de la mer du Nord au sens large. Dans le cas de la sous-région treize l'augmentation la plus importante des dépositions est de 15%. En 2004, on relève une baisse des retombées par rapport à 1990 en particulier dans les sous-régions douze et neuf, respectivement de 26 % and 20 % (Tableau 7 et figure 24).

Les retombées modélisées annuelles d'azote total en 2004 sont supérieures à celles de 1990 dans une seule des treize sous-régions. Il s'agit de la sous-région treize (Manche) avec une augmentation de 5% (Tableau 8 et figure 25).

On a comparé les retombées humides annuelles d'azote oxydé, réduit et total, relevées et calculées, des années 1990, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003 et 2004 pour les stations situées dans les principales régions d'OSPAR et dans les sous-régions de la Région II d'OSPAR (Mer du Nord au sens large). Les teneurs analysées correspondent aux teneurs modélisées dans la plupart des stations. D'une manière générale, les retombées humides modélisées pour les stations situées dans les sous-régions de la mer du Nord au sens large correspondent mieux aux observations effectuées que pour celles situées dans les principales régions d'OSPAR (Figures 26 à 31).

Une incertitude de 30% est typique pour les teneurs et les retombées calculées d'azote. Dans certains cas, les différences entre les valeurs relevées et celles qui sont calculées peuvent cependant être bien plus importantes.

1. Introduction

The 1992 OSPAR Convention is the regional Convention for the Protection of the Marine Environment of the North-East Atlantic to which the European Community and the following countries are Contracting Parties: Belgium, Denmark, Finland, France, Germany, Iceland, Ireland, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom of Great Britain and Northern Ireland.

The work under the Convention is organised by six strategies, including the Eutrophication Strategy and the Joint Assessment and Monitoring Programme (JAMP). The objective of the Eutrophication Strategy is to achieve and maintain, by 2010, a healthy marine environment where eutrophication does not occur. The Strategy is implemented through measures reducing emissions, discharges and losses of nutrients in all areas from which nutrient inputs are likely, directly or indirectly, to contribute to inputs into problem areas with regard to eutrophication, classified as such under the OSPAR Common Procedure (OSPAR agreement 2005-3). The implementation is supported by monitoring and assessment under the OSPAR JAMP of waterborne inputs through the OSPAR Comprehensive Study on Riverine Inputs and Direct Discharges (RID) and of atmospheric inputs through the OSPAR Comprehensive Atmospheric Monitoring Programme (CAMP). This work is supplemented by information collection from other international bodies such as for example on emissions to air and atmospheric deposition via EMEP. The present report is intended to support the upcoming 2009 assessment of CAMP data; for this purpose, data products are intended to be updated to include calculations up to 2006.

In support of this work, a first report on "Atmospheric nitrogen in the OSPAR Convention Area 1990 – 2001" had been prepared by EMEP for the German Federal Environment Agency in 2004 (Bartnicki and Fagerli, 2003, 2004). Based on this report, OSPAR prepared in 2005 an assessment of how the effectiveness of agreed international (reduction) measures could contribute to achieve the objective of the Eutrophication Strategy in 2010 of a healthy marine environment in which eutrophication does not occur (OSPAR Commission 2005a). This work, as well as the 2005 OSPAR assessment of CAMP data (OSPAR Commission 2005b) suggest that atmospheric nitrogen inputs seem to play a major role for certain regions of OSPAR maritime area.

Upon request from OSPAR, EMEP prepared the present second report on "Atmospheric Nitrogen in the OSPAR Convention Area for the period 1990 – 2004" to update the first report with deposition estimates for the years 2002 – 2004 and with new information and data which had become available for the entire assessment period. New information includes mainly the updated nitrogen emissions for international ship traffic on the North Atlantic and the North Sea and the updated emissions for EMEP Contracting Parties, including OSPAR Contracting Parties. The new data means the results from the latest recently updated version of the EMEP Unified model, using the latest available emissions. This report is based on model estimates and monitoring results presented to the thirtieth session of the Steering Body of EMEP (Co-operative Programme for Monitoring and Evaluation of Long-Range Transmission of Air Pollutants in Europe). It presents results of EMEP estimates of atmospheric emissions of nitrogen as well as calculations of atmospheric nitrogen deposition in the OSPAR Convention Waters for the period 1990 – 2004. It does not, however, include source-receptor computations and does not update the 2004 report in this point. The 2004 results of the source-receptor computations are also available in OSPAR 2005a. An estimation of the overall nitrogen input to the Greater North Sea, comparing computed atmospheric inputs with inputs measured under OSPAR RID has been prepared by OSPAR and is presented in Chapter 8.

The role of atmospheric deposition of nitrogen in the total fluxes to the North Sea and North-East Atlantic, as well as discussion of related chemical and biological processes has been a subject of many scientific publications (e.g. Rendell *et al.,* 1993; Peierls and Paerl, 1977; Shultz *et al.,* 1999; de Leuw *et al.,* 2001 and Klein, L. M., 2002). However, most of the studies related to atmospheric supply of nitrogen to OSPAR Convention waters were based on measurements and limited to rather small coastal (or mainly coastal) regions, not covering the entire area of interest. In the present report we have used model calculations for the estimation of annual nitrogen deposition in all five main Regions of the OSPAR Convention area. In addition, we have also calculated annual deposition in 13 sub-regions of the main OSPAR Region II – Greater North Sea. The model calculations cover eleven years, 1990, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003 and 2004. All specific results (maps, tables, ascii files with data) of this study are available on internet on the EMEP web site www.emep.int/index_facts.html.

The EMEP Unified Eulerian model system has been used for all nitrogen computations presented here. This system has undergone a major overhaul in 2001 – 2003, when the previous EMEP models (Lagrangian as well as Eulerian) have been merged and re-written in order to produce the Unified EMEP Eulerian model. The model has been documented in detail in the EMEP Status Report 1/2003, Part I. It has been verified against measurement data at EMEP stations for 13 different years (1980, 1985, 1990, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003 and 2004) in the EMEP Status Report 2003 Part II, EMEP Status Report 2004, EMEP Status Report 2005 and EMEP Status Report 2006. A short description of the main EMEP model features is given in the next chapter.

Similar computations as for the OSPAR Convention Waters have already been performed for the Baltic Sea in the framework of cooperation between the Helsinki Commission (HELCOM) and EMEP (Bartnicki *et al.,* 2002, 2005). The results of the computations for the OSPAR Convention waters are presented here, as in the first report in 2004, in a similar way as it has been done for HELCOM to possibly facilitate comparative considerations in future (e.g. under the EU Marine Strategy or the implementation of the EC Water Framework Directive).

The following topics are included and discussed in the present report:

- Annual emissions of nitrogen oxides (NO_2) and ammonia (NH_3) from the OSPAR Contracting Parties and the three largest contributors, outside the OSPAR Convention area, to nitrogen deposition in the OSPAR maritime area in the period 1990 – 2004;
- Modelled annual deposition of nitrogen oxides (NO_2) and ammonia ($NH_{3)}$ in the five main OSPAR regions and 13 sub-regions of the Greater North Sea for the years 1990, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003 and 2004;
- Comparison of model results and measurements currently available from the OSPAR coastal monitoring stations under the CAMP, for wet deposition of nitrogen in the years 1990, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003 and 2004;
- Comments on uncertainties of computed results;
- Comparison of computed atmospheric inputs with waterborne inputs.

2. Short description of the Unified EMEP model

The Unified EMEP model is an Eulerian model that has been developed at EMEP/MSC-W (Meteorological Synthesizing Centre – West of EMEP) for simulating atmospheric transport and deposition of acidifying and eutrophying compounds as well as photo-oxidants in Europe. The model has been documented in EMEP Status Report 2003, Part I and updates of the model have been described in EMEP Status Report 2004, 2005, 2006. Here we only give a short description of the basic features of the model. Model details and its applications can be also found on the EMEP web site www.emep.int.

The model domain covers Europe and the Atlantic Ocean (Figure 1). The model grid (of the size 170 ×133) has a horizontal resolution of 50 km at 60^{o} N, which is consistent with the resolution of emission data reported to CLRTAP (Vestreng, 2003). In the vertical, the model has 20 sigma layers reaching up to 100 hPa. Approximately 10 of these layers are placed below 2 km to obtain high resolution of the boundary layer which is of special importance to the long range transport of air pollution.

The Unified Model uses 3-hourly resolution meteorological data from the PARLAM-PS model, a dedicated version of the HIRLAM (High Resolution Limited Area Model) Numerical Weather Prediction model.

The emissions consist of gridded national annual emissions of sulphur dioxide, nitrogen oxides, ammonia, non-methane volatile organic compounds (VOC) and carbon monoxide. They are available in each of the 50 × 50 km^2 model grid. These emissions are distributed temporally according to monthly and daily factors derived from data provided by the University of Stuttgart (IER).

Concentrations of 71 species are computed in the latest version of the Unified EMEP model (56 are advected, 15 are short-lived and not advected). The sulphur and nitrogen chemistry is coupled to the photo-chemistry, which allows a more sophisticated description of e.g. the oxidation of sulphur dioxide to sulphate.

Dry deposition is calculated using the resistance analogy and is a function of the pollutant type, meteorological conditions and surface properties. Parameterization of wet deposition processes includes both in-cloud and sub-cloud scavenging of gases and particles using scavenging coefficients.

3. Definitions of the OSPAR regions and sub-regions in the EMEP grid system

Annual deposition of nitrogen has been calculated for the five main Regions of the OSPAR maritime area and for 13 sub-regions of the main OSPAR Region II - Greater North Sea.

The OSPAR maritime area is divided into five main regions (see also Figure 2):

Region I: Arctic Waters – $5.5×10^6$ km^2
Region II: Greater North Sea – $7.6×10^5$ km^2
Region III: Celtic Seas – $3.6×10^5$ km^2
Region IV: Bay of Biscay and Iberian Coast – $5.3×10^5$ km^2
Region V: Wider Atlantic – $6.3×10^6$ km^2

The border lines of the five main Regions are described in geographic coordinates in Appendix 1 of the OSPAR Joint Monitoring and Assessment Programme (agreement 2003-22) which is available on the OSPAR web site http://www.ospar.org. The surface area was calculated from the co-ordinates available in the EMEP model and can be slightly different from the actual area. The 13 sub-regions of OSPAR Region II – Greater North Sea were defined in the form of geographical co-ordinates and in accordance with the sub-regions used by OSPAR in the OSPAR Quality Status Reports.

The sub-regions of the main OSPAR Region II - Greater North Sea are related to the ICES Boxes in the following way (see also Figure 3):

Sub-region 1: ICES Box 1 – 81 000 km^2
Sub-region 2: ICES Box 2a – 60 000 km^2
Sub-region 3: ICES Box 2b – 52 000 km^2
Sub-region 4: ICES Box 3a – 47 000 km^2
Sub-region 5: ICES Box 3b – 40 000 km^2
Sub-region 6: ICES Box 4 – 49 000 km^2
Sub-region 7: ICES Box 5a – 18 000 km^2
Sub-region 8: ICES Box 5b – 34 000 km^2
Sub-region 9: ICES Box 6 – 85 000 km^2
Sub-region 10: ICES Box 7a – 95 000 km^2
Sub-region 11: ICES Box 7b – 68 000 km^2
Sub-region 12: ICES Box 8 – 60 000 km^2
Sub-region 13: ICES Box 9 – 80 000 km^2

In order to calculate nitrogen deposition in the OSPAR regions, the borders of the main OSPAR Regions and sub-regions had to be converted into the EMEP grid system, which is shown in Figure 1. In the first stage of this conversion, descriptive geographical coordinates were transformed into the sets of discrete geographical coordinates describing each main Region or sub-region. A major problem in this stage was the lack of a data set with geographical coordinates defining the western border of Region III – Wider Atlantic (see Figure 2). These coordinates were finally read manually from the map.

In a second, more difficult and time consuming stage, borders of the regions in the EMEP grid system were used to calculate what percentage of the considered OSPAR Region or sub-region was included in each EMEP grid square. In this way, a separate percentage file was created for each Region and sub-region.

A map with the borders of the main OSPAR Regions in the EMEP grid system is shown in Figure 2, and a map with the borders of the sub-regions (ICES Boxes) of OSPAR Region II - Greater North Sea, is shown in Figure 3.

The border of the main OSPAR Region V, Wider Atlantic, goes slightly outside the EMEP model grid system resulting in the underestimation of computed nitrogen deposition in this region. The underestimation is small, approximately less than 0.1 %, because of the small number of missing grids and small values of deposition in the missing grids, which are located far away from the significant sources of nitrogen emission.

An additional reason for the underestimation of nitrogen deposition in the Wider Atlantic Region is the formulation of boundary conditions in the EMEP model. According to this formulation, the values of the deposition in the lowest row in the EMEP grid system are always equal to zero. Also in this case underestimation is practically insignificant, below 0.1 % of the total deposition value in this region.

These two problems could be solved by the extension of the EMEP model domain to the south. EMEP is working on this problem at present. The Unified EMEP model domain will be extended to the south, so that all main OSPAR Regions will be covered by the model grid. In addition, the model resolution will be significantly increased from 50×50 km^2 to 10×10 km^2. The new model version should be ready in 2008.

4. Atmospheric emissions of nitrogen

In the deposition calculations, official figures on national emissions reported to EMEP were used (Vestreng, 2003; Vestreng et al., 2006). Emission inventories from the EMEP Parties, which include OSPAR Contracting Parties and the three selected countries (Italy, Russian Federation and Poland) with the largest deposition of nitrogen in the OSPAR maritime area, are presented in this report for the period 1990 – 2004.

There are two kinds of nitrogen emissions used as input files to the EMEP model calculations: nitrogen oxides emissions as NO_2 and ammonia emissions as NH_3, both in nitrogen units. Nitrogen oxides emissions from national ship traffic in the costal zone are included in the national total emissions.

According to the results of source-receptor calculations performed with the EMEP Unified Model for the year 2000, the three largest contributors to nitrogen deposition to OSPAR Convention waters from outside OSPAR Parties were Poland, Italy and the Russian Federation.

An additional and very important source of atmospheric NO_x emissions to the OSPAR Convention waters is the international ship traffic. Official data for 2004 give 799 kt NO_x (as N) annual emissions from the international ship traffic on the North-East Atlantic (within the EMEP domain) and 720 kt NO_x (as N) from the international ship traffic on the North Sea. In addition, ship emissions from outside the EMEP area, 240 kt NO_x (as N) in 2004, were also taken into account in the model calculations. These are the largest individual sources of NO_x emissions in the OSPAR area of interest. Total releases of nitrogen oxides emissions from ship traffic in the Atlantic Ocean and the North Sea was estimated by Lloyd's Register of Shipping. These estimations are very similar to the estimates derived later by ENTEC (Environmental and Engineering Consultancy) for the year 2000. The ENTEC emissions were used in the model calculations (EMEP Status Report 2006) assuming the annual 2.5% increase of nitrogen oxides emissions in the considered period as suggested in Endersen et al. 2003). Nitrogen oxides emissions from the ship traffic on the North Sea and on the Atlantic Ocean increased more than 40% from 1990 to 2004. The same emission factors were applied for the entire considered period 1990 – 2004. A map with nitrogen oxides emissions from the international ship traffic over the North Sea and Atlantic Ocean used in the model calculations for 2004 is shown in Figure 4. Annual total nitrogen oxides emissions from the international ship traffic are included in Table 1 for each year of the period 1990 – 2004.

A map with time series of nitrogen oxides (NO_x) emissions from the OSPAR Contracting Parties, and additionally Italy, Russian Federation and Poland, is shown in Figure 5 for the period 1990 - 2004. A similar map for ammonia (NH_3) emissions is shown in Figure 6. The same data are available as numbers in Tables 1 and 2, for nitrogen oxides (NO_2) and ammonia (NH_3) emissions, respectively. All emissions data, both for nitrogen oxides and ammonia are presented in nitrogen units in Tables 1 and, and in Figures 5 and 6.

For most of the OSPAR Contracting Parties a reduction of nitrogen oxides emissions (NO_2) has been reported for the period 1990 – 2004 (Figure 5 and Table 1). Out of 18 countries relevant for OSPAR, only in three countries (Luxembourg, Spain and Portugal) annual emissions of nitrogen oxides were reported to be higher in 2004 than in 1990 by 50%, 22%, and 10%, respectively. However, in Luxembourg emissions in both years were very low (6 and 9 kt N a^{-1}, respectively) compared to the rest of the countries. In addition to Spain, the largest emitters of nitrogen oxides among the OSPAR Contracting Parties were the United Kingdom, Germany and France. In these three countries, emissions were significantly lower in 2004 than in 1990 by 45%, 45%, and 33%, respectively. The three largest contributors, outside the OSPAR Convention area, to nitrogen deposition to the OSPAR Convention waters were Poland, Italy and the part of the Russian Federation included in the EMEP area. In these three countries, emissions in 2004 were reported to be lower than in 1990 by 49%, 36% and 14%, respectively.

Annual emissions of nitrogen oxides, as a sum of emissions from all OSPAR Contracting Parties and selected additional three countries outside OSPAR were 22% lower in 2004 than the annual emissions in the year 1990. Taking into account the uncertainties regarding the reporting of emission data, there seems to be evidence for nitrogen oxides emissions going down in the OSPAR Convention area.

Ammonia (NH_3) emissions for the period 1990 – 2004 are shown in Figure 6 and Table 2. Also annual emissions of ammonia (NH_3) were lower in 2004 than in 1990 for most of the OSPAR Contracting Parties and two (Russian Federation and Poland) out of three selected countries outside OSPAR. Out of 18 countries relevant for OSPAR, annual emissions in nine countries were lower in 2004 than in 1990. In the Russian Federation, the Netherlands, and Poland, ammonia (NH_3) emission reductions were significant (48%, 46% and 38%, respectively).

The rate of ammonia (NH_3) emission reduction was slightly lower than the rate of nitrogen oxides (NO_2) emission reduction in the period 1990 – 2004. Annual emissions of ammonia, as a sum of emissions from all OSPAR Parties and the three selected countries outside the OSPAR Convention area were 14% lower in 2004 than the annual emissions in the year 1990.

Annual emissions of nitrogen oxides (NO_2), as a sum of emissions from all OSPAR Parties and the three selected countries outside the OSPAR Convention area were 10% higher than the corresponding annual emissions of ammonia (NH_3) in the year 2004, in terms of nitrogen emitted.

5. Atmospheric nitrogen deposition in the OSPAR Convention Waters

Atmospheric deposition of oxidized nitrogen and reduced nitrogen were calculated for eleven years; 1990, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003 and 2004. Oxidized nitrogen deposition calculated in nitrogen units consists of the sum of peroxyacetyl nitrate (PAN), NO_2, HNO_3 and aerosol nitrate (ammonium nitrate + coarse nitrate) deposition. Deposition of reduced nitrogen includes deposition of NH_3 and aerosol ammonium (ammonium sulphate + ammonium nitrate).

Maps of modelled annual deposition of oxidized nitrogen in the five main OSPAR regions in 1990 and 2004 are shown in Figures 7 and 8, respectively. Maps of annual deposition of reduced nitrogen in 1990 and 2004 are shown in Figures 9 and 10, respectively. Numerical values of the deposition in the five main OSPAR Regions for all nine years are included in Tables 3 and 4 for oxidized and reduced nitrogen, respectively.

For oxidized nitrogen, annual deposition was lower in 2004 than in 1990 in all main OSPAR Regions, by 24%, 23%, 22%, 21% and 1% for Arctic Waters, Celtic Seas, Greater North Sea, Wider Atlantic and Bay of Biscay/Iberian Coast, respectively. Thus, the declining pattern of nitrogen oxides (NO_2) emissions is followed by the deposition pattern for the same period.

In case of reduced nitrogen, annual deposition in 2004 was slightly higher than in 1990 in the main OSPAR Region IV Bay of Biscay/Iberian Coast (10 %). In the remaining main OSPAR Regions deposition of reduced nitrogen was lower by 25%, 16%, 8% and 2%, for the Wider Atlantic, Arctic Waters, Greater North Sea, and Celtic Seas, respectively. The figures clearly show that there was a large inter-annual variability of deposition, probably caused by different meteorological conditions in different years. The year-to-year variations were large and had the same magnitude as the change in deposition in the period from 1990 to 2004. This illustrates that in order to detect trends caused by changes in emissions, many years of observational data are necessary. Moreover, model calculations can be a helpful tool to assess whether observed changes are related to changes in the meteorological conditions or to emission changes. For instance in the Wider Atlantic, deposition of nitrogen peaked in 1996/1997, whilst the relevant reported emissions exhibit no such peak. Both observations and model results at the Portuguese Atlantic coast point towards high wet deposition of nitrogen in 1996/1997. Thus, the peaks of nitrogen deposition in the Wider Atlantic in the mid-1990s were likely caused by specific meteorological conditions.

For both oxidized and reduced nitrogen, a clear gradient of deposition towards the open sea can be noticed with maxima of deposition in OSPAR Region II (Greater North Sea). In 2004, the maximum deposition of oxidized nitrogen (513 mg N m^{-2}) was slightly lower than the maximum deposition of reduced nitrogen (522 mg N m^{-2}). However, total deposition of oxidized nitrogen is much (64%) higher in 2004 than the total deposition of reduced nitrogen to the OSPAR Convention waters. This means that the nitrogen emitted from mobile sources contributed more to the deposition than the nitrogen emitted mainly from sources related to agriculture. This conclusion applies to the entire considered period 1990 – 2004.

Total annual nitrogen deposition in the main OSPAR Regions is shown in Figures 11 and 12, for the years 1990 and 2004, respectively. Numerical values of total (oxidized plus reduced) nitrogen deposition for all seven years are given in Table 5. Also in this case a clear gradient of the deposition towards the open sea can be concluded especially from Figures 11 and 12 with a maximum of deposition in OSPAR Region II (Greater North Sea). Compared to 1990, annual deposition of total nitrogen in 2004 was higher only in OSPAR Region IV – Bay of Biscay/Iberian Coast.

Annual nitrogen deposition in the entire OSPAR maritime area is shown in Figure 13 for the years 1990, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003 and 2004. Deposition of oxidized and total (oxidized plus reduced) nitrogen was going down from 1990 to 1995, whereas deposition of reduced nitrogen was slightly higher in 1995 than in 1990. There is a clear maximum for all three types of nitrogen deposition in the year 1996 and then a decrease until 1999. From 1999 to 2003, deposition of nitrogen was going slightly up, but in 2004 all types of nitrogen deposition reached the minimum for the entire considered period.

Maps of modelled annual deposition of oxidized nitrogen in the sub-regions of OSPAR Region II (Greater North Sea) in 1990 and 2004 are shown in Figures 14 and 15, respectively. Maps of modelled annual deposition of reduced nitrogen in 1990 and 2004 are shown in Figures 16 and 17, respectively. Numerical values of the modelled deposition in 13 sub-regions of the Greater North Sea for all eleven years are given in Tables 6 and 7 for oxidized and reduced nitrogen, respectively.

For oxidized nitrogen, annual deposition in all sub-regions of the Greater North Sea (Table 6) was 5% to 29% lower in 2004 compared to 1990. Maxima (over 600 mg N m^{-2}) of the deposition in 2004 could be observed in sub-regions 5, 6, and 8, and a minimum (below 150 mg N m^{-2}) in sub-region 2. The largest deposition reduction (down 29%) was calculated for sub-region 9, from 40.5 kt N a^{-1} in 1990 to 28.8 kt N a^{-1} in 2004.

In 3 out of 13 sub-regions of the Greater North Sea annual deposition of reduced nitrogen was higher in 2004 than in 1990 (Table 7). For the sub-region 13 deposition increase was significant, 15%. Maxima (over 1,000 mg N m^{-2}) of the deposition in 2004 could be observed close to the German, Belgian and French coasts in sub-regions 8, 6, and 13, and a minimum (below 150 mg N m^{-2}) again in sub-region 2. Lower deposition in 2004 than in 1990 could be observed especially in sub-regions 12 and 9 of the Greater North Sea with 26% and 20% reduction, respectively. The largest deposition reduction (down 26%) was calculated for sub-region 12, from 28 kt N a^{-1} in 1990 to 20.7 kt N a^{-1} in 2004. The highest increase of the deposition (up 15%) was calculated for sub-region 13, from 28.7 kt N a^{-1} in 1990 to 32.9 kt N a^{-1} in 2004.

Total modelled annual nitrogen (oxidized plus reduced nitrogen) deposition in the sub-regions of the Greater North Sea is shown in Figures 18 and 19, for the years 1990 and 2004, respectively. Numerical values of modelled total (oxidized plus reduced) nitrogen deposition for all eleven years are given in Table 8. Compared to 1990, annual deposition of total nitrogen in 2004 was higher only in one out of 13 sub-regions of the Greater North Sea namely in the sub-region 8 with a maximum over 1000 mg N m^{-2}. The largest deposition reduction (down 28%) was calculated for sub-region 12, from 61.8 kt N a^{-1} in 1990 to 44.7 kt N a^{-1} in 2004. The increase of the deposition by 5% was calculated for sub-region 13, from 54.4 kt N a^{-1} in 1990 to 57.2 kt N a^{-1} in 2004.

Maps with time series of modelled oxidized, reduced and total nitrogen deposition in the five main OSPAR Regions are shown for the years 1990, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003 and 2004 in Figures 20, 21 and 22, respectively. For all types of deposition and for all components a maximum in all main OSPAR regions occurred in 1996, whereas a minimum can be noticed either in 2000 or in 2004.

Maps with time series of modelled oxidized, reduced and total nitrogen deposition in the 13 sub-regions of main OSPAR Region II (Greater North Sea) are shown for the years 1990, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003 and 2004 in Figures 23, 24 and 25, respectively. In all sub-regions, in 2004 deposition values of oxidized nitrogen were lower than deposition in 1990. Compared to 1990, deposition of reduced nitrogen was higher in 2004 in three sub-regions and no clear trend is visible in the deposition pattern. The same applies to the deposition of total nitrogen.

6. Comparison of computed versus measured deposition at OSPAR coastal monitoring stations

Within the framework of the OSPAR Working Group on Inputs to the Marine Environment (INPUT), every year a report of the Comprehensive Atmospheric Monitoring Programme (CAMP) - Pollutant deposits and air quality at coastal stations - is prepared and published. This is based on data which OSPAR Contracting Parties report annually to OSPAR under CAMP. These are data from measurements at national coastal monitoring stations of atmospheric pollutants' concentrations in precipitation and related amount of precipitation. These data were used for the comparison of modelled and measured annual wet deposition. "Measured" deposition was in fact not measured but calculated as a product of precipitation amount and concentration in precipitation of each pollutant. Maps with modelled versus measured annual wet depositions of oxidized, reduced and total (oxidized plus reduced) nitrogen for the years 1990, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003 and 2004 at the stations located in the main OSPAR Regions are shown in Figures 26, 27 and 28, respectively. Similar maps with measured versus calculated deposition of oxidized, reduced and total nitrogen, for the stations located in OSPAR Region II (Greater North Sea), are shown in Figures 29, 30 and 31, respectively.

The agreement between model results and observations depends not only on the "model performance" and the adequacy of emissions employed, but also on the quality and representativeness of the measurement sites. It is worth mentioning here that for some stations, double sets of measurement data (e.g. obtained with different methods) have been reported. In some cases, these data sets differ by more than 50 %. This indicates that there is a substantial uncertainty in the measurements. Thus, the following discussion on model *underestimation* and *overestimation* simply implies that the calculated values are lower or higher than the observations and does not refer to model deficiency only.

For the majority of the stations considered, modelled and measured wet depositions match well. In general, modelled wet deposition for stations situated in the sub-regions is in better agreement with observations than for stations located in the main Regions. Also, wet depositions of both oxidized and reduced nitrogen are underestimated, but the underestimation is larger for the sites in the main Regions.

Many of the sites in the main Regions (e.g. sites in Iceland and at Spitsbergen) are situated close to the boundary of the model domain. Therefore, the model results are sensitive to the choice of boundary conditions in the model. Consequently, the results for these stations are expected to be worse than for other stations. It might also be that these sites are influenced by local sources that are not accounted for in the emission inventory.

Observed wet deposition for sites situated in the sub-regions of the Greater North Sea matches very well modelled wet deposition. It is especially encouraging that the model manages to reproduce the monitored year-to-year variations.

In general, wet deposition of ammonium and nitrate is somewhat underestimated, but the reason is not fully understood. Both uncertainties in emissions and the model formulation itself may play a role. In addition, it is well known that dry deposition of NH_3 to open bulk collectors can account for a substantial part of the measured wet deposition. Thus, the apparent under-prediction of wet deposition may partly be caused by the bias in measured wet deposition.

7. Possible uncertainties

Precise estimation of uncertainties in measurements, emission data and model results is always very difficult and in some cases (e.g. source-receptor matrices) not possible at all. Therefore, in this chapter, we will only comment on uncertainties related to the data presented in the report.

The uncertainties in the emissions lead to inaccuracies in the modelling of chemical transformation, deposition processes and transport. The ship emissions contribute significantly to the nitrogen depositions in the OSPAR maritime area, and their magnitude, distribution and trends are not very well known, thus they constitute an important source of uncertainty. The Regions Wider Atlantic and Artic Waters are close to the model domain boundary and thus the deposition here is largely affected by the boundary conditions. In the EMEP model, these are based on observations. However, there is a large span in reported observations of e.g. ammonium and nitrate over the Atlantic Ocean, and therefore the accuracy in the estimation of contribution from the boundary condition values is uncertain.

However, comparisons of modelled and measured concentrations and deposition of nitrogen at stations scattered around Europe show that the annual average of most stations are computed within a factor of two (e.g. EMEP Status Report 2003).

Concerning computed concentrations and deposition of nitrogen, a typical value of uncertainty is 30 % (EMEP, 2002), but in some cases differences between measured and computed values can be much larger. Such a comparison of computed and measured wet deposition of nitrogen compounds was found in Chapter 6.

The EMEP model grid does not cover the entire area of the main OSPAR Region V – Wider Atlantic (see Figure 1). The missing part in the south corresponds to 23 EMEP grid cells. This is a source of uncertainty which leads to a small underestimation of the computed nitrogen deposition in Region V. Assuming that deposition in the missing grid cells was not higher than deposition in the adjacent EMEP grid cells, we could estimate the amount of deposition in the missing grids to be not higher than 30 tonnes for oxidized and reduced nitrogen and 60 tonnes for the total nitrogen. These values are lower than 0.1 % of the corresponding deposition in Region V.

8. Comparison of computed atmospheric inputs with waterborne inputs to the Greater North Sea

In this section a comparison is made of atmospheric nitrogen inputs with inputs through direct discharges and riverine inputs to the Greater North Sea. The figures for waterborne inputs are based on the data annually reported by Contracting Parties under the OSPAR Comprehensive Study on Riverine Inputs and Direct Discharges (RID) (agreement 1998-5). For the Greater North Sea, Table 9 presents the results for the selected years from 1990 to 2004. In this period, riverine and direct nitrogen inputs varied from 745 to 1,282 kt total N/y. For the same period, airborne nitrogen input amounted to 457 – 582 kt total N/y (EMEP, see also Table 5). The portion of atmospheric nitrogen inputs in total nitrogen inputs varied from 25 to 39 %. These results clearly show that atmospheric nitrogen input cannot be neglected for large parts of the OSPAR maritime area, in particular the Greater North Sea, and should therefore be included in future assessments of nitrogen inputs to, and the eutrophication status of, the OSPAR Convention area.

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Figures

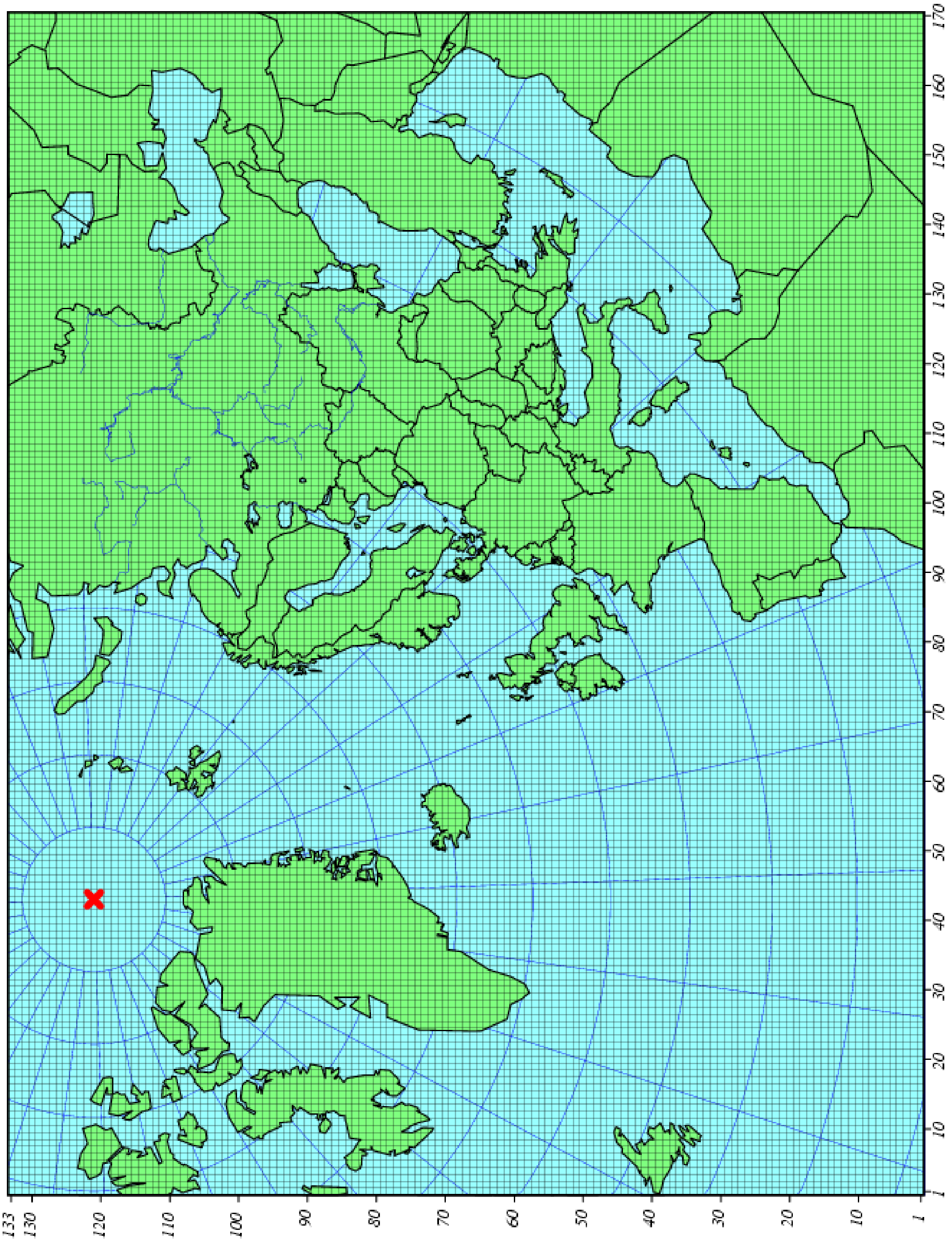

Figure 1. The EMEP model grid system of the size 170 × 133 in the Polar Stereographic projection. The grid resolution is 50 km at 60° N.

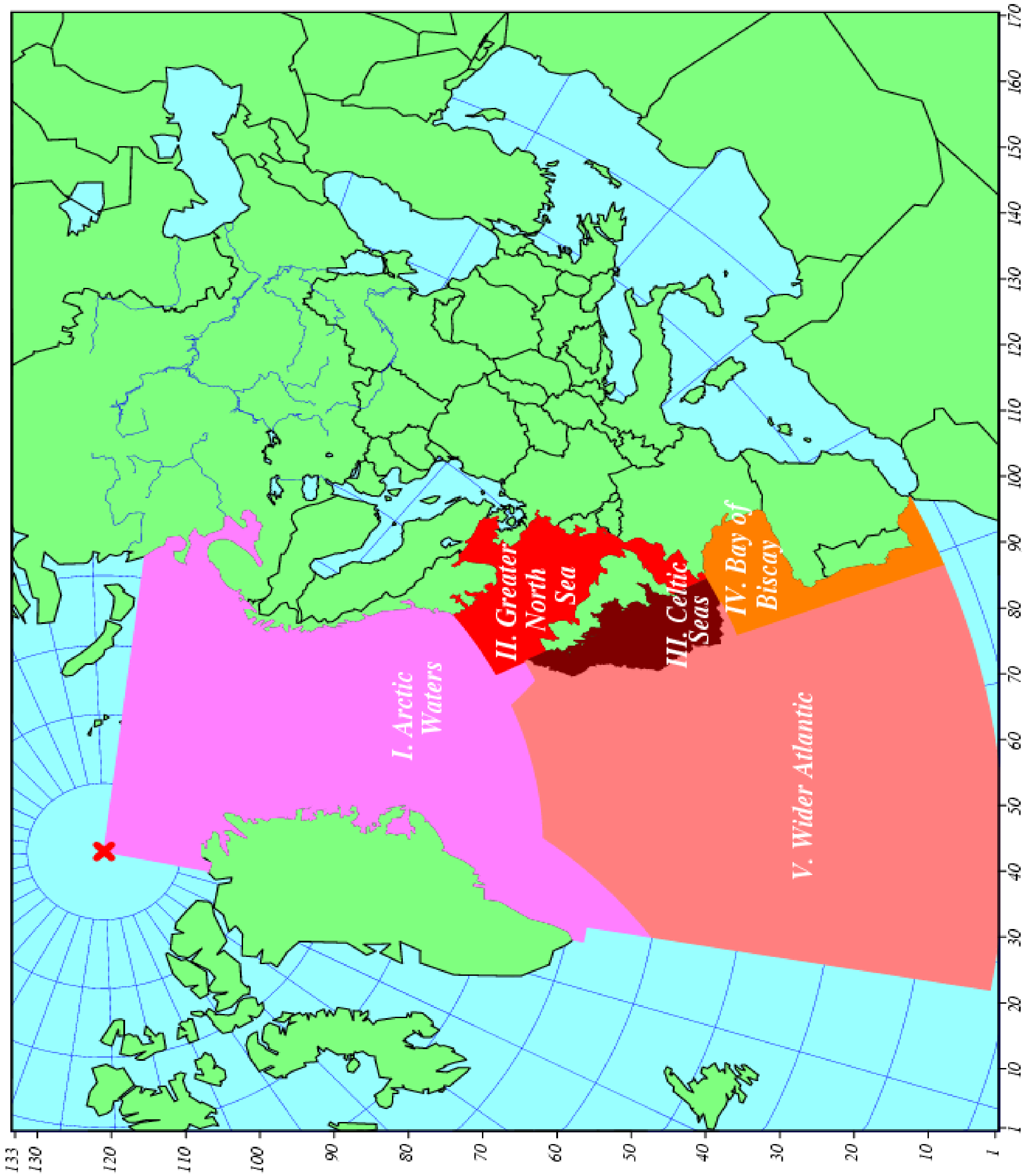

Figure 2. Location of the five main OSPAR Regions in the EMEP model grid system.

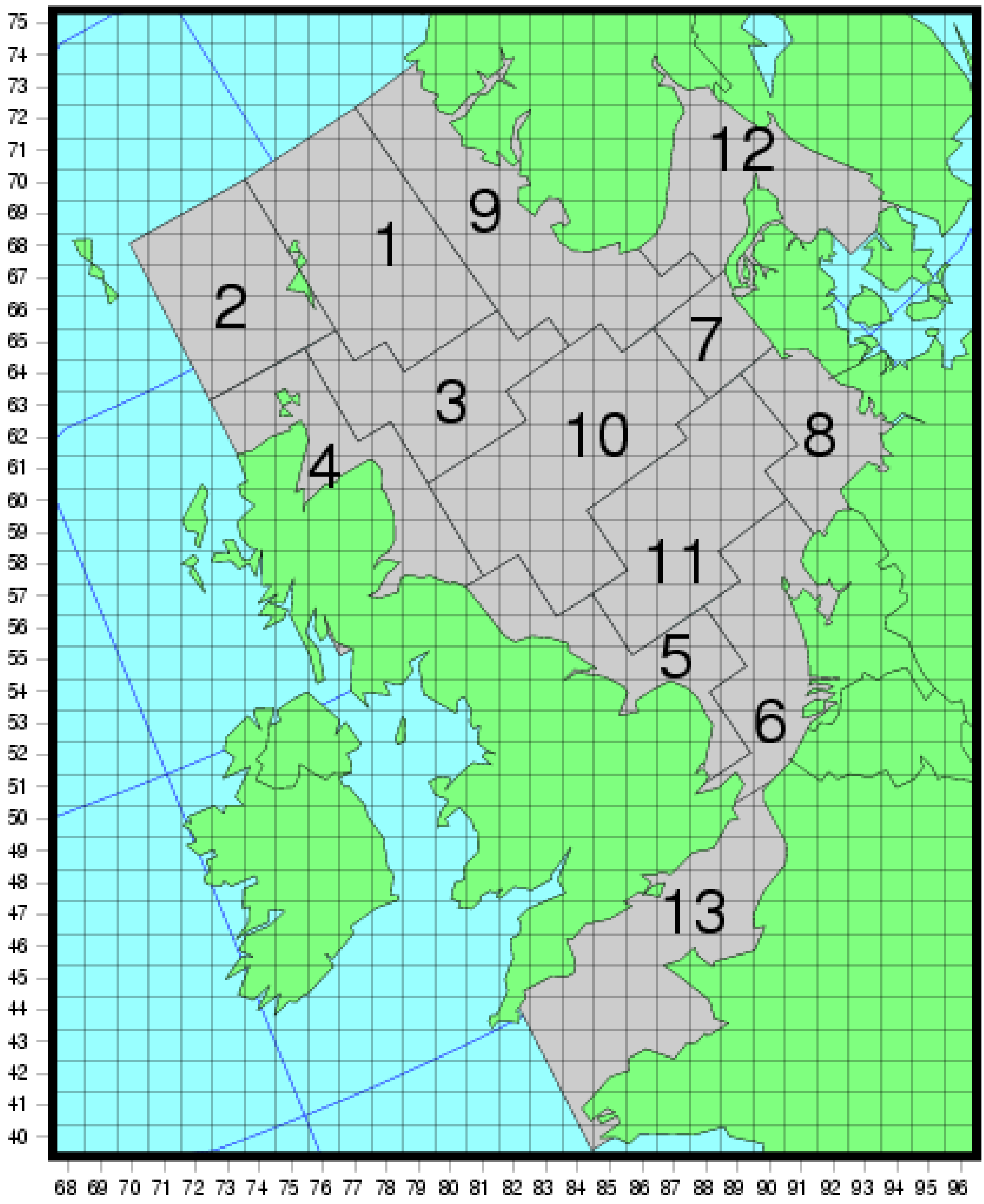

Figure 3. Location of the 13 sub-regions of OSPAR Region II (Greater North Sea) in the EMEP model grid system.

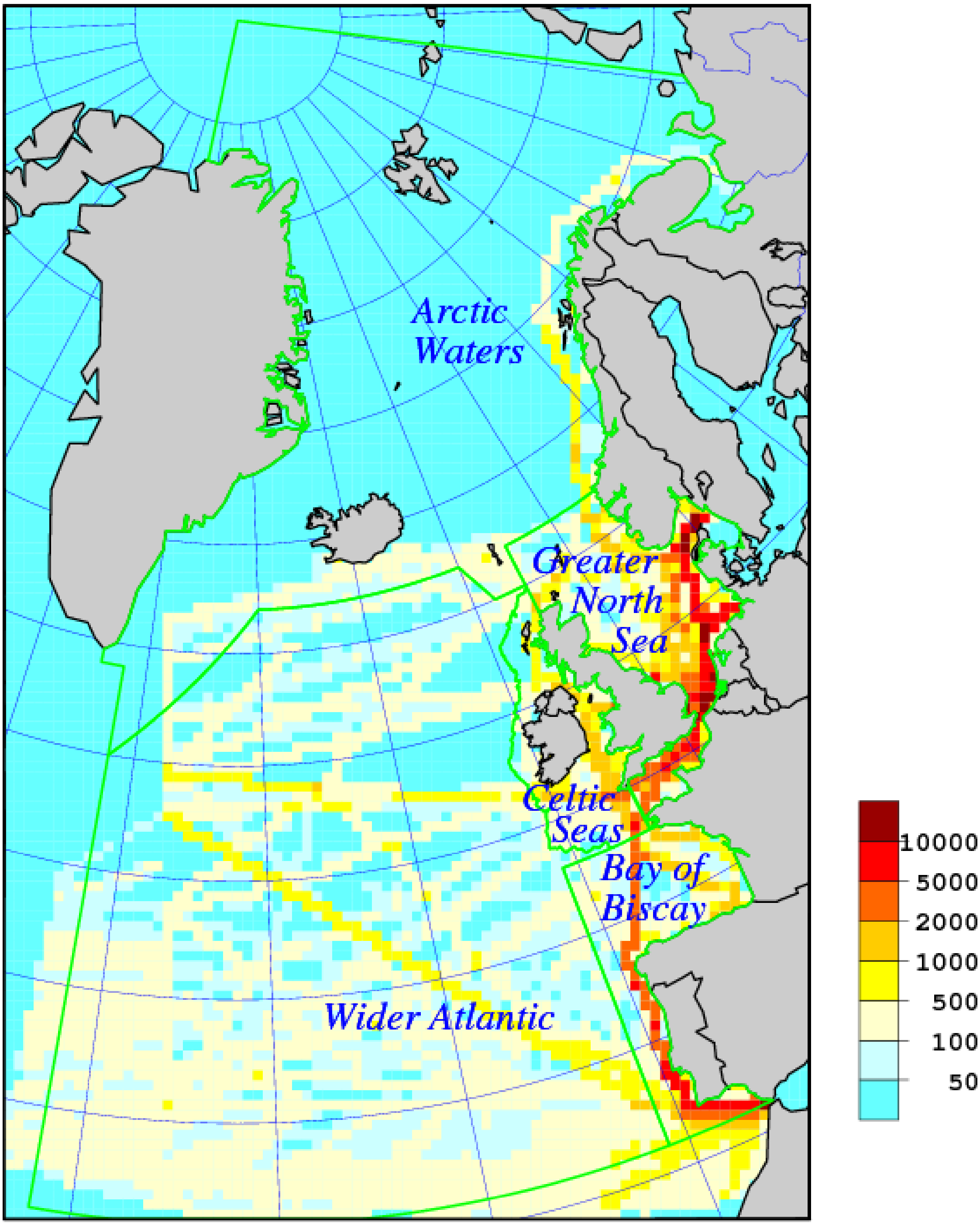

Figure 4. A map of 2004 nitrogen oxides emissions from the international ship traffic over the North Sea and Atlantic Ocean used in the model calculations for 2004. Units: t N a^{-1} (50 × 50 km2 model grid square)$^{-1}$.

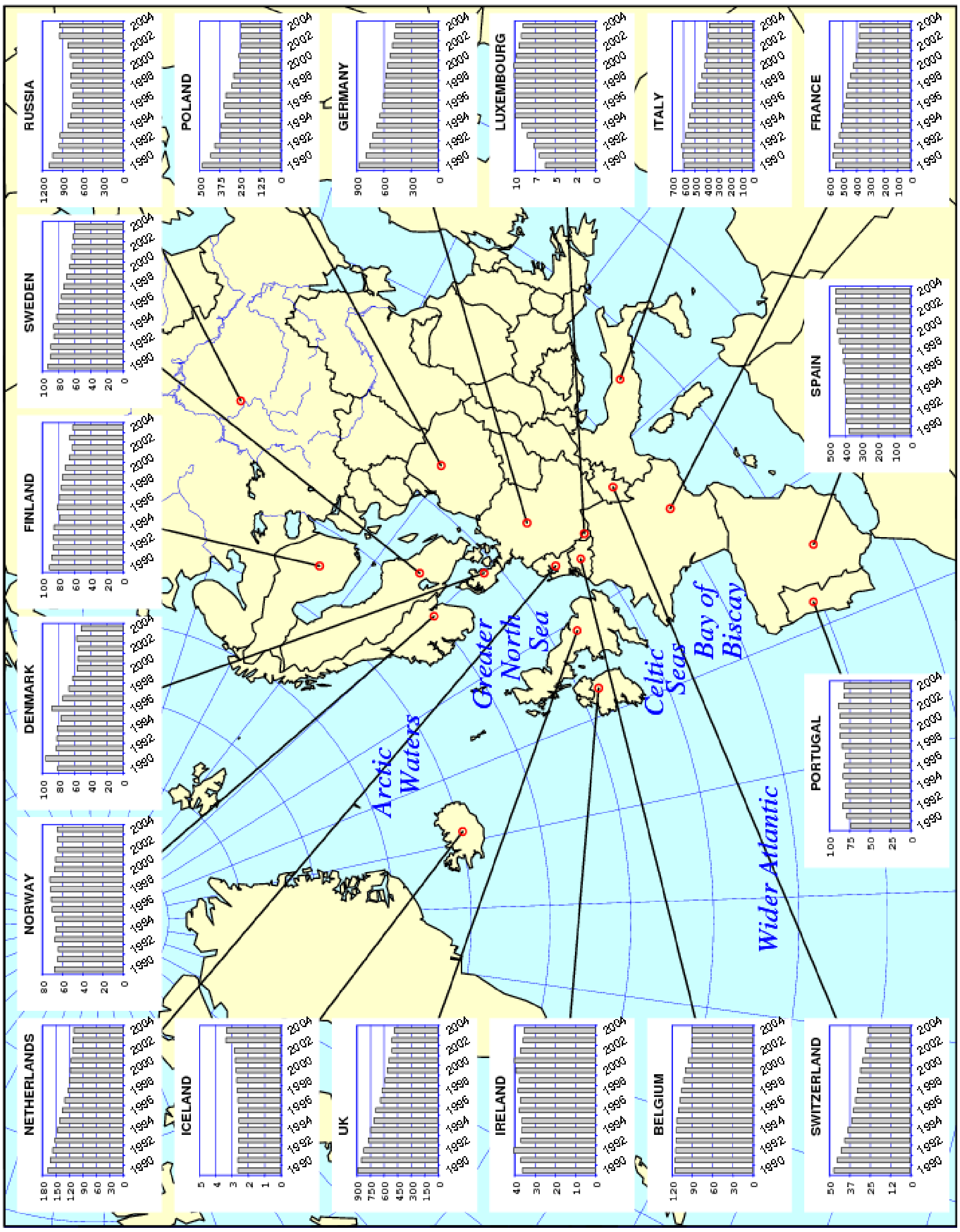

Figure 5. EMEP time series of nitrogen oxides emissions (as NO_2) from the OSPAR Contracting Parties, and selected countries (Poland, Italy and part of the Russian Federation within the EMEP domain) with the largest contribution to deposition in the OSPAR maritime area. Unit: kt N a^{-1}. Different scales are used for emissions from different countries.

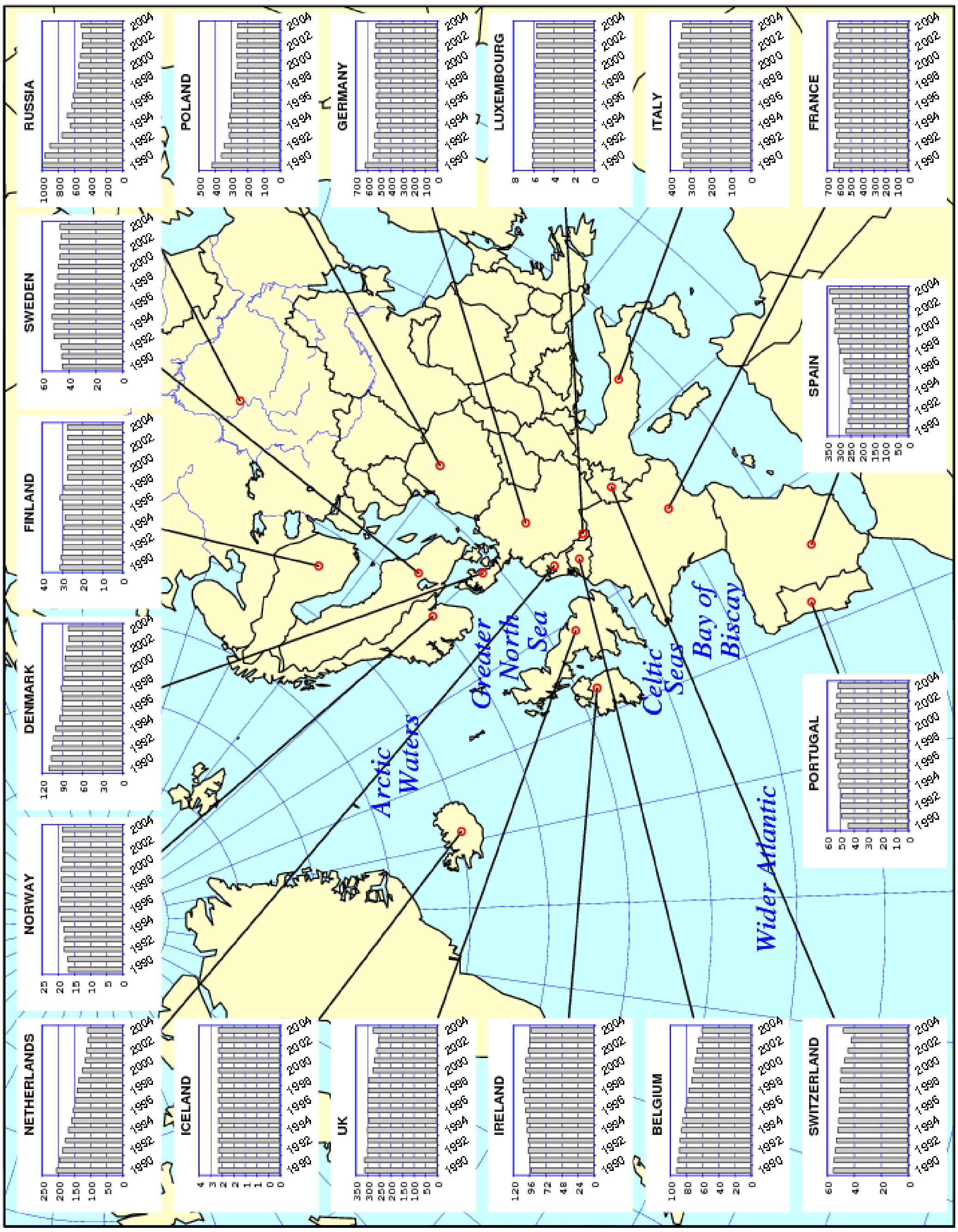

Figure 6. EMEP time series of ammonia (NH_3) emissions from the OSPAR Contracting Parties, and selected countries (Poland, Italy and part of the Russian Federation within the EMEP domain) with the largest contribution to deposition in the OSPAR maritime area. Unit: kt N a^{-1}. Different scales are used for emissions from different countries.

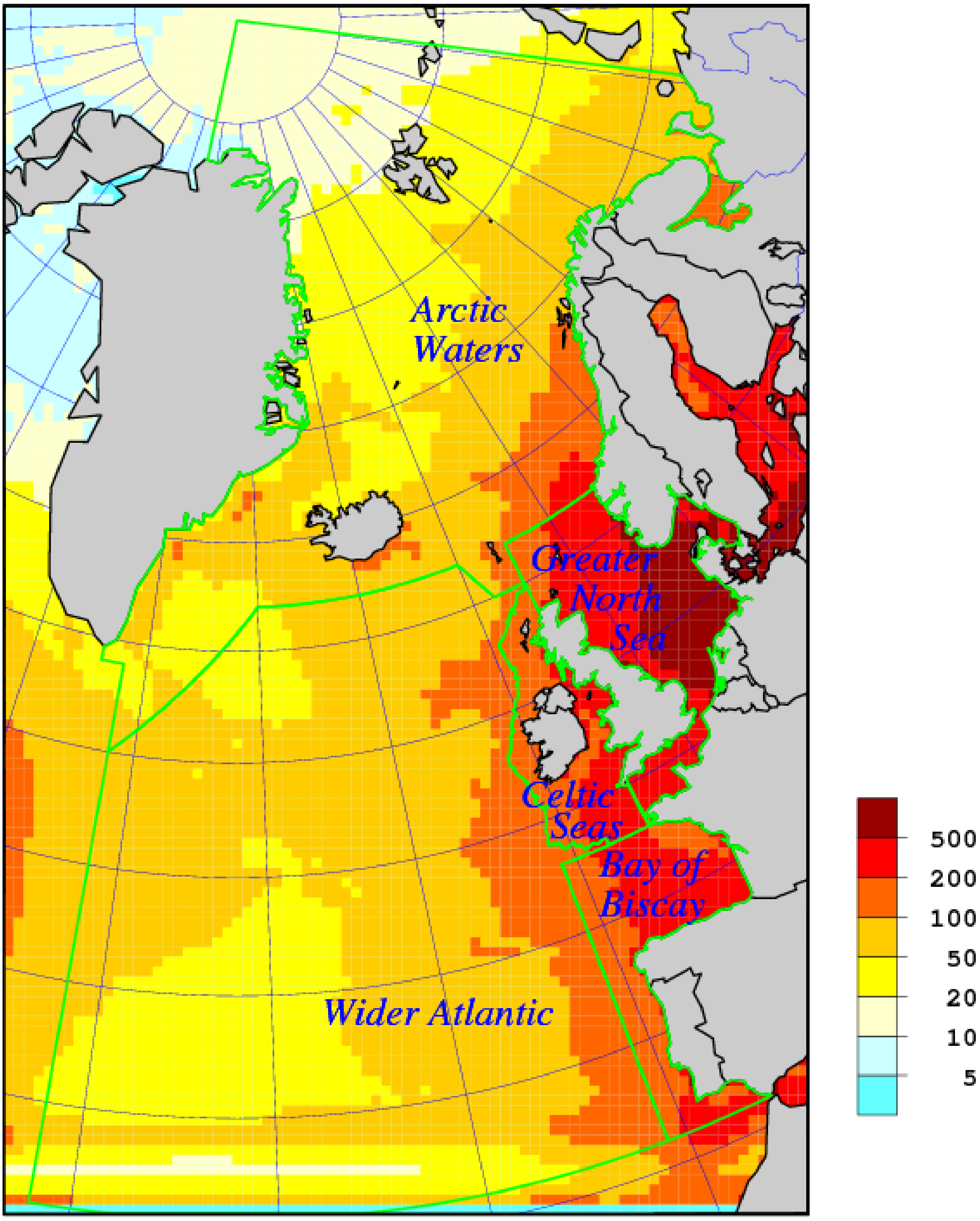

Figure 7. EMEP map of modelled annual oxidized nitrogen deposition in the five main OSPAR Regions in 1990. Unit: mg N m^{-2}.

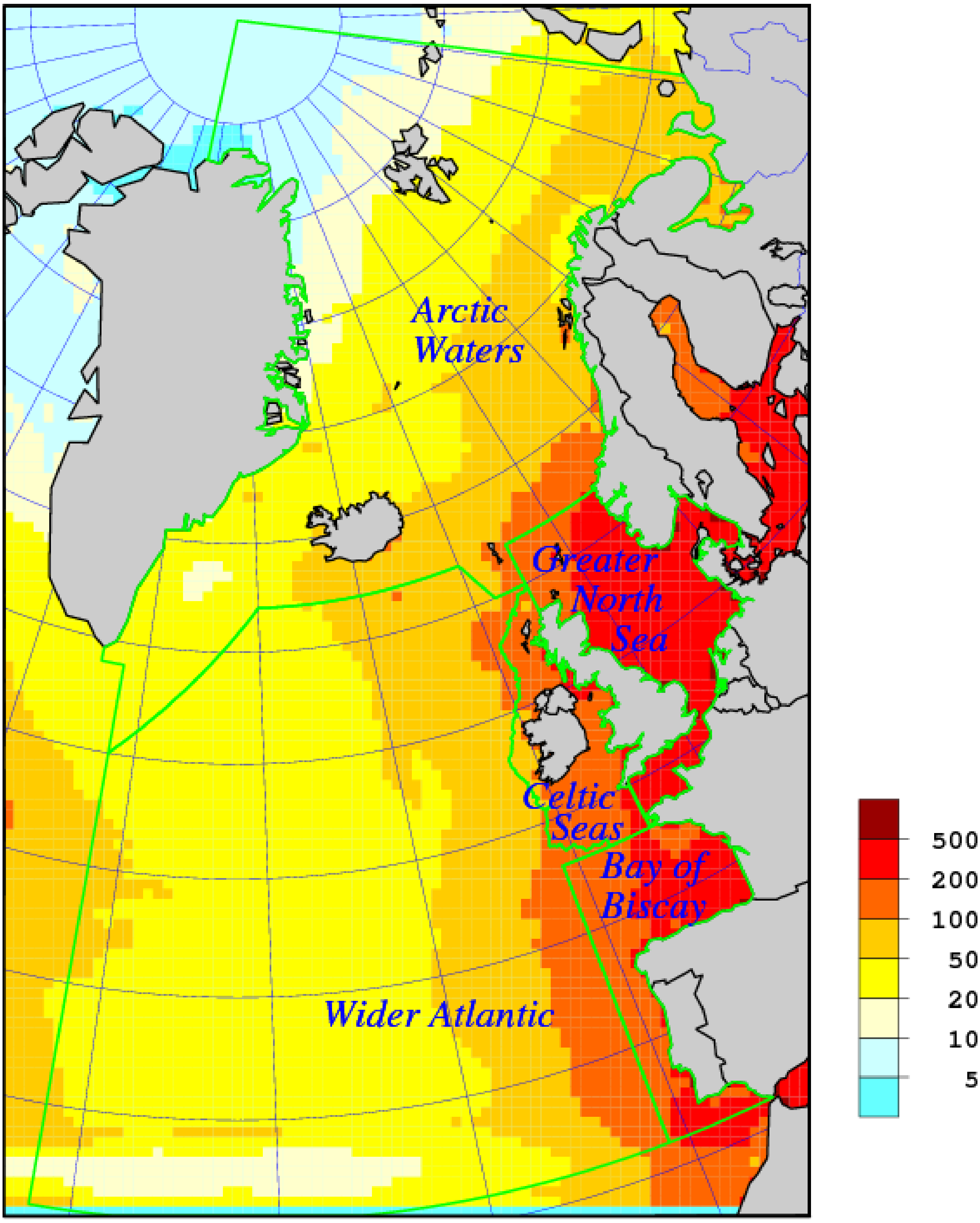

Figure 8. EMEP map of modelled annual oxidized nitrogen deposition in the five main OSPAR Regions in 2004. Unit: mg N m^{-2}.

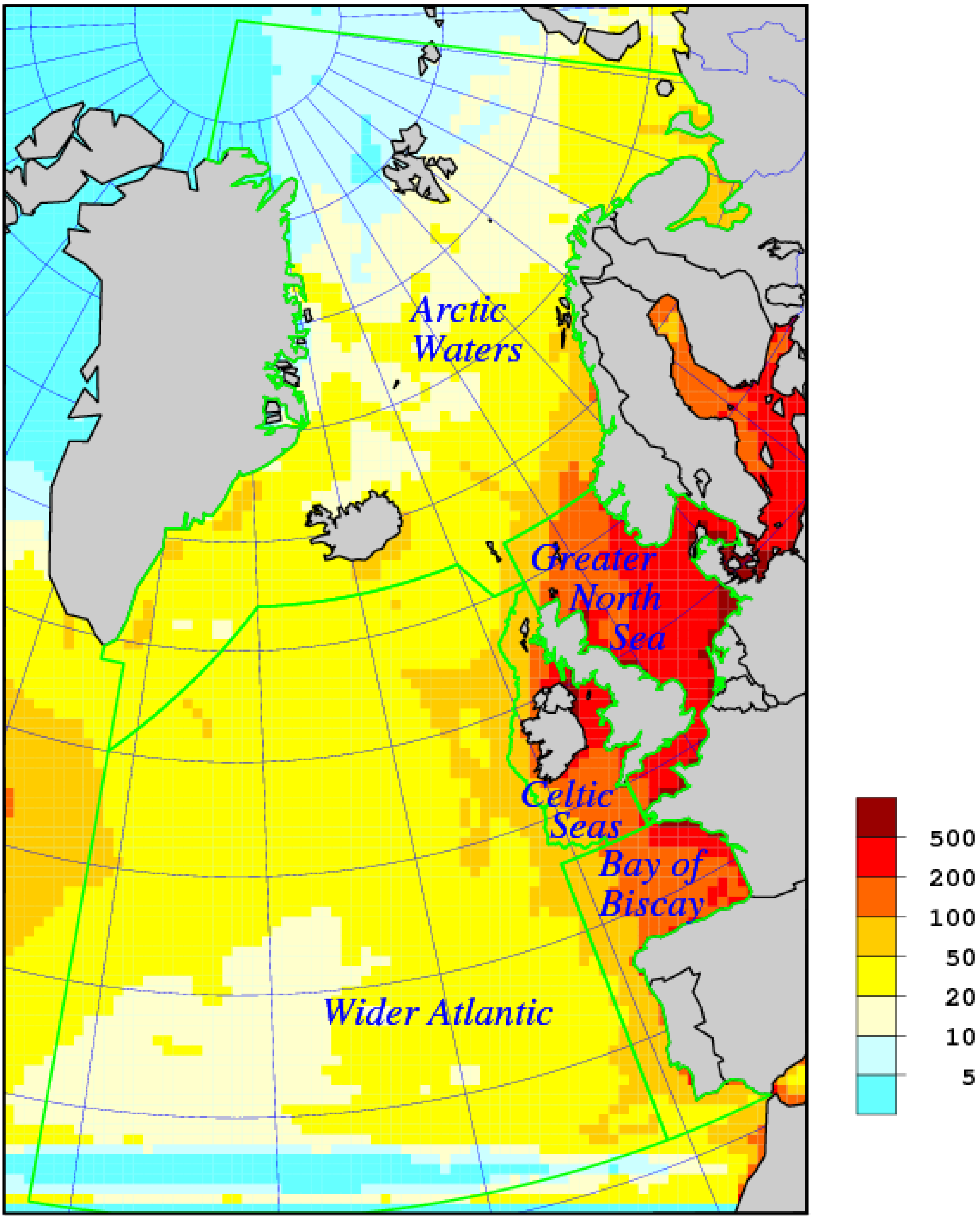

Figure 9. EMEP map of modelled annual reduced nitrogen deposition in the five main OSPAR Regions in 1990. Unit: mg N m^{-2}.

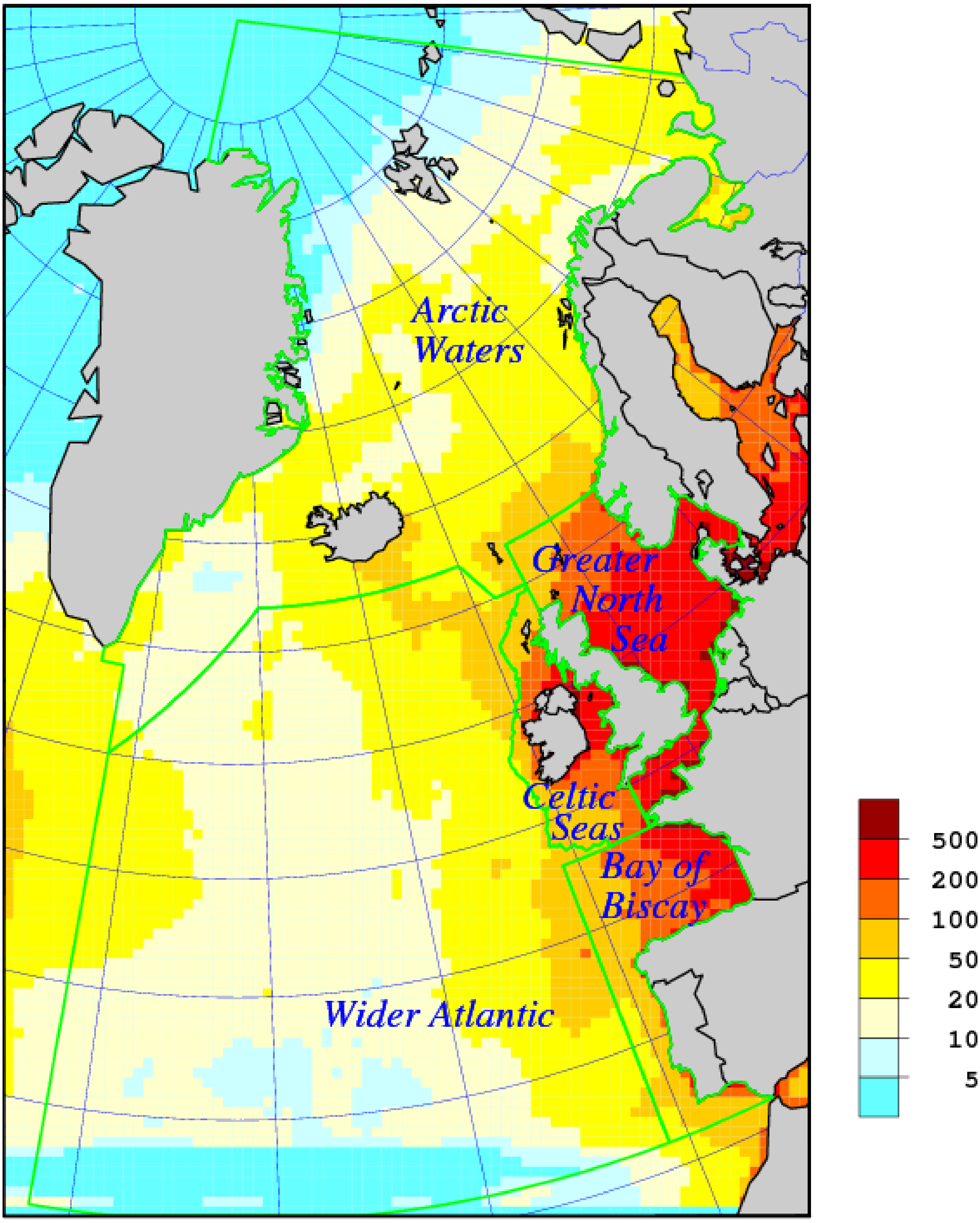

Figure 10. EMEP map of modelled annual reduced nitrogen deposition in the five main OSPAR Regions in 2004. Unit: mg N m^{-2}.

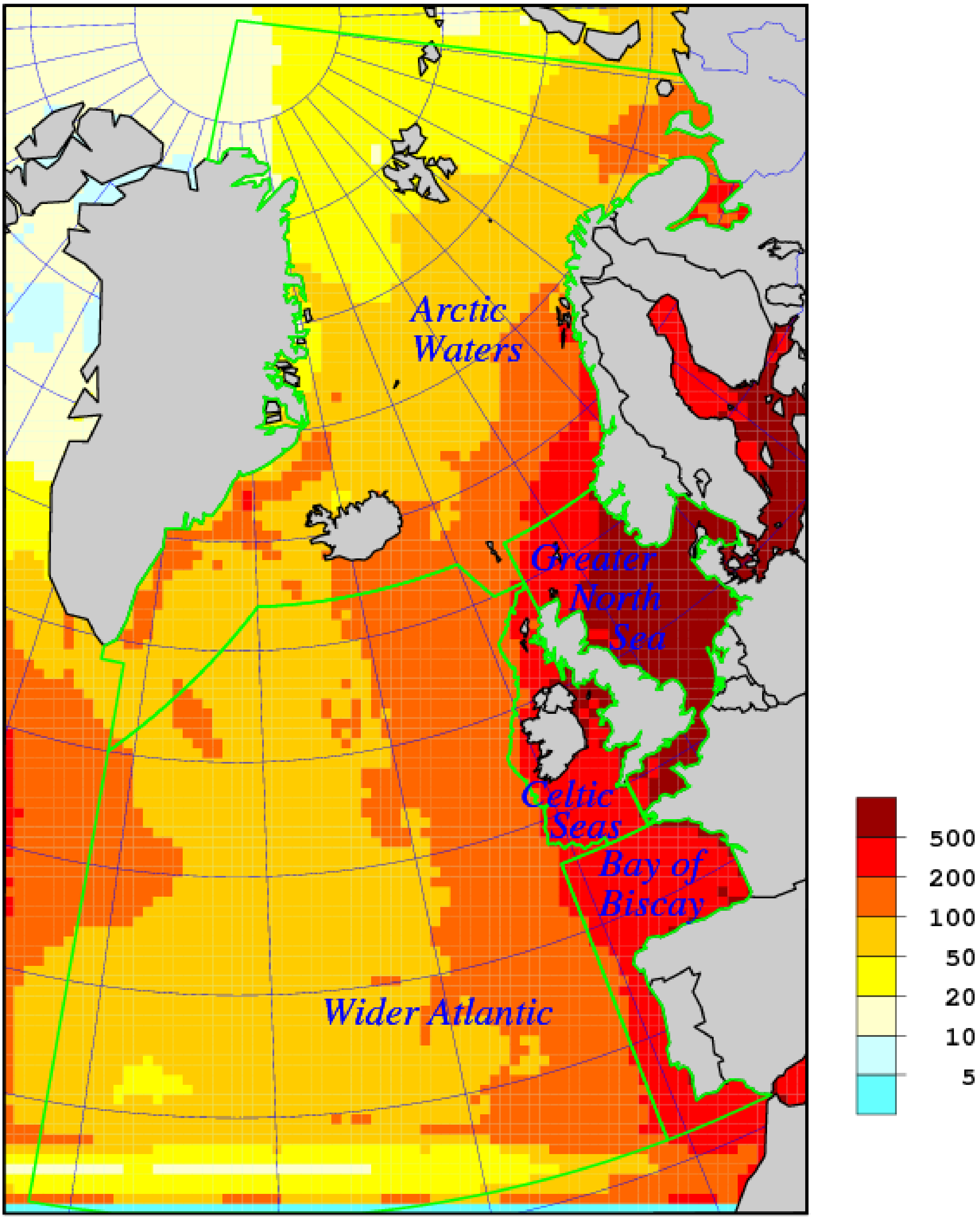

Figure 11. EMEP map of modelled total annual nitrogen deposition in the five main OSPAR Regions in 1990. Unit: mg N m^{-2}.

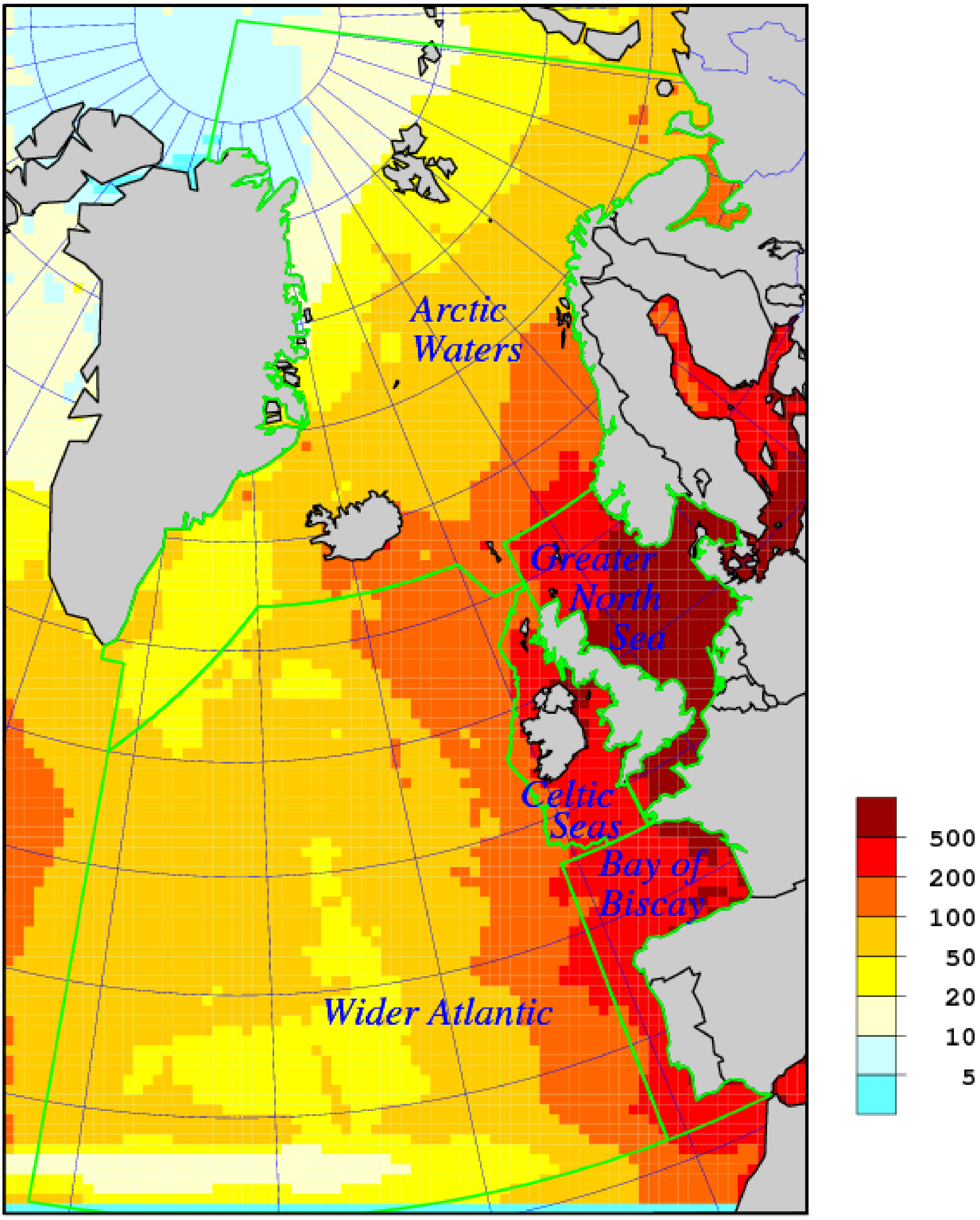

Figure 12. EMEP map of modelled annual total nitrogen (oxidized and reduced) deposition in the five main OSPAR Regions in 2004. Unit: mg N m^{-2}.

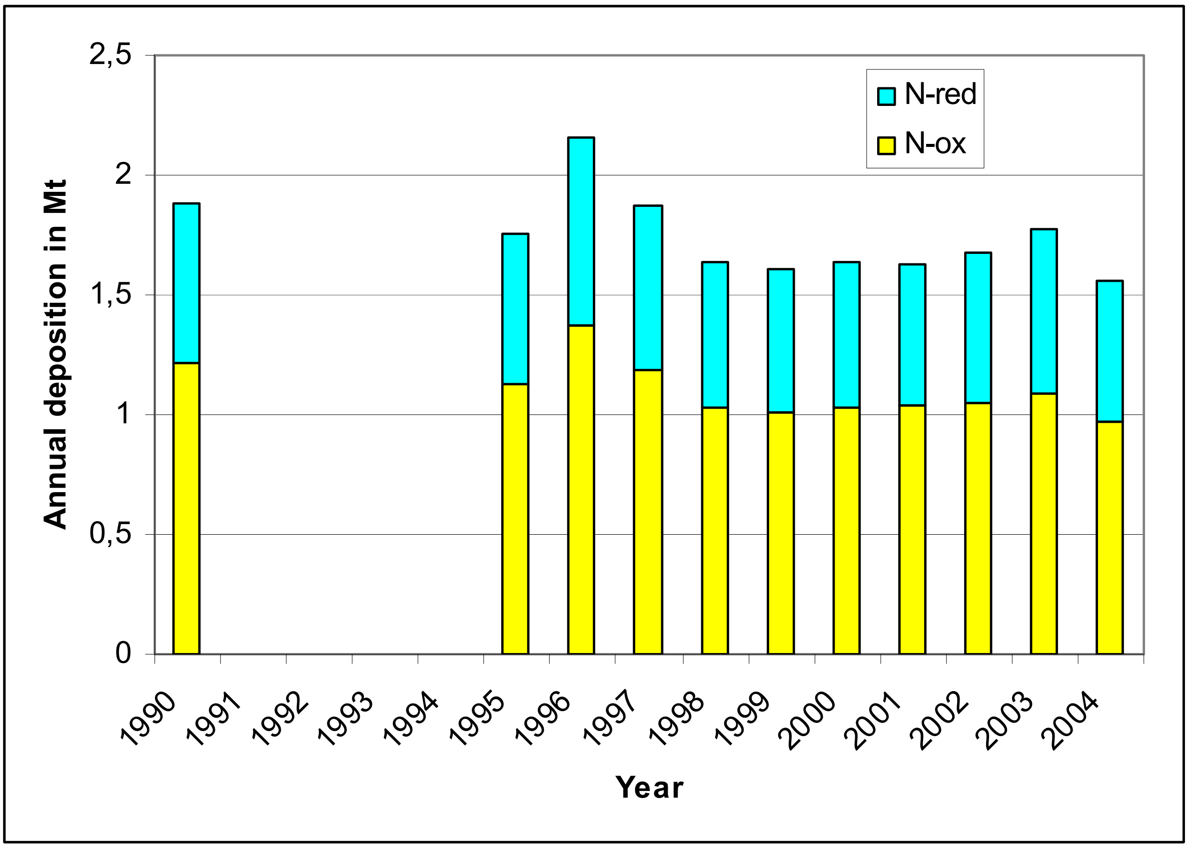

Figure 13. EMEP Annual oxidized (N-ox), reduced (N-red) and total (N-tot = N-ox + N-red) nitrogen deposition in the entire area of OSPAR Convention waters in the period 1990 - 2004. Unit: Mt N a^{-1}.

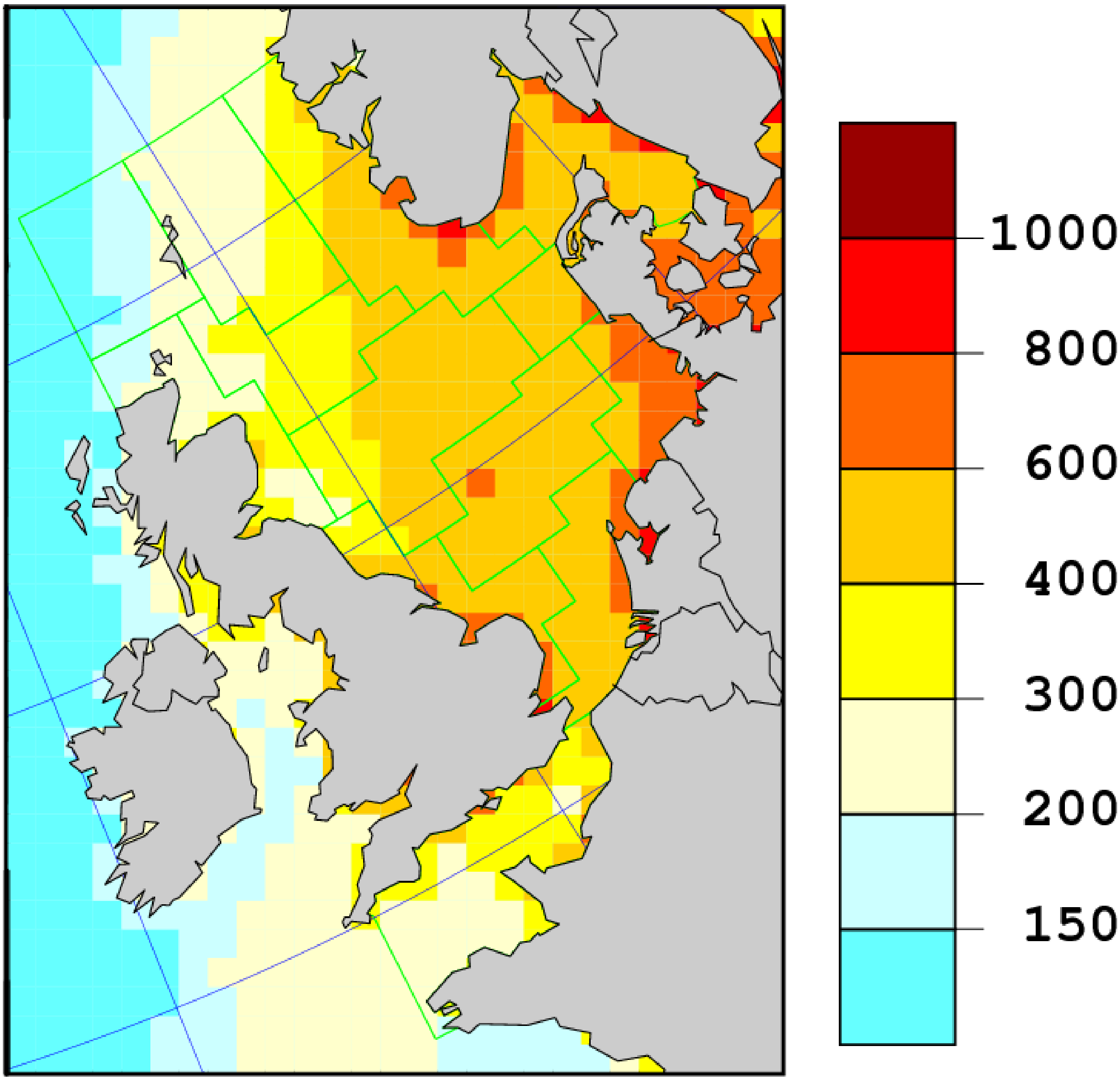

Figure 14. EMEP map of modelled annual oxidized nitrogen deposition in 13 sub-regions of OSPAR Region II (Greater North Sea) in 1990. Unit: mg N m^{-2}.

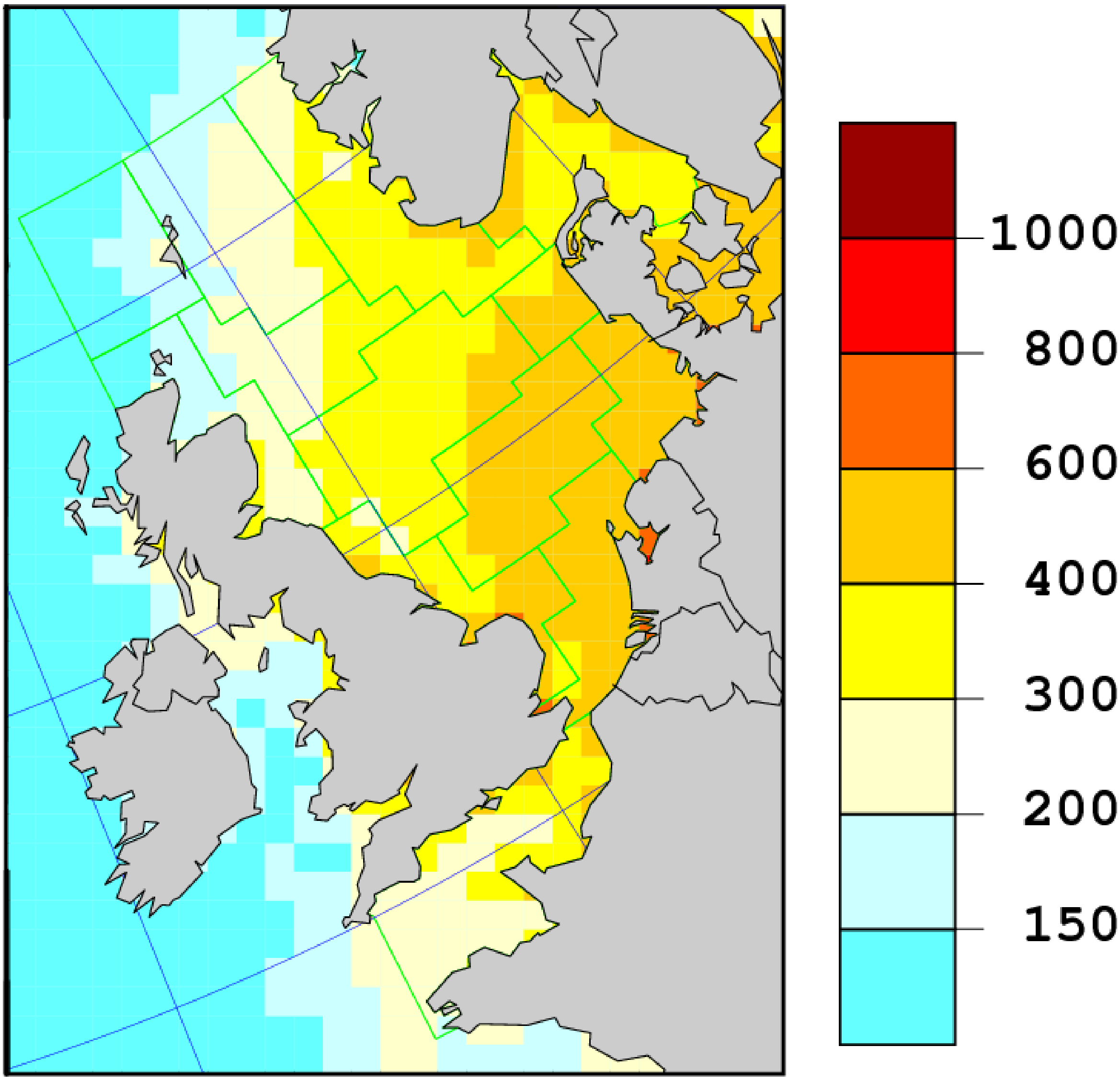

Figure 15. EMEP map of modelled annual oxidized nitrogen deposition in 13 sub-regions of OSPAR Region II (Greater North Sea) in 2004. Unit: mg N m^{-2}.

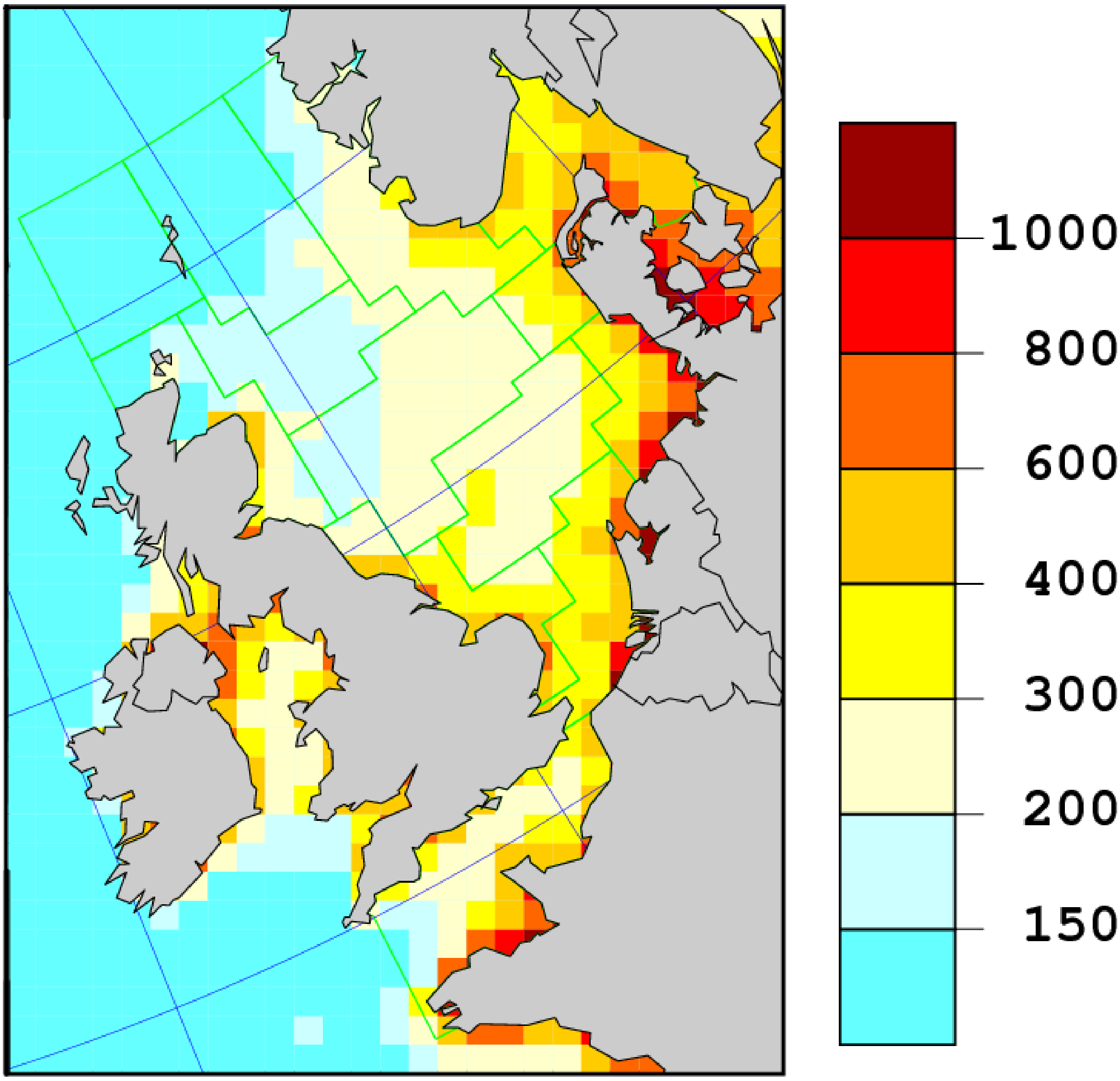

Figure 16. EMEP map of modelled annual reduced nitrogen deposition in 13 sub-regions of OSPAR Region II (Greater North Sea) in 1990. Unit: mg N m^{-2}.

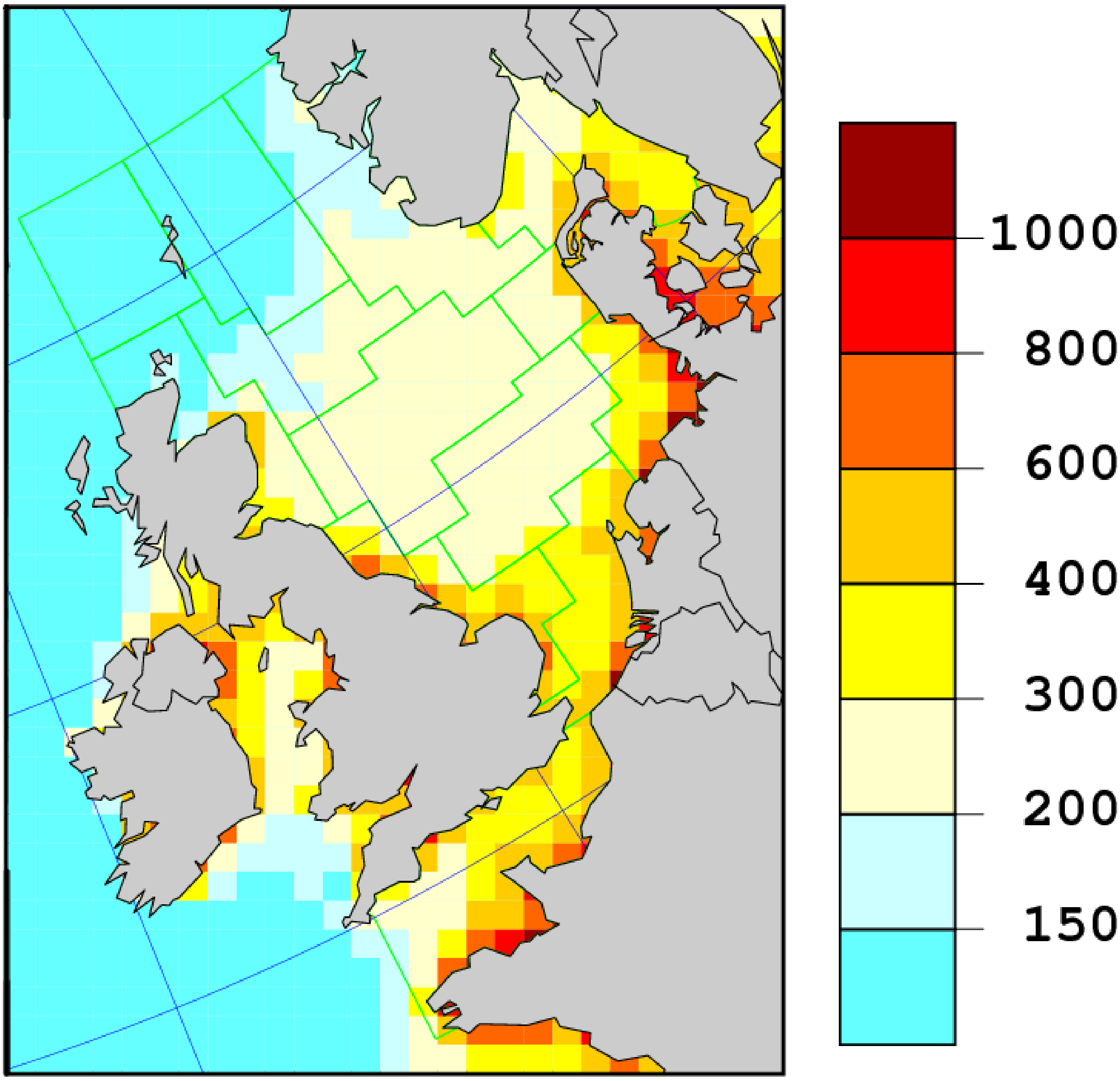

Figure 17. EMEP map of modelled annual reduced nitrogen deposition in13 sub-regions of OSPAR Region II (Greater North Sea) in 2004. Unit: mg N m^{-2}.

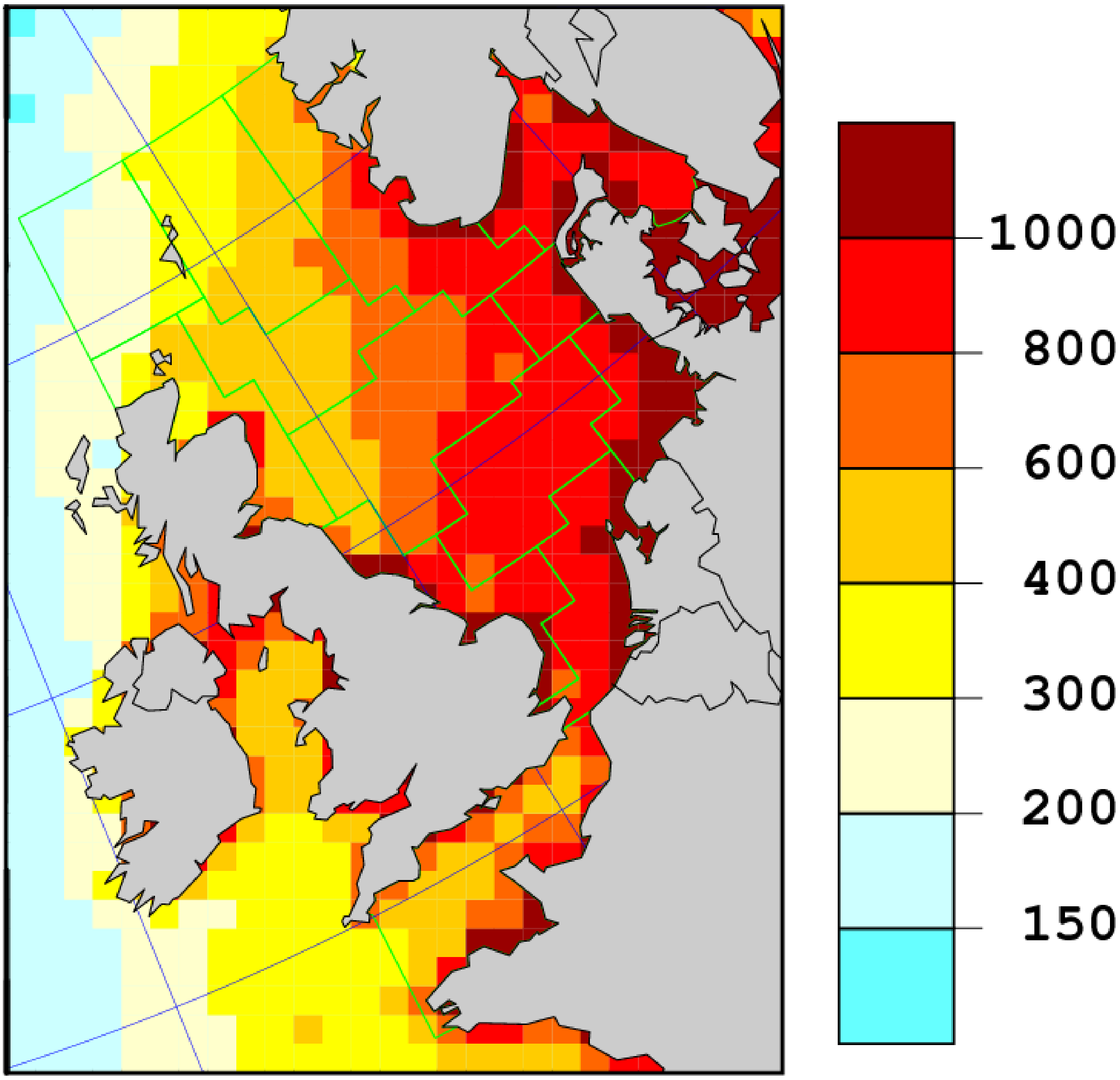

Figure 18. EMEP map of modelled total annual nitrogen (oxidized and reduced) deposition in 13 sub-regions of OSPAR Region II (Greater North Sea) in 1990. Unit: mg N m^{-2}.

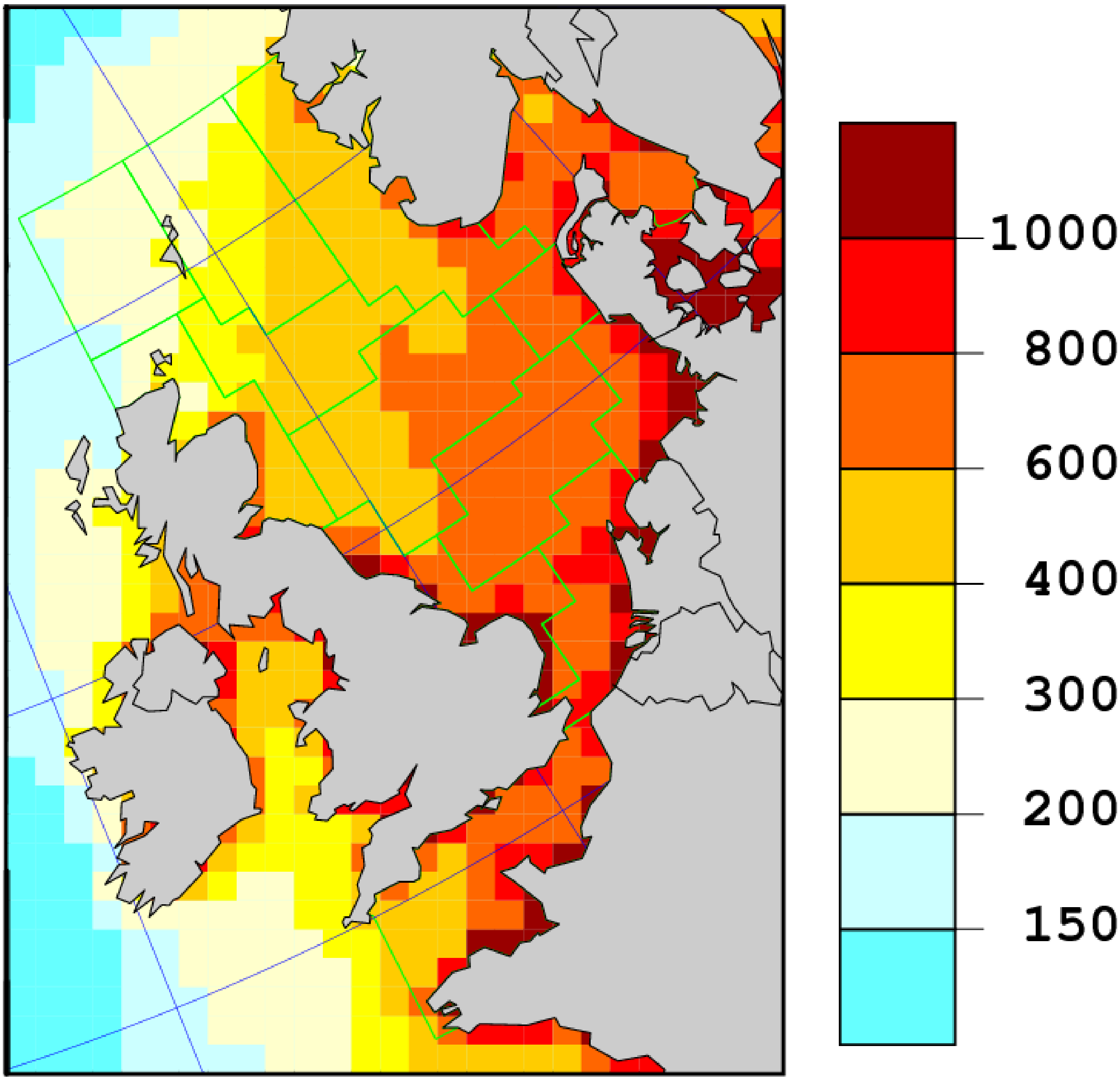

Figure 19. EMEP map of modelled total annual nitrogen (oxidized and reduced) deposition in 13 sub-regions of OSPAR Region II (Greater North Sea) in 2004. Unit: mg N m^{-2}.

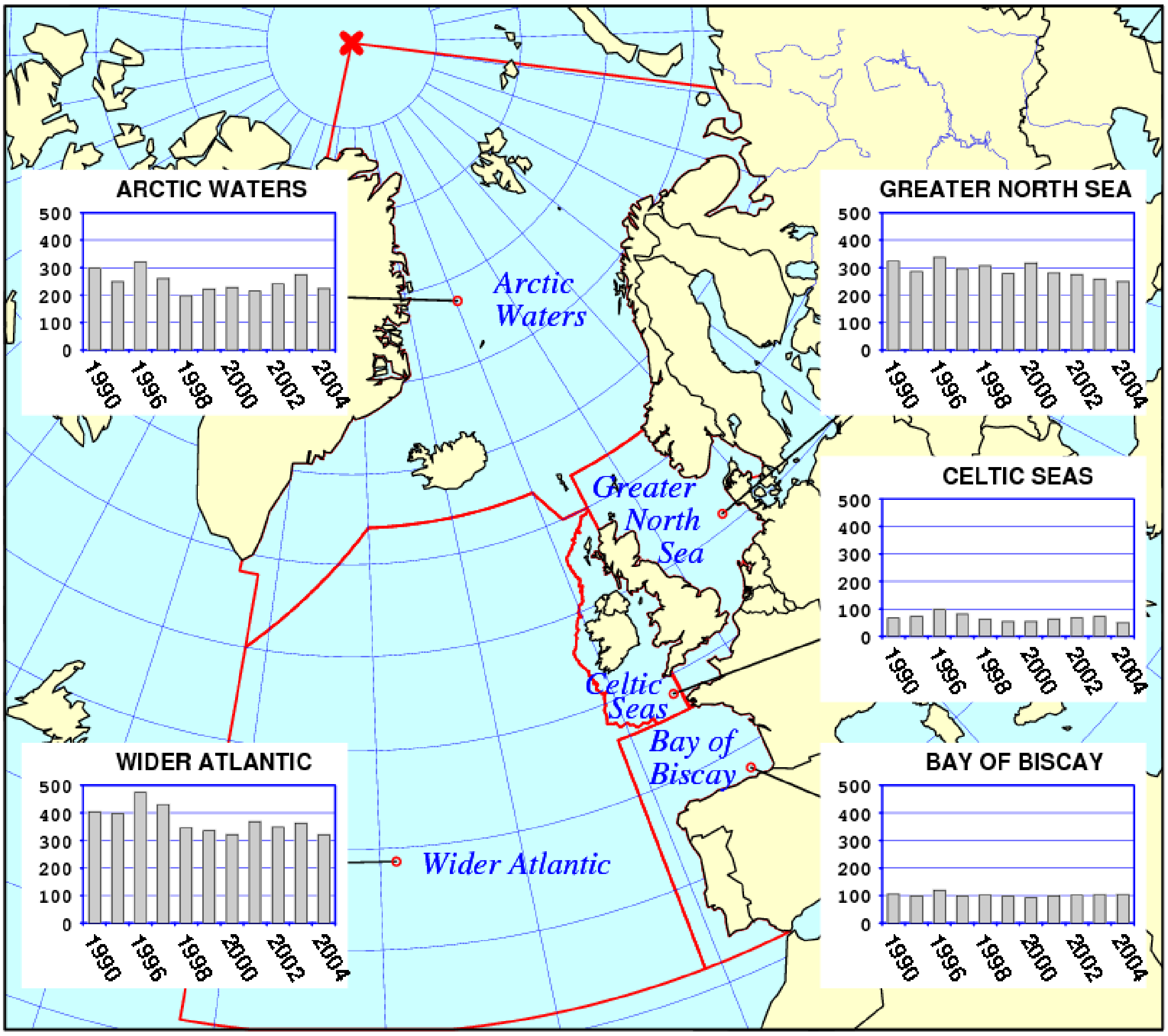

Figure 20. EMEP map with time series of modelled annual oxidized nitrogen depositions in the five main OSPAR Regions. Unit: kt N a^{-1}.

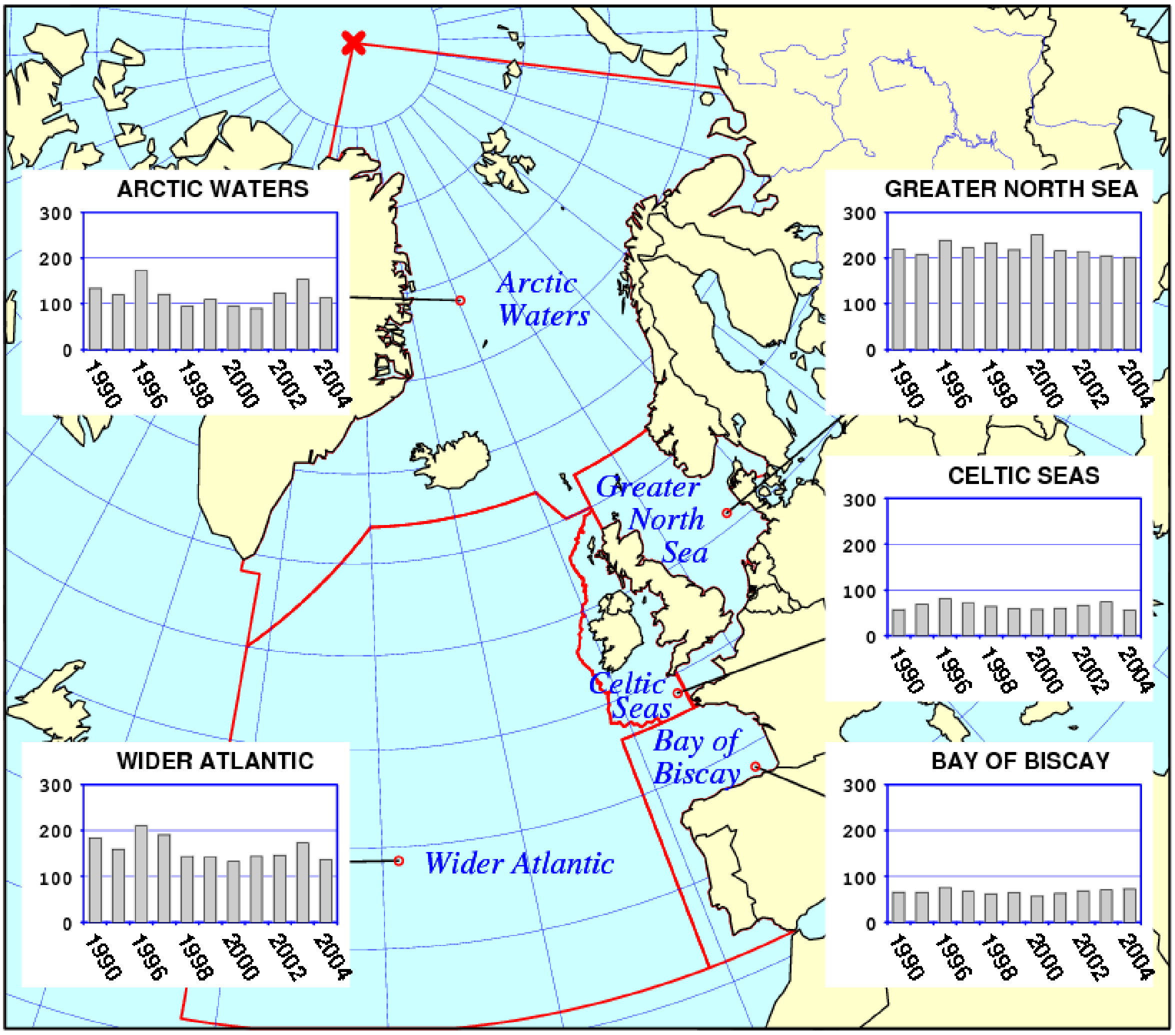

Figure 21. EMEP map with time series of modelled annual reduced nitrogen depositions in the five main OSPAR Regions. Unit: kt N a^{-1}.

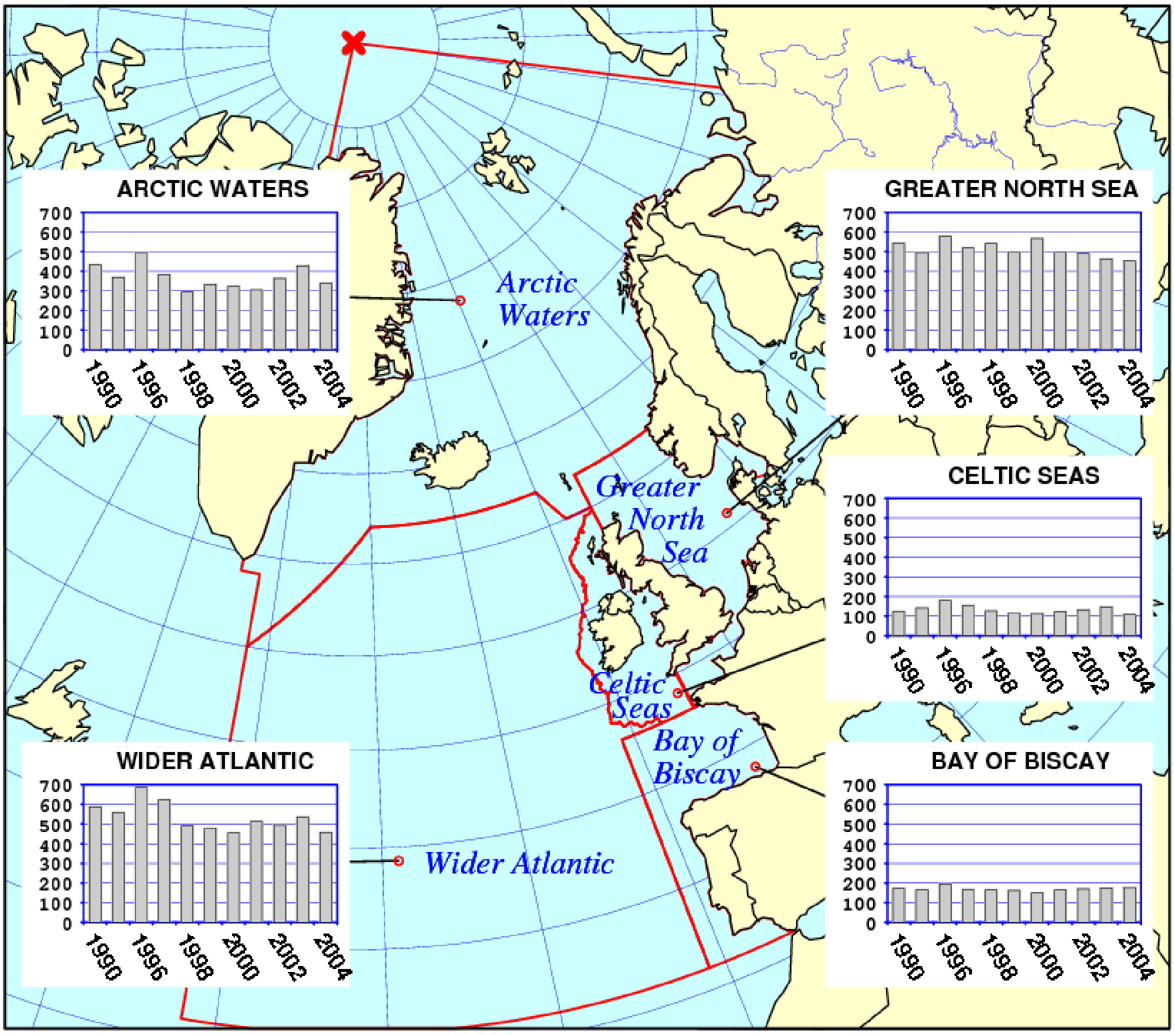

Figure 22. EMEP map with time series of modelled total annual nitrogen (oxidized + reduced) deposition in the five main OSPAR Regions. Unit: kt N a^{-1}.

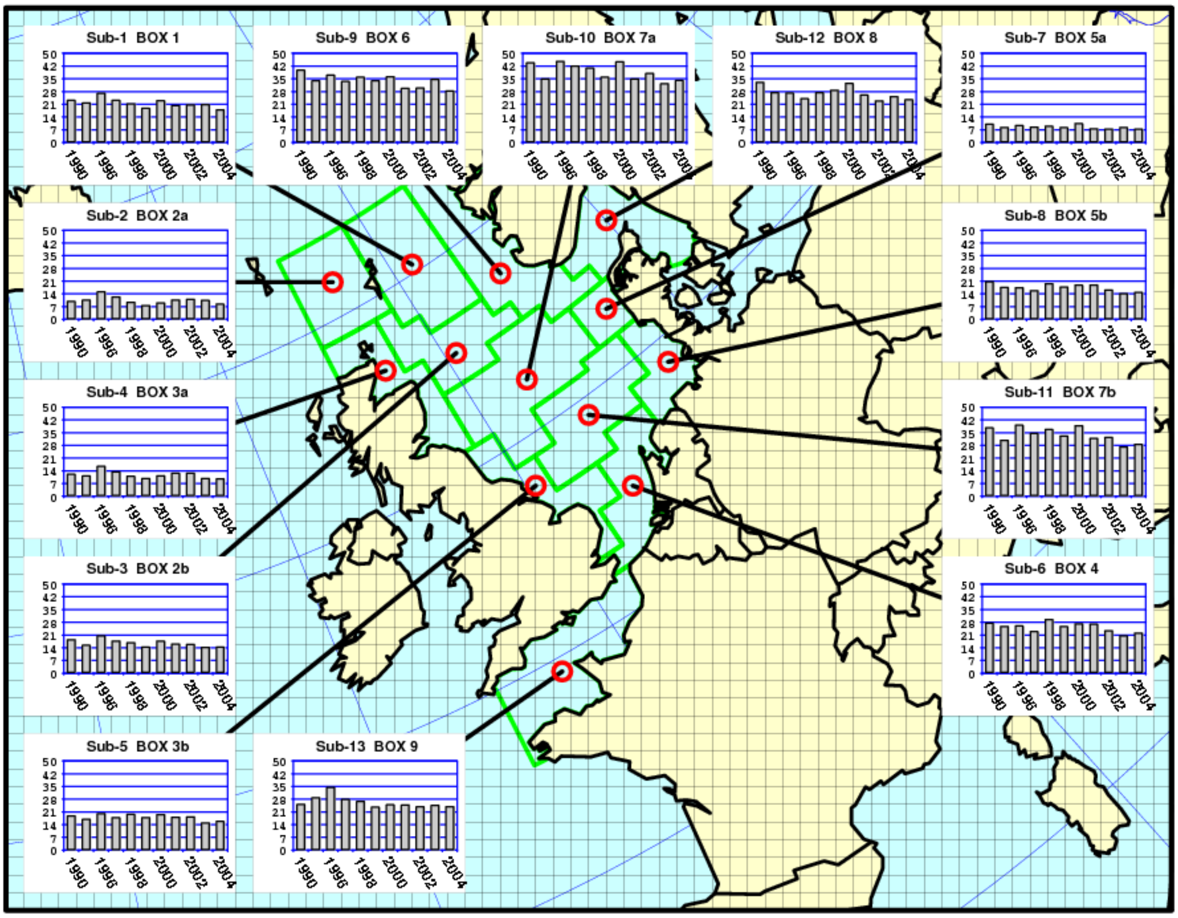

Figure 23. EMEP map with time series of modelled annual oxidized nitrogen deposition in 13 sub-regions of OSPAR Region II (Greater North Sea). Unit: kt N a^{-1}.

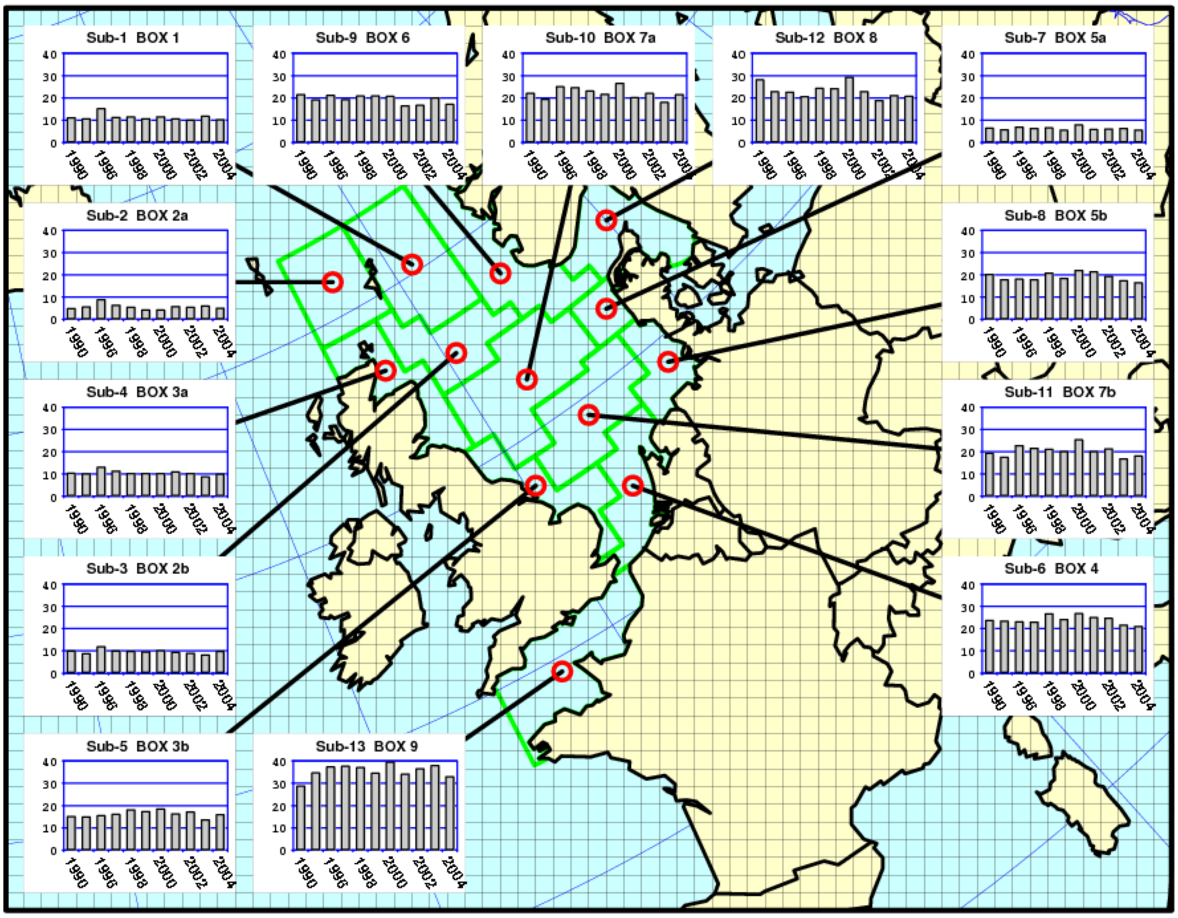

Figure 24. EMEP map with time series of modelled annual reduced nitrogen deposition in 13 sub-regions of OSPAR Region II (Greater North Sea). Unit: kt N a^{-1}.

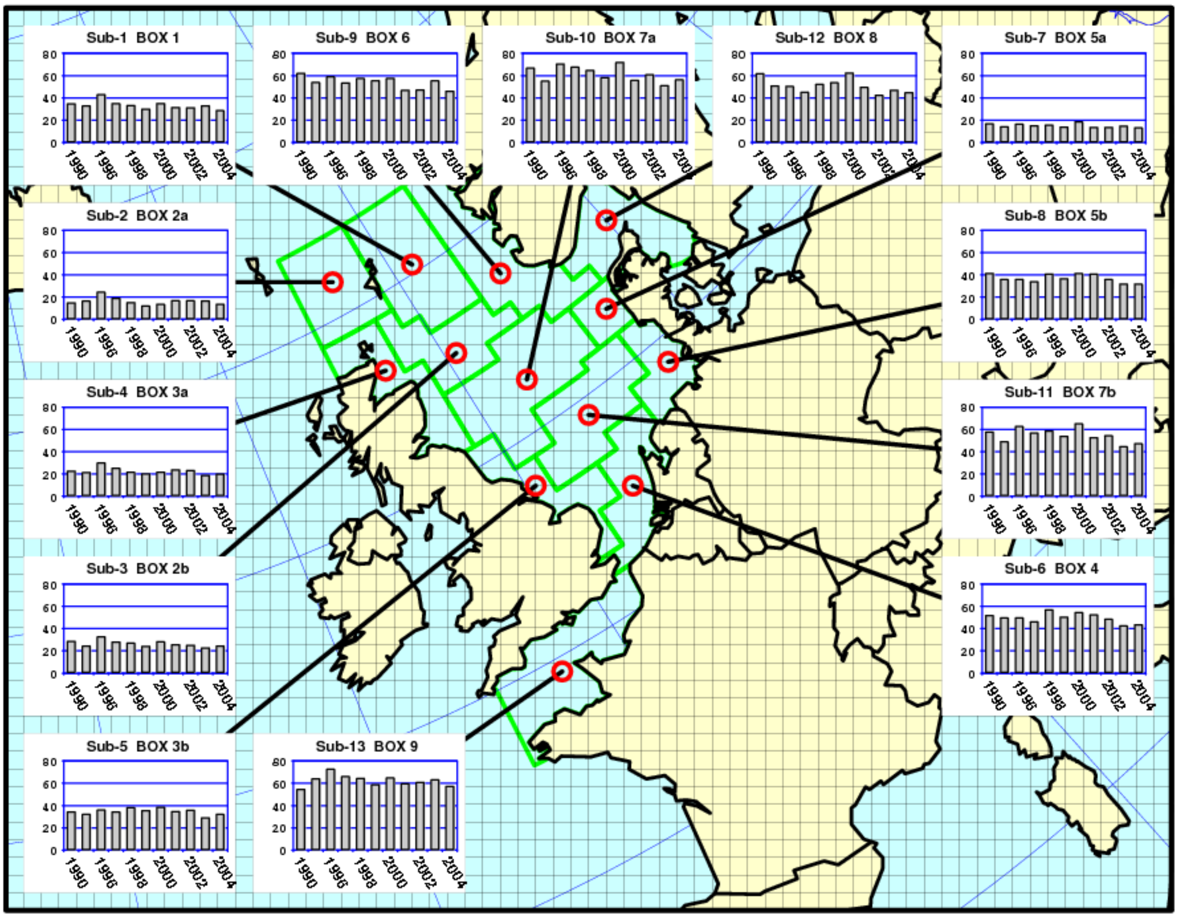

Figure 25. EMEP map with time series of modelled total annual nitrogen (oxidized + reduced) deposition in 13 sub-regions of OSPAR Region II (Greater North Sea). Unit: kt N a^{-1}.

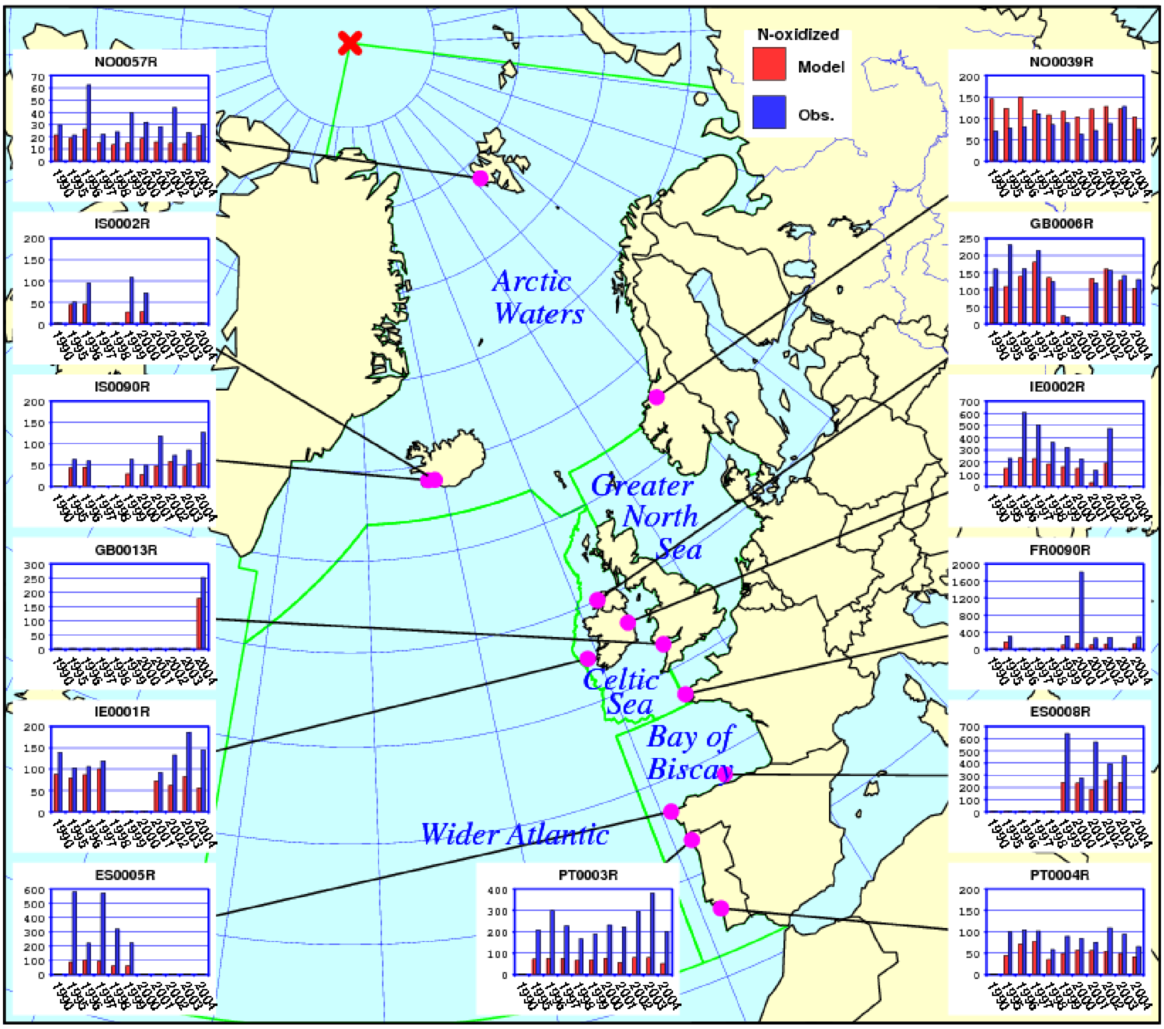

Figure 26. EMEP map with time series of modelled versus measured annual oxidized nitrogen deposition at the coastal monitoring stations in the five main OSPAR Regions. Unit: mg N m^{-2}.

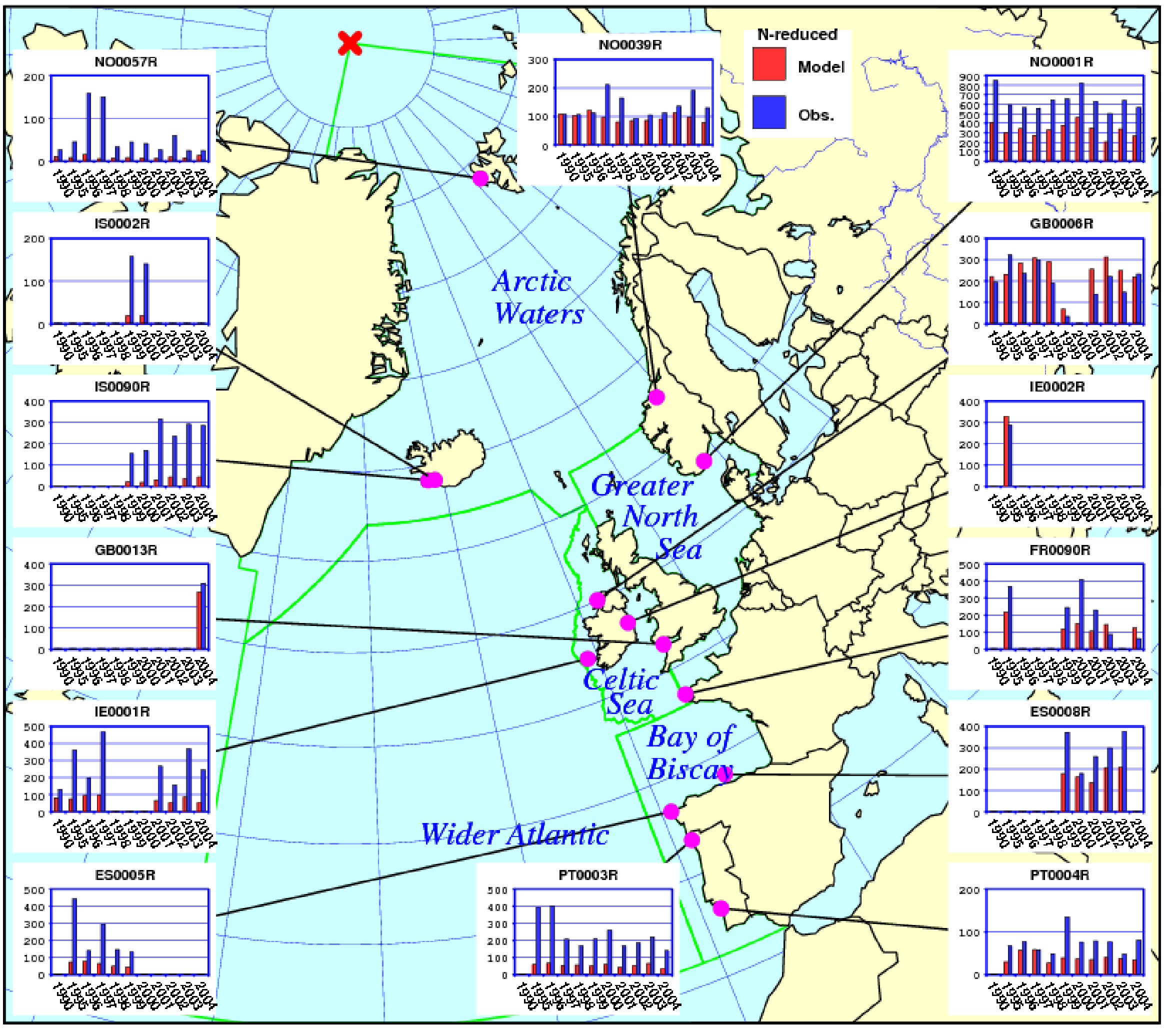

Figure 27. EMEP map with time series of modelled versus measured annual reduced nitrogen deposition at the coastal monitoring stations in the five main OSPAR Regions. Unit: mg N m^{-2}.

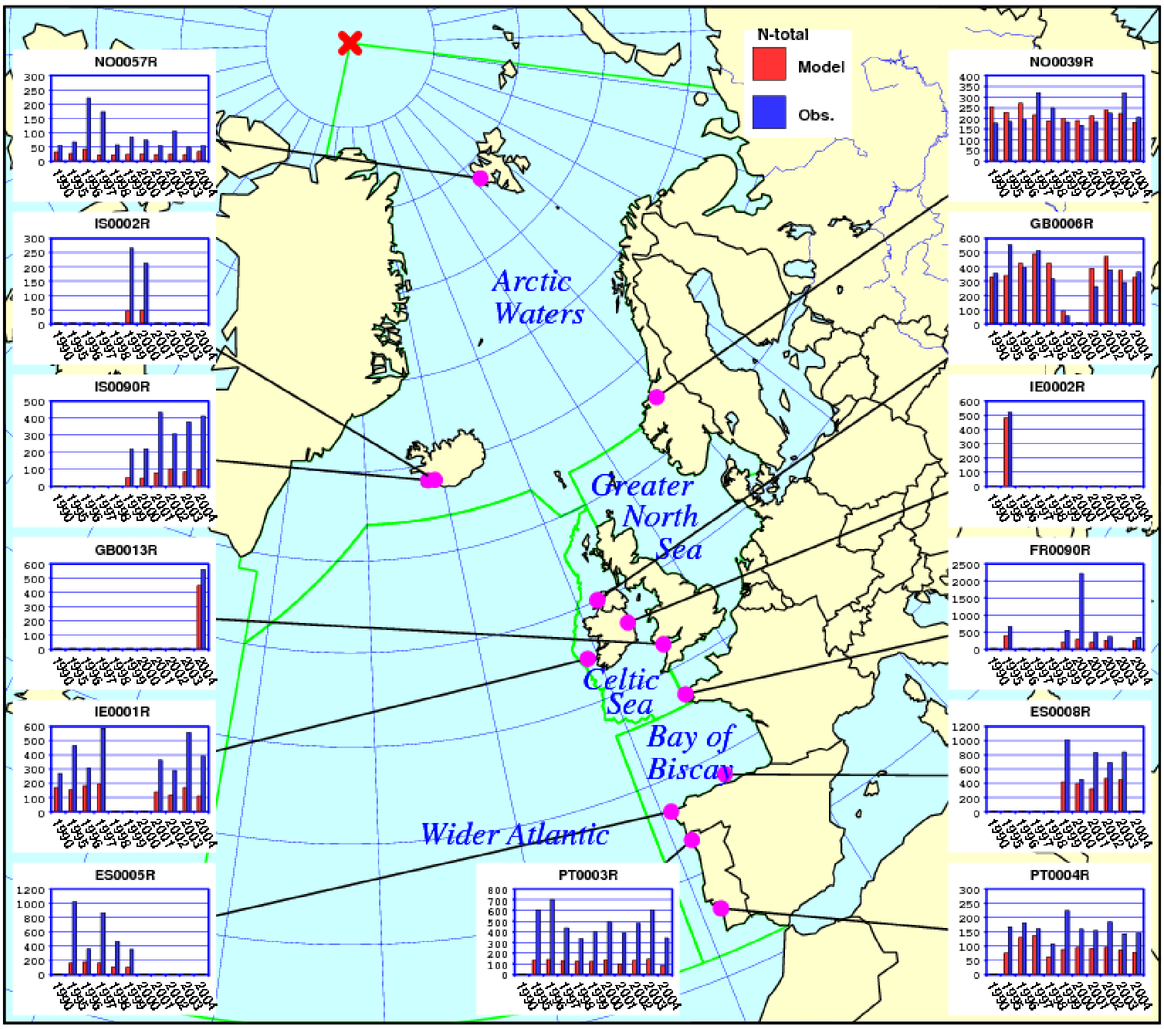

Figure 28. EMEP map with time series of modelled versus measured total annual nitrogen (oxidized plus reduced) deposition at the coastal monitoring stations in the five main OSPAR Regions. Unit: mg N m^{-2}.

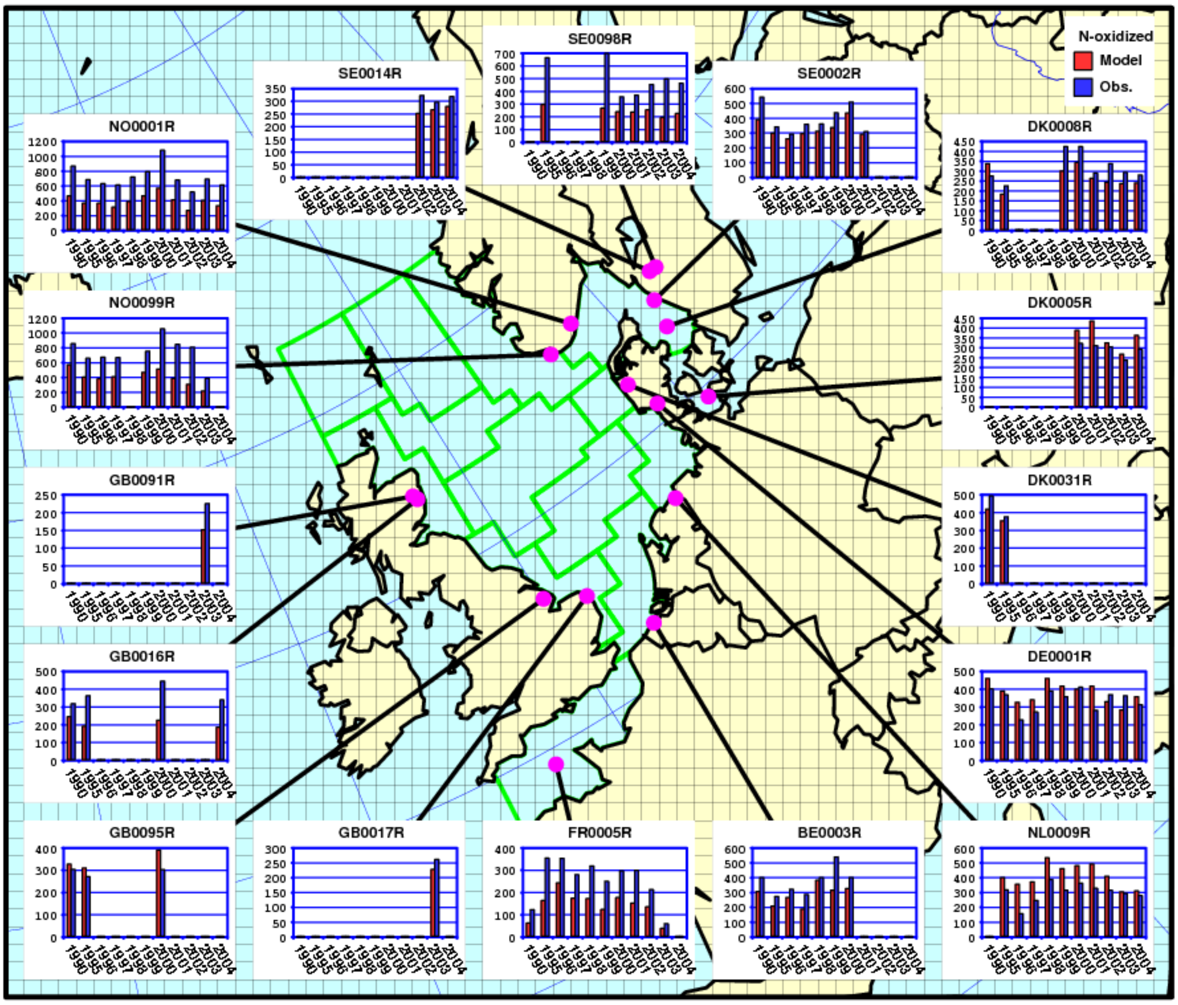

Figure 29. EMEP map with time series of modelled versus measured annual oxidized nitrogen deposition at the coastal monitoring stations in OSPAR Region II (Greater North Sea). Unit: mg N m^{-2}.

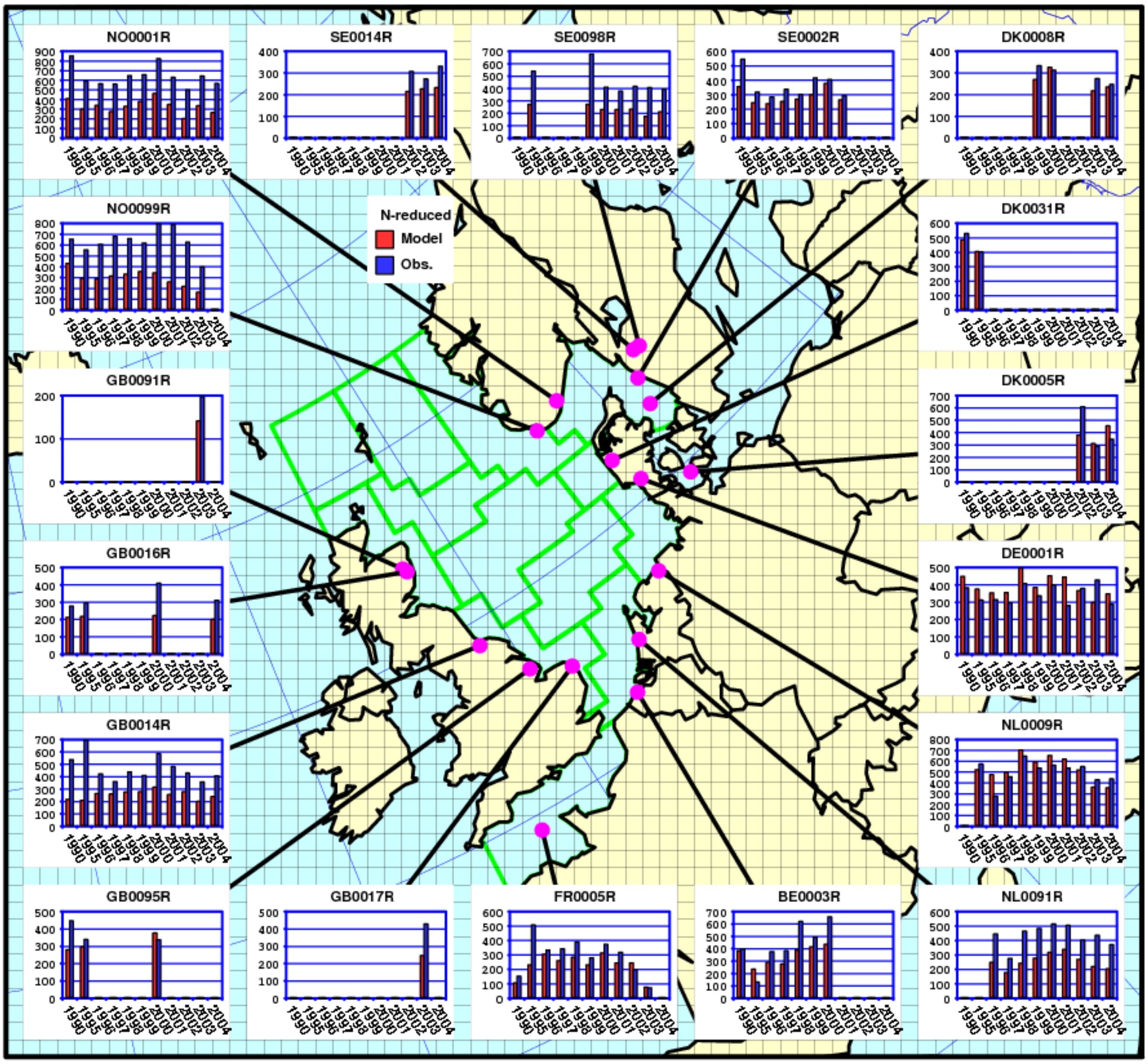

Figure 30. EMEP map with time series of modelled versus measured annual reduced nitrogen deposition at the coastal monitoring stations in OSPAR Region II (Greater North Sea). Unit: mg N m^{-2}.

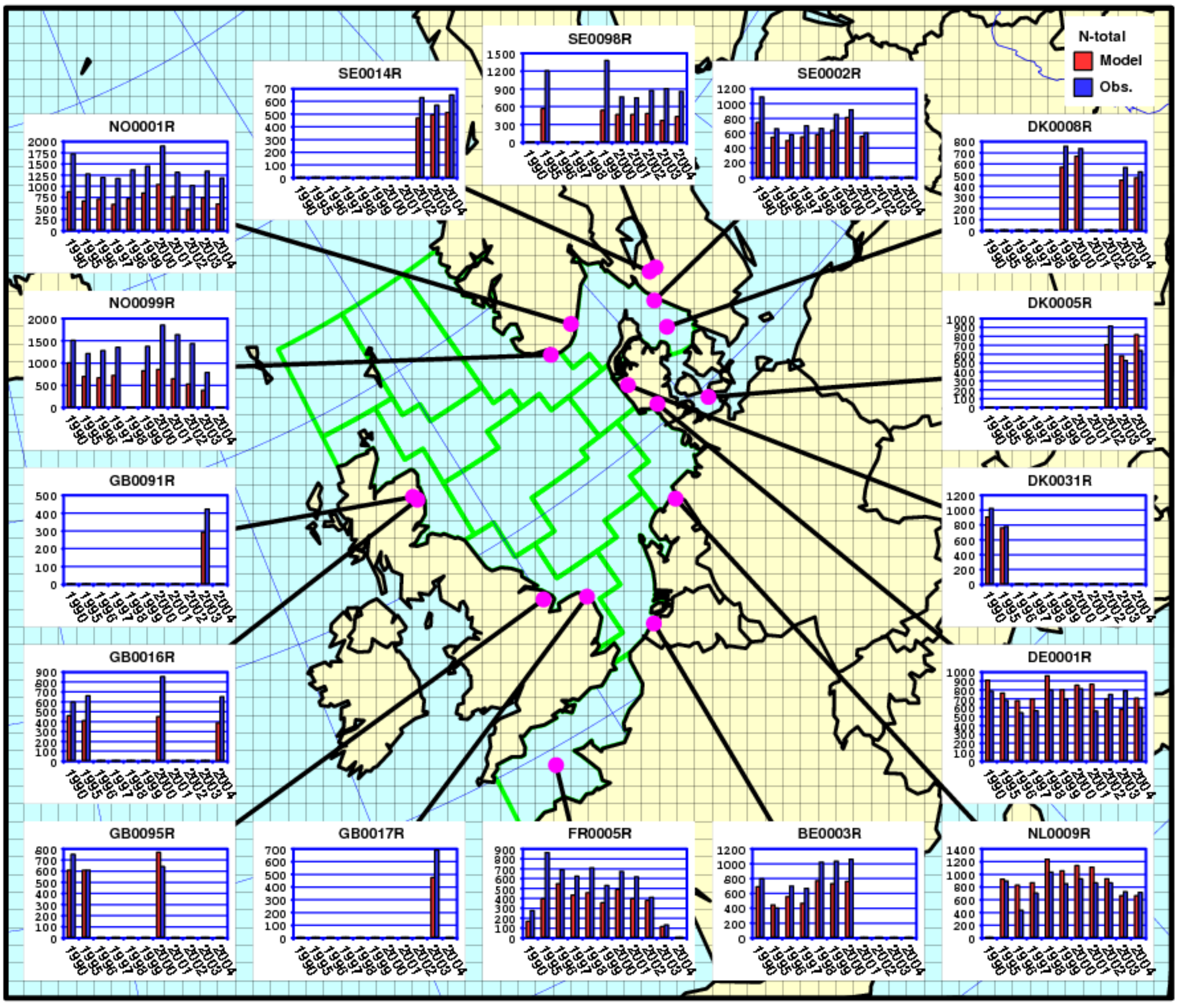

Figure 31. EMEP map with time series of modelled versus measured total annual nitrogen (oxidized plus reduced) deposition at the coastal monitoring stations in OSPAR Region II (Greater North Sea). Unit: mg N m^{-2}.

Tables

Table 1. EMEP annual nitrogen oxides emissions (as NO_2) from the OSPAR Contracting Parties and three main contributors to deposition. Unit: kt N a^{-1}.

Country	Year														
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Belgium	116	116	115	114	114	113	111	108	105	103	100	96	91	91	91
Denmark	81	96	82	82	82	77	88	74	67	63	57	56	55	58	52
Finland	91	88	86	86	85	79	82	79	76	75	72	67	63	66	62
France	557	575	564	529	515	500	492	472	466	445	423	406	390	378	371
Germany	876	806	758	725	680	649	624	601	590	583	564	537	510	488	473
Iceland	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Ireland	36	37	40	37	37	37	38	37	38	38	39	40	37	36	35
Luxembourg	6	7	8	8	9	10	10	10	10	10	10	10	9	9	9
Netherlands	167	162	157	151	146	141	135	130	122	121	118	116	112	112	109
Norway	68	65	65	68	67	67	70	71	72	72	68	67	65	65	65
Portugal	74	78	84	81	81	84	82	81	85	87	87	87	89	83	82
Spain	380	393	403	396	404	411	401	415	419	440	449	444	463	462	462
Sweden	93	90	89	85	86	82	79	76	74	70	66	64	63	62	60
Switzerland	47	45	43	41	39	36	35	34	33	32	31	29	28	27	26
UK	892	853	828	775	747	717	693	645	625	589	565	547	515	513	493
Italy	592	609	614	584	560	550	527	503	472	443	419	416	388	383	379
Poland	481	432	405	372	367	341	352	339	302	290	255	258	242	246	245
Russia	1 096	1 045	950	929	812	782	754	737	774	784	748	786	821	945	941
North Sea	508	521	534	547	561	575	590	605	620	636	652	668	685	703	721
ATL	565	579	593	608	624	639	655	672	689	706	724	742	760	779	799
EMEP-ext	169	174	178	182	187	192	197	202	207	212	217	223	228	234	240
Total ship	1 242	1 273	1 305	1 338	1 372	1 406	1 442	1 478	1 515	1 553	1 593	1 633	1 674	1 716	1 759

North Sea – nitrogen oxides emissions from the international ship traffic over North Sea.
ATL – nitrogen oxides emissions from the international ship traffic over North Sea.
EMEP-ext – additional nitrogen oxides emissions from the international ship traffic over Atlantic Ocean from outside official EMEP area.
Total Ship – a sum of nitrogen oxides emissions from the international ship traffic used in the model calculations.

Table 2. EMEP annual ammonia emissions (NH_3) from the OSPAR Contracting Parties and three main contributors to deposition. Unit: kt N a^{-1}.

Country	Year														
	1990	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
Belgium	92	91	89	88	86	85	82	79	77	74	71	69	67	65	61
Denmark	110	107	105	103	100	94	90	90	91	87	87	86	84	80	81
Finland	31	31	30	30	29	29	30	31	29	27	27	27	27	27	27
France	648	636	640	624	631	636	638	650	649	642	650	638	640	618	611
Germany	624	552	538	538	521	529	531	524	530	535	532	543	535	534	528
Iceland	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Ireland	94	96	98	98	99	100	102	103	106	105	101	101	98	96	93
Luxembourg	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Netherlands	205	196	187	178	168	159	153	148	142	137	125	117	112	107	110
Norway	17	17	18	18	18	19	20	19	19	19	19	19	19	19	19
Portugal	45	49	50	49	52	52	52	54	54	54	53	54	53	53	53
Spain	271	262	260	245	261	252	280	279	295	305	320	316	317	329	340
Sweden	45	45	46	51	51	53	50	51	50	48	48	47	47	46	46
Switzerland	56	55	54	53	53	52	51	51	51	50	50	47	45	43	48
UK	314	315	303	300	303	296	298	300	297	295	277	272	263	254	277
Italy	333	343	339	346	342	343	339	351	352	359	349	357	358	349	339
Poland	421	364	343	314	315	311	299	287	304	280	264	270	268	266	261
Russia	992	967	903	754	646	689	628	612	567	552	546	525	505	505	511

Table 3. EMEP modelled annual oxidized nitrogen deposition in the main regions of the OSPAR maritime area. Unit: t N a^{-1}.

Year	Main OSPAR Regions				
	I. Arctic Waters	**II. Greater North Sea**	**III. Celtic Seas**	**IV. Bay of Biscay/Iberian Coast**	**V. Wider Atlantic**
1990	301083	326370	70371	109115	408494
1995	252730	289114	76413	102723	401927
1996	323908	341096	101945	123085	478853
1997	263879	299157	84885	101813	434450
1998	200858	309645	66299	105693	349990
1999	225428	280805	58812	100760	339136
2000	231054	319714	58842	94423	325731
2001	217781	283995	66936	102951	372491
2002	244074	277883	71298	104553	352423
2003	277116	261965	76173	106999	366735
2004	227323	253545	54184	107785	324530

Table 4. EMEP modelled annual reduced nitrogen (NH_3^--N + NH_4^+-N) deposition in the main regions of the OSPAR maritime area. Unit: t N a^{-1}.

Year	Main OSPAR Regions				
	I. Arctic Waters	II. Greater North Sea	III. Celtic Seas	IV. Bay of Biscay/Iberian Coast	V. Wider Atlantic
1990	136525	220800	59793	67762	185860
1995	121649	209626	70926	67649	161283
1996	175050	240939	83502	77564	212725
1997	122452	224958	74594	69446	193175
1998	97023	235021	66384	63782	145812
1999	111720	220706	61789	66514	144694
2000	97474	251934	60513	59090	134393
2001	92231	218246	62386	65623	145983
2002	125028	216454	68251	70222	148293
2003	156053	206613	76594	71985	175162
2004	115346	203737	58503	74331	138486

Table 5. EMEP modelled total annual (NO_x-N + NH_4-N) nitrogen deposition in the main regions of the OSPAR maritime area. Unit: t N a^{-1}.

Year	Main OSPAR Regions				
	I. Arctic Waters	II. Greater North Sea	III. Celtic Seas	IV. Bay of Biscay/Iberian Coast	V. Wider Atlantic
1990	437608	547170	130163	176877	594354
1995	374379	498740	147339	170371	563211
1996	498958	582036	185447	200649	691577
1997	386331	524114	159479	171259	627625
1998	297882	544665	132683	169475	495803
1999	337149	501511	120601	167275	483830
2000	328528	571648	119355	153513	460124
2001	310012	502241	129321	168574	518475
2002	369103	494337	139549	174775	500717
2003	433169	468578	152767	178984	541897
2004	342669	457282	112688	182116	463016

Table 6. EMEP modelled annual oxidized nitrogen deposition in the sub-regions of OSPAR Region II (Greater North Sea) of the OSPAR maritime area. Unit: t N a^{-1}.

Year	Sub-regions of OSPAR Region II Greater North Sea												
	1	2	3	4	5	6	7	8	9	10	11	12	13
1990	23555	10022	18703	12310	19162	28052	10254	21140	40538	44747	38341	33675	25719
1995	22241	10842	15696	11409	17326	26238	8443	17922	34714	35614	31368	27990	29371
1996	27613	15511	20875	16824	20509	26483	9536	17804	37752	45460	39827	27702	35184
1997	23579	12525	18074	13710	18134	23309	8589	16027	34192	42851	35245	24529	28361
1998	21673	9538	17091	11201	19982	30124	9044	19938	36621	41617	37451	27926	27313
1999	19133	7690	14586	10009	18237	26137	8296	18122	34648	36602	33802	29320	24083
2000	23380	9219	17947	11525	19945	27660	10541	19124	36850	45257	39617	33080	25419
2001	20696	10908	16321	12868	18385	27420	7630	19299	30396	35628	32447	26555	25367
2002	21095	11271	16161	12894	18664	23728	7533	16438	30499	38748	33072	23363	24367
2003	21145	10567	14474	10016	15230	20875	8442	14343	35317	32976	27662	25745	25176
2004	18328	8536	14628	9848	16134	22478	7493	15125	28833	34738	29039	23969	24337

Table 7. EMEP modelled annual reduced nitrogen deposition in the sub-regions of OSPAR Region II (Greater North Sea) of the OSPAR maritime area. Unit: t N a^{-1}.

Year	Sub-regions of OSPAR Region II Greater North Sea												
	1	2	3	4	5	6	7	8	9	10	11	12	13
1990	11089	4784	9874	10268	15011	23682	6445	20130	21430	22030	19223	28088	28696
1995	10605	5559	8770	9997	14876	23307	5654	17778	19079	19374	17498	22729	34618
1996	15235	8836	11848	13078	15496	23093	6857	18021	21105	24958	22714	22540	37292
1997	11160	6326	9894	11293	16000	22865	6275	17767	19226	24641	21532	20567	37612
1998	11423	5397	9797	10248	17989	26655	6530	20746	20787	23057	21038	24257	37075
1999	10650	4174	9544	10152	17238	24041	5446	18365	20863	21587	20000	24168	34491
2000	11522	4172	10098	10142	18400	26726	7852	21954	20648	26540	25319	29209	39359
2001	10580	5760	9268	10872	16247	24989	5785	21264	16447	20138	20084	22747	34129
2002	10018	5403	8871	10258	17073	24627	6022	19296	16613	21986	21190	18795	36440
2003	11739	5960	8182	8653	13571	21541	6236	17326	20026	17989	16746	20987	37947
2004	10174	5010	9832	9912	15919	20966	5502	16380	17053	21421	18030	20724	32877

Table 8. EMEP modelled total annual nitrogen deposition in the sub-regions of OSPAR Region II (Greater North Sea) of the OSPAR maritime area. Unit: t N a^{-1}.

Year	Sub-regions of OSPAR Region II Greater North Sea												
	1	2	3	4	5	6	7	8	9	10	11	12	13
1990	34644	14806	28577	22578	34173	51734	16700	41270	61968	66777	57564	61763	54414
1995	32846	16401	24466	21406	32202	49545	14097	35700	53793	54989	48866	50719	63989
1996	42848	24346	32723	29903	36005	49576	16393	35825	58857	70418	62541	50242	72475
1997	34739	18851	27968	25004	34134	46174	14863	33793	53418	67492	56777	45096	65974
1998	33096	14935	26888	21449	37971	56779	15574	40684	57408	64674	58489	52184	64388
1999	29782	11863	24131	20161	35476	50178	13742	36487	55511	58190	53802	53487	58574
2000	34902	13391	28045	21667	38345	54386	18393	41078	57497	71797	64936	62288	64778
2001	31276	16668	25589	23740	34632	52410	13416	40563	46843	55766	52531	49302	59495
2002	31113	16673	25031	23152	35737	48354	13555	35734	47112	60734	54262	42159	60807
2003	32884	16528	22656	18669	28801	42415	14678	31669	55342	50965	44408	46732	63122
2004	28502	13546	24460	19760	32052	43444	12995	31505	45887	56158	47069	44693	57214

Table 9. OSPAR riverine inputs and direct discharges in comparison with EMEP atmospheric nitrogen deposition to the Greater North Sea. Units: kt N a^{-1}.

Year	Waterborne inputs[1]			Atmospheric inputs			Total N inputs (waterborne and atmospheric)	% Contribution of atmospheric inputs to total N inputs		
	Direct	Riverine	Total waterborne N	Oxidised N	Reduced N	Total atmospheric N	Total N inputs	Oxidised N	Reduced N	Total atmospheric N
1990	109	907	1016	326	221	547	1563	21 %	14 %	35 %
1995	86	1382	1467	289	210	499	1966	15 %	11 %	25 %
1996	78	856	935	341	241	582	1517	22 %	16 %	38%
1997	79	836	914	299	225	524	1438	21 %	16 %	36 %
1998	74	1037	1111	310	235	545	1656	19 %	14 %	33 %
1999	73	1053	1126	281	221	502	1628	17 %	14 %	31 %
2000	78	1203	1282	320	252	572	1854	17 %	14 %	31 %
2001	79	1021	1100	284	218	502	1602	18 %	14 %	32 %
2002	70	1111	1181	278	216	494	1675	17 %	13 %	30 %
2003	79	666	745	262	207	469	1214	22 %	17 %	39 %
2004	60	747	807	253	204	457	1264	20 %	16 %	36 %

[1] These are summary nitrogen load data for the OSPAR maritime area reported by Contracting Parties under the OSPAR Comprehensive Study on Riverine Inputs and Direct Discharges (RID) (agreement 1998-5).

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OSPAR's vision is of a clean, healthy and biologically diverse North-East Atlantic used sustainably

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