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Long term nutrient loads entering European seas

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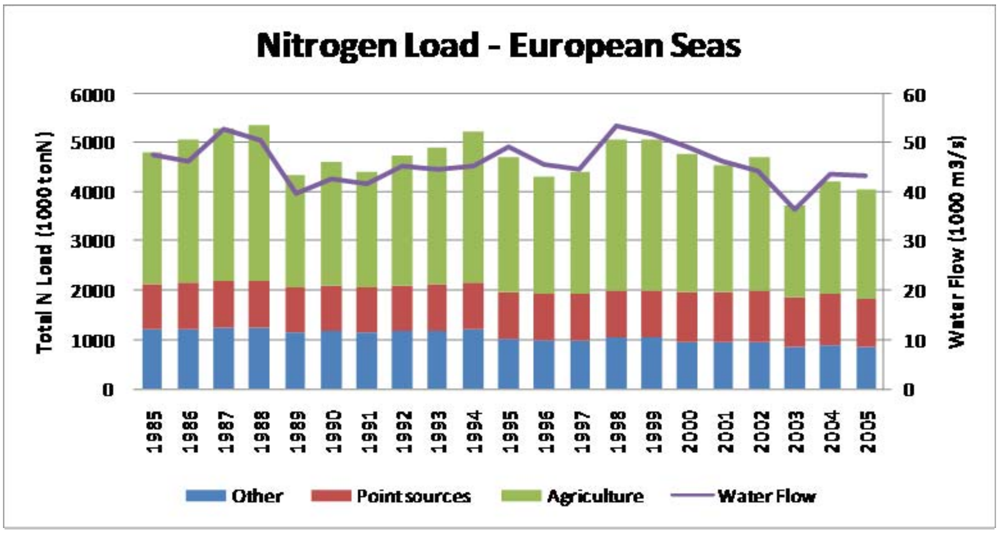

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1. Introduction

Eutrophication has been an acute problem in European waters for about two decades. To tackle eutrophication, the European Commission has set up various pieces of legislations controlling the input of nutrients from urban areas and agriculture, but also setting end of pipes water quality limits. Two major legislations were enforced in 1991 to control point source emission of nutrients, and losses of nitrates from agriculture:

- The Directive 91/676 concerning the protection of waters against pollution caused by nitrates from agricultural sources, [OJ (1991) L375/1,] also known as the “Nitrates Directive”, which aims at reducing pollution from nitrate coming from agriculture and prevents any further pollution.
- The Directive 91/271 concerning urban waste water treatment, [OJ (1991) L271/40], which aims at protecting the environment from discharges from urban waste water and waste of certain food processing industries.

The Commission monitors rather strictly the status of implementation of these Directives through periodic reports. Even though these Directives are legally binding, for the Urban Waste Water Treatment Directive, several infringements cases (7 out of 15 Member States) are still going on more than four years after the expiry of the last deadline 31.12.2005 (for the 12 new Member States, staggered transition periods are enshrined in the Accession Treaties, largely until 2015, in the case of Romania until 2018) even after two decades of implementation. Based on reports of few Member States on the status of implementation of the Nitrates Directive, the Commission (EC, 2007; EC, 2010) indicated that restoration of water quality to acceptable levels might range from two years to more than three decades. It is important also to note that prediction of nitrogen use in Europe (old and new Member States) is expected to remain at the same the levels of 1995 (Bouwman et al., 2005; Bruinsma, 2003) with an increase of N leaching in both Western and Central-Eastern Europe (Bouwman et al., 2005) indicating that full restoration of water quality is highly unlikely even by 2030. Cases on infringements are also ongoing concerning the Urban Waste Water Treatment Directive.

In this context, in 2008, DG ENV invited the JRC to conduct a three year study on the impact of EU environmental legislation on nutrient loads to European Seas. The objective of the study is to perform a long term retrospective analysis (20 years) of land based nutrient loads in European Seas to assess the effectiveness of the EU environmental policies and other management plans adopted by countries with rivers discharging in European Seas, and assess future scenarios linked to alternative management plans different policies to control nutrient loading. The focus is both on the nutrient loading to the sea and the inland response to various policies.

The first phase of the study focused on setting up the methodology to be used for a reference year chosen to be year 2000. The work concentrated on data collection and model development. The second phase, described hereafter, was dedicated to the retrospective analysis including trend analysis (1985-2005), and the elaboration of scenarios to be tested in the third year of the project.

2. Model description

The approach used to assess the nutrient loads to European Seas from 1985 to 2005 is described in Grizzetti et al. (2008). The models uses input from anthropogenic activities including agriculture, industries, urban point sources, and calculates the load of nitrogen and phosphorus at the outlet of each sub-catchment taking into account basin and stream retention. The model is applied to continental Europe on a sub-catchment basis.

The model requires the calibration of two parameters one related to the annual rainfall, driving the basin retention, and the second to the river length controlling the stream retention.

The model in any point in the river basin can be formulated as follows:

$$L = \left[DS\,\alpha_P f(R) + (PS + UL)\right]\alpha_R f(L) \qquad 1$$

where L is the annual nutrient load (tons), DS is the sum of diffuse sources within the basin (tons), PS are all the point sources emitted in the basin, UL is the upstream loads (tons), f is a reduction function which depends on the annual rainfall R(mm) for the retention taking place in the basin, and on the river length (L) for the retention in the streams. α_P is the basin retention parameter, and α_R is the water body retention parameter. The calibration approach consists in determining the two parameters α_P and α_R. The model was slightly modified to take into account the retention in lakes. For the larger lakes (area larger than 50 km^2) the retention for nitrogen was calculated according to Kronvang et al. (2004) as follows:

$$R_N = \left(1 - \frac{1}{1+\left(^{7.3}/_{z}\right)*RT}\right) \qquad 2$$

where R_N if the fraction of retained load of incoming nitrogen in the lake, z is the average lake depth (m), and RT is the hydraulic residence time (yr). The average lake depth and hydraulic residence time were obtained from Pistocchi and Pennington (2006). A similar approach was used for phosphorus (Kronvang et al., 2004):

$$R_P = \left(1 - \frac{1}{1+\left(^{26}/_{z}\right)*RT}\right) \qquad 3$$

where R_P is the fraction of retained load of incoming phosphorus in the lake.

3. Data

3.1 Catchment database

The structure of the catchment database is similar to that described in Bouraoui et al. (2009). The only addition was the determination of the lakes larger than 50 km^2 for which the retention of nitrogen and phosphorus was calculated and the extension of the monitoring database with the inclusion of stations for Portugal, UK and Italy. The extent of the area with the monitoring network included in the study is shown in Figure 1. The area of interest covers a surface of 5.9 10^6 km^2, it is divided into 2235 basins (outlet to the sea), and 33,000 sub-basins of an average size of 180 km^2.

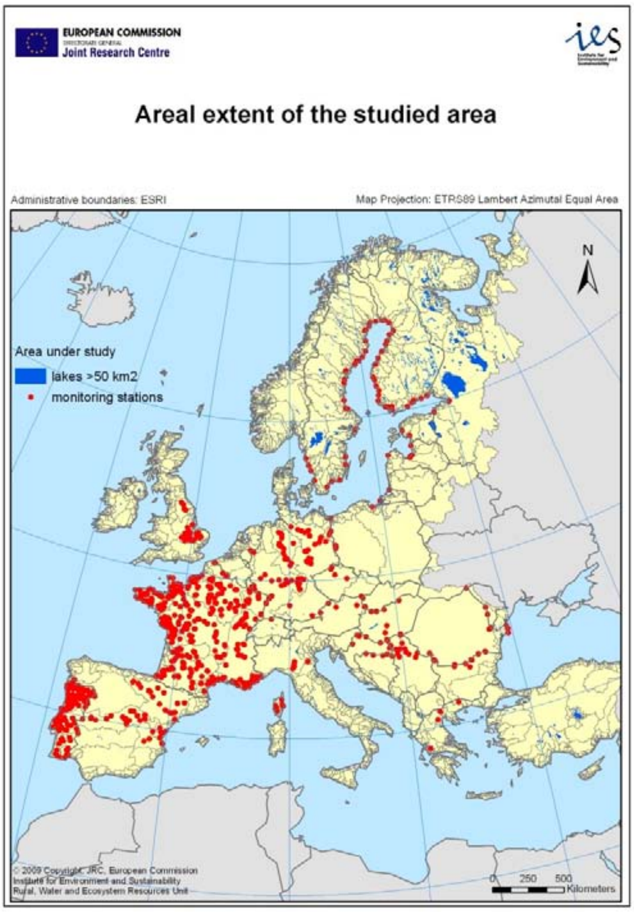


Figure 1. Extent of the area with the monitoring network and the lakes larger than 50 km^2.

3.2 Land use

For modelling nutrient fluxes in the European river basins, land use maps for the years 1985, 1990, 1995 2000 and 2005 were developed, according to the methodology described in Bouraoui et al. (2009). Data on geographical layers covering the continental Europe and statistical data available for European administrative regions were combined to produce land use maps suitable to distribute the nutrient input through mineral and manure fertilizers and biological fixation for nitrogen. Several global databases were combined: the spatial information on areas occupied by agriculture and pasture was taken from the HYDE 3 database (Klein Goldewijk and Van Drecht, 2006), available for the years 1980, 1990, 2000 and 2005, the geographical location of urban and water cover types was based on the GLC2000 (Bartholomé and Belward, 2005), available only for year 2000, and the information on crop shares and crop types was derived from the CAPRI database for EU27, Norway and Balkan region (Britz, 2004), which covers all years from 1985 to 2004, and from the FAO database for the rest of Europe (FAO, 2009). The reference years of the different data sources used in the land use maps for this study are reported in Table 1.

Table 1. Data sources and reference years used to build the land use map for this study for 1985, 1990, 1995, 2000 and 2005.

Land Use Map (this study)	HYDE data (Klein Goldewijk & Van Drecht, 2006)	CAPRI data (Britz, 2004)	FAO data (FAO, 2009)	GLC data (Bartholomé & Belward, 2005)
1985	1980	1985	1985	2000
1990	1990	1990	1990	2000
1995	1990	1995	1995	2000
2000	2000	2000	2000	2000
2005	2005	2004	2005	2000

3.3 Fertilizer application

The fertiliser application rates for EU27, Norway and the Balkan region were obtained from CAPRI (Britz, 2004) and covered the period 1985-2004. For the remaining countries, fertilisation rates were taken from the FAO. The time series of mineral and organic fertilizer application shown below in Figure 2 to Figure 5 for nitrogen, and from Figure 6 to Figure 9 for phosphorus, respectively. It is interesting to note the decrease of the mineral fertilisation for many parts of Europe, while the application is increasing in Spain. Trend in manure application are less clear, but one can notice the increase of application in Spain and in the Po valley. The application of mineral phosphorus is steadily decreasing in Europe with exception of Spain that exhibits also an increase of phosphorus manure application.

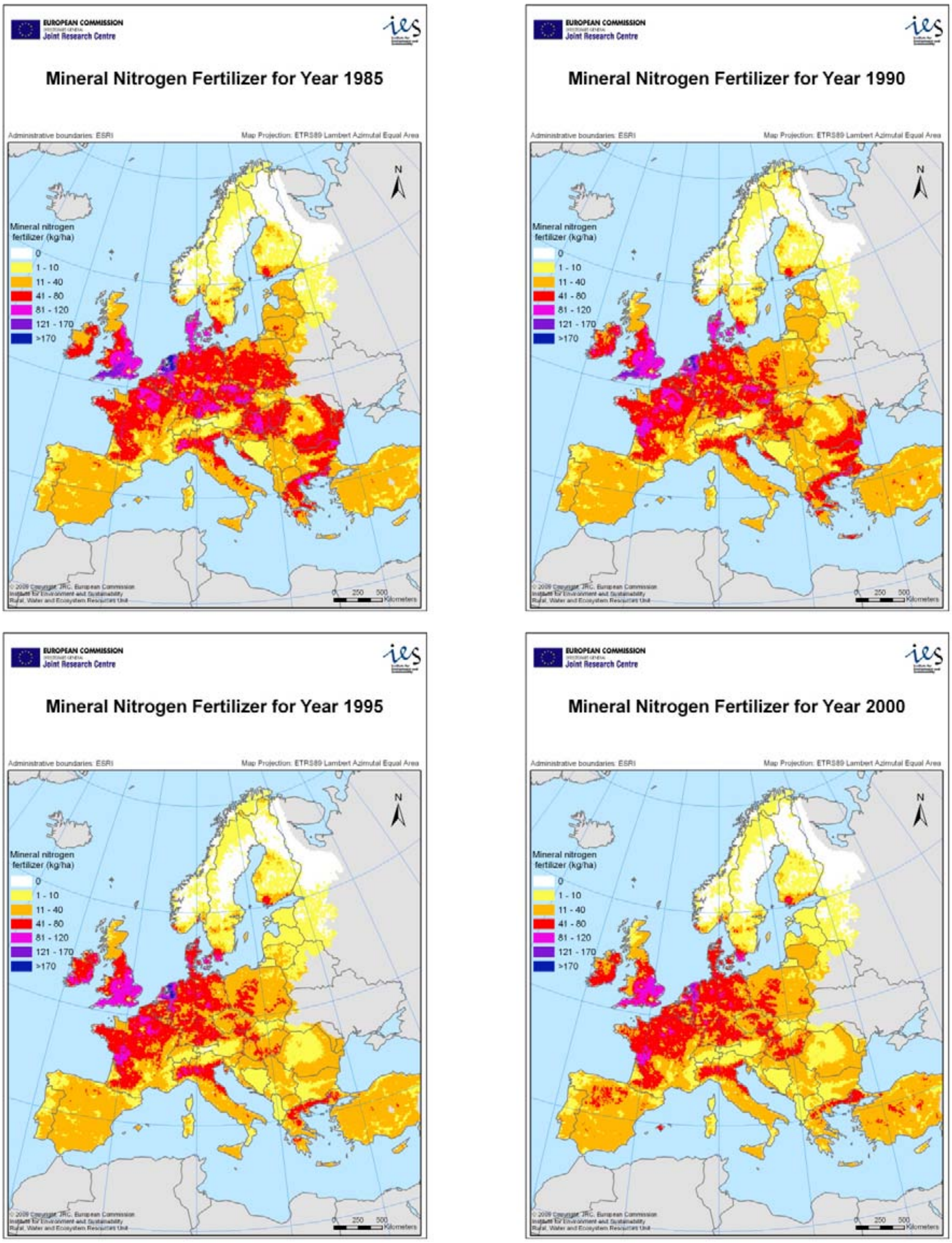


Figure 2. Map of mineral nitrogen application (kg N/ha of total area) per sub-basin for the period 1985-2000

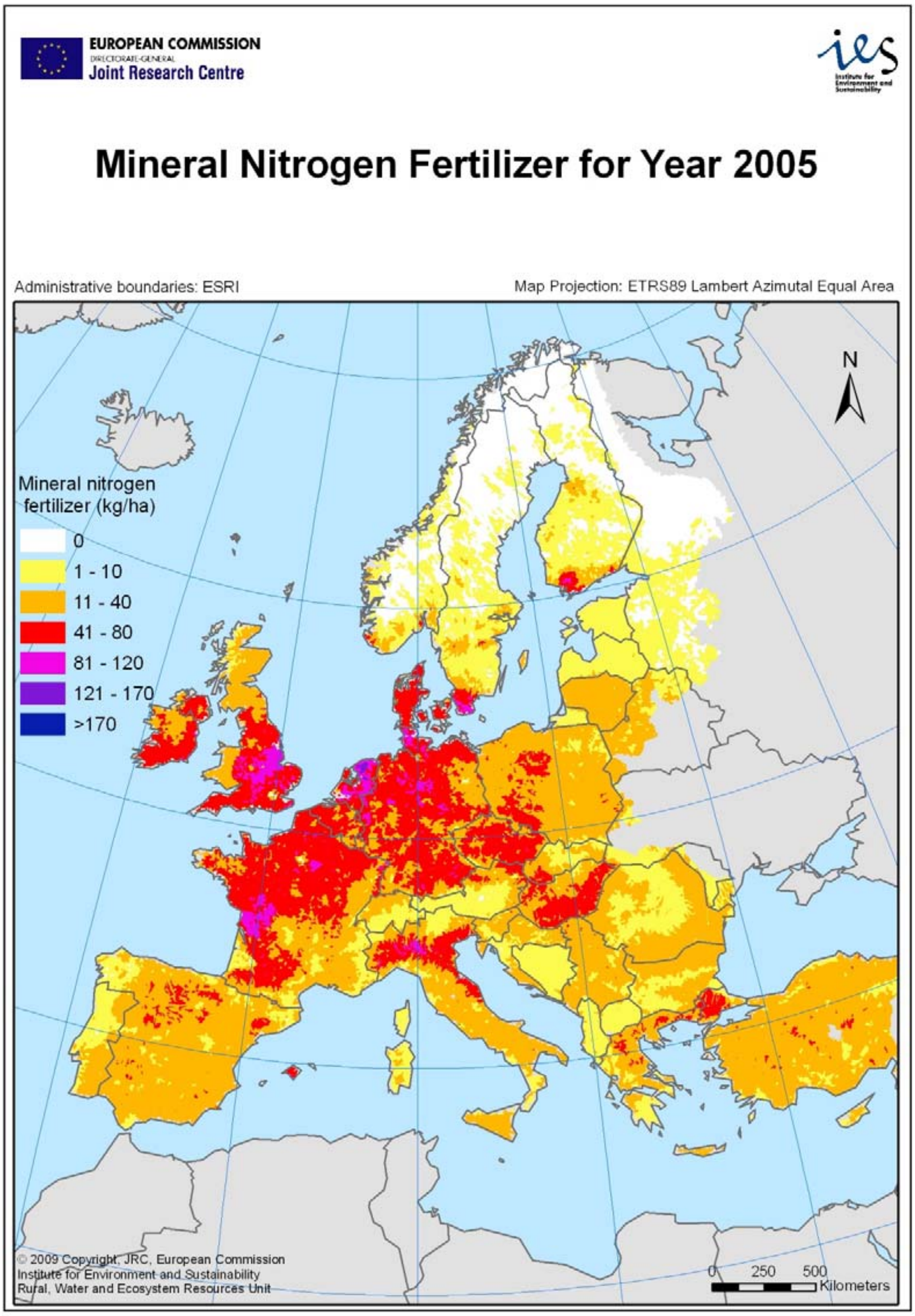


Figure 3. Map of mineral nitrogen application (kg N/ha of total area) per sub-basin for year 2005

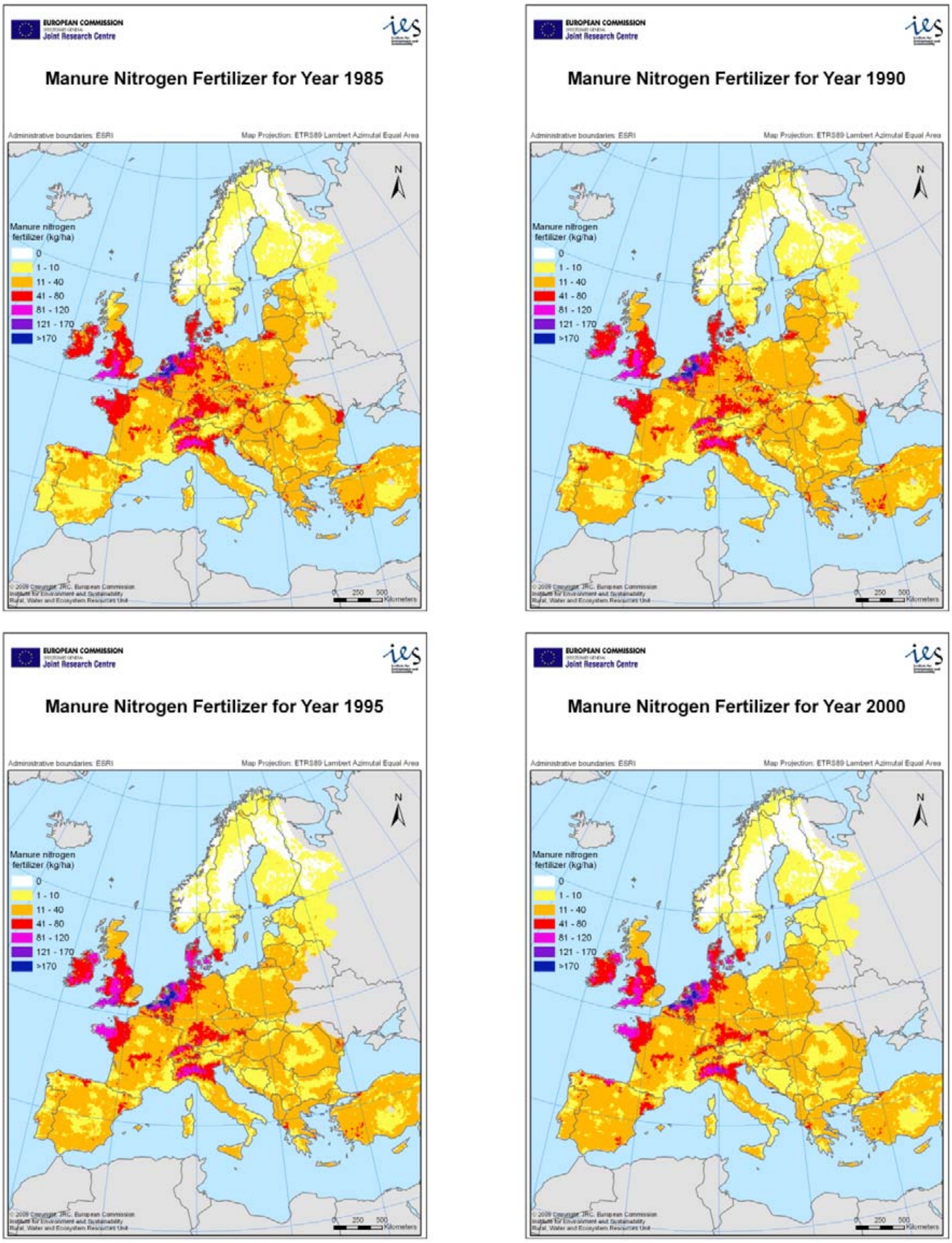


Figure 4. Map of manure nitrogen application (kg N/ha of total area) per sub-basin for the period 1985-2000

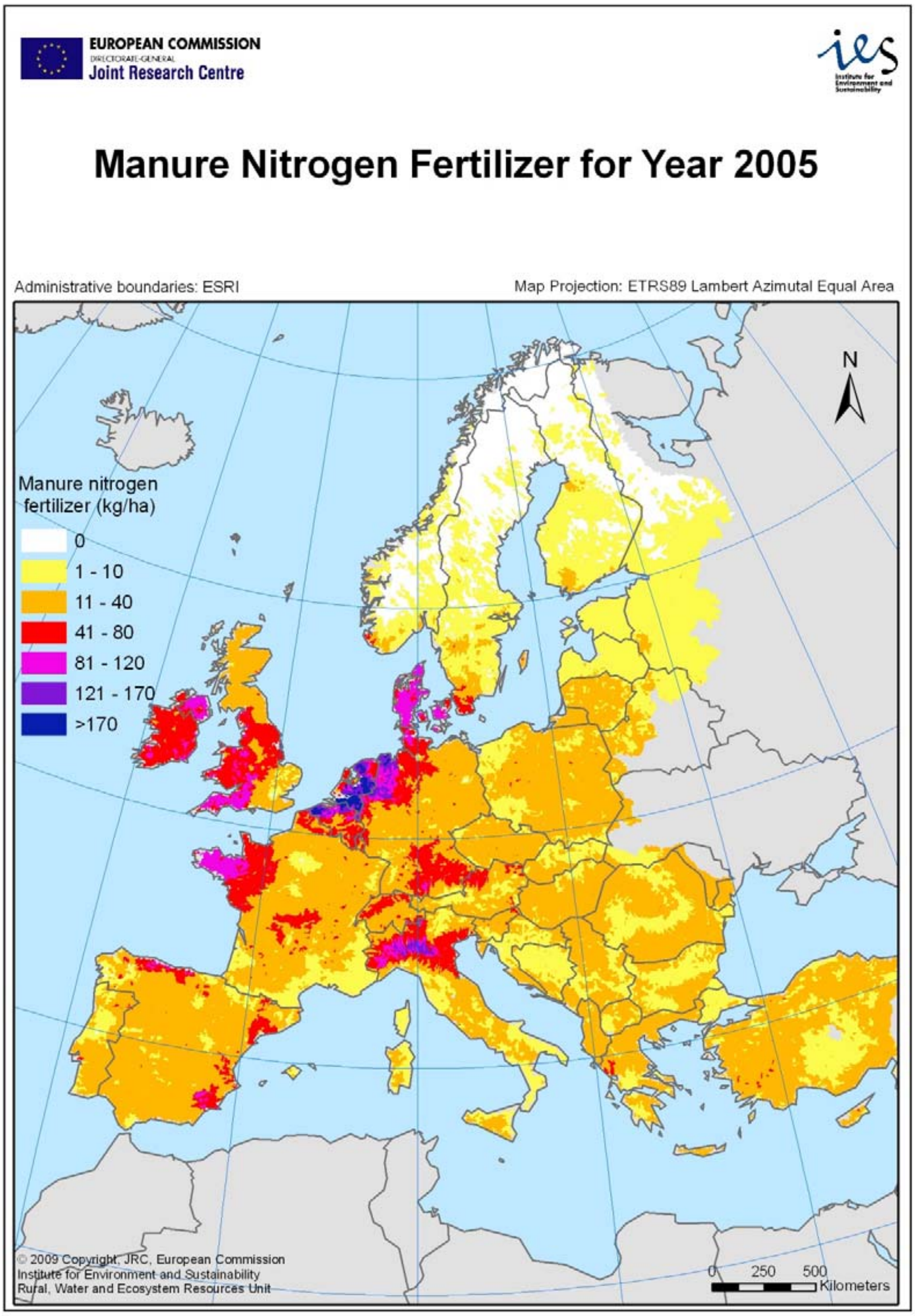


Figure 5. Map of manure nitrogen application (kg N/ha of total area) per sub-basin for year 2005

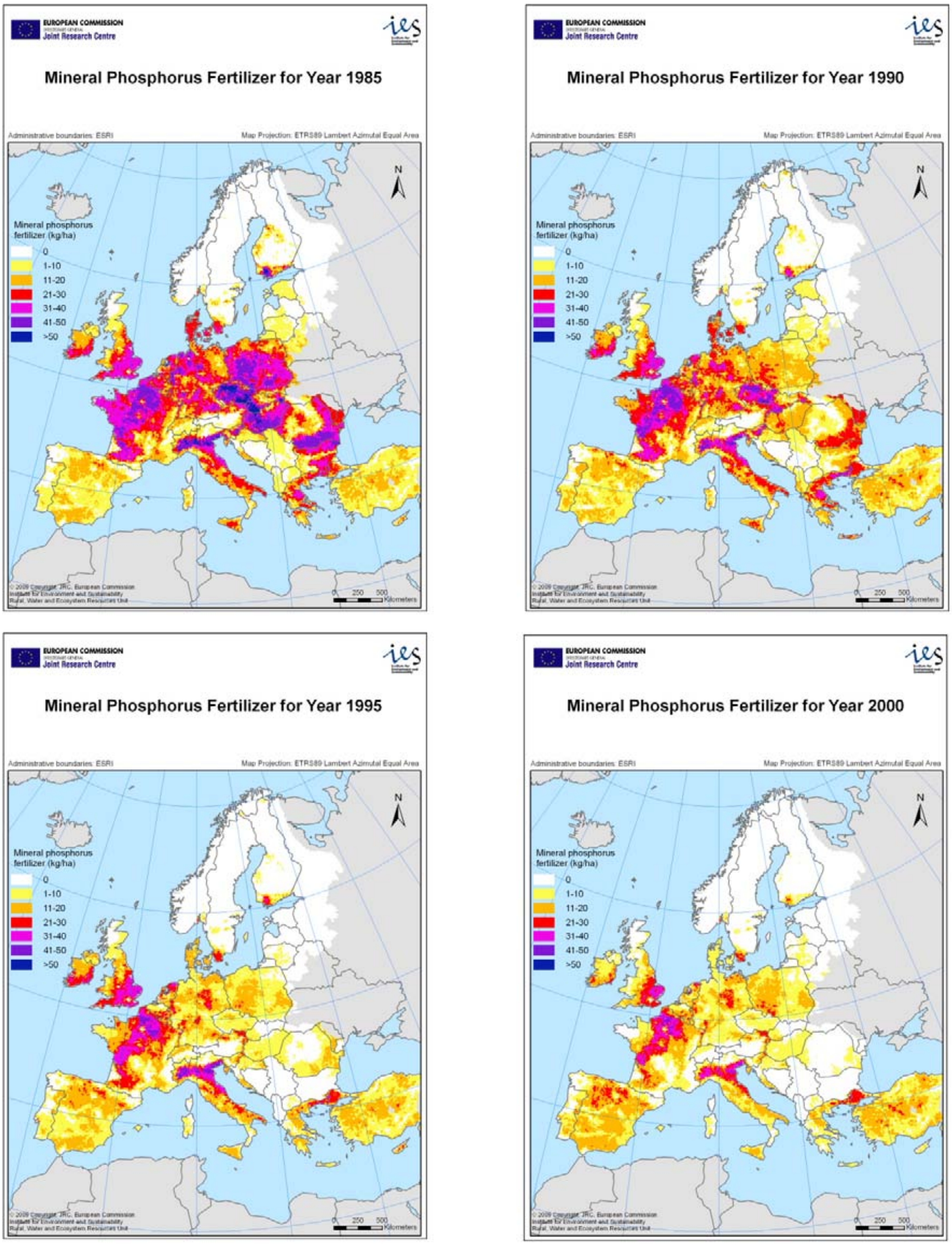


Figure 6. Map of mineral phosphorus application (kg P/ha of total area) per sub-basin for the period 1985-2000

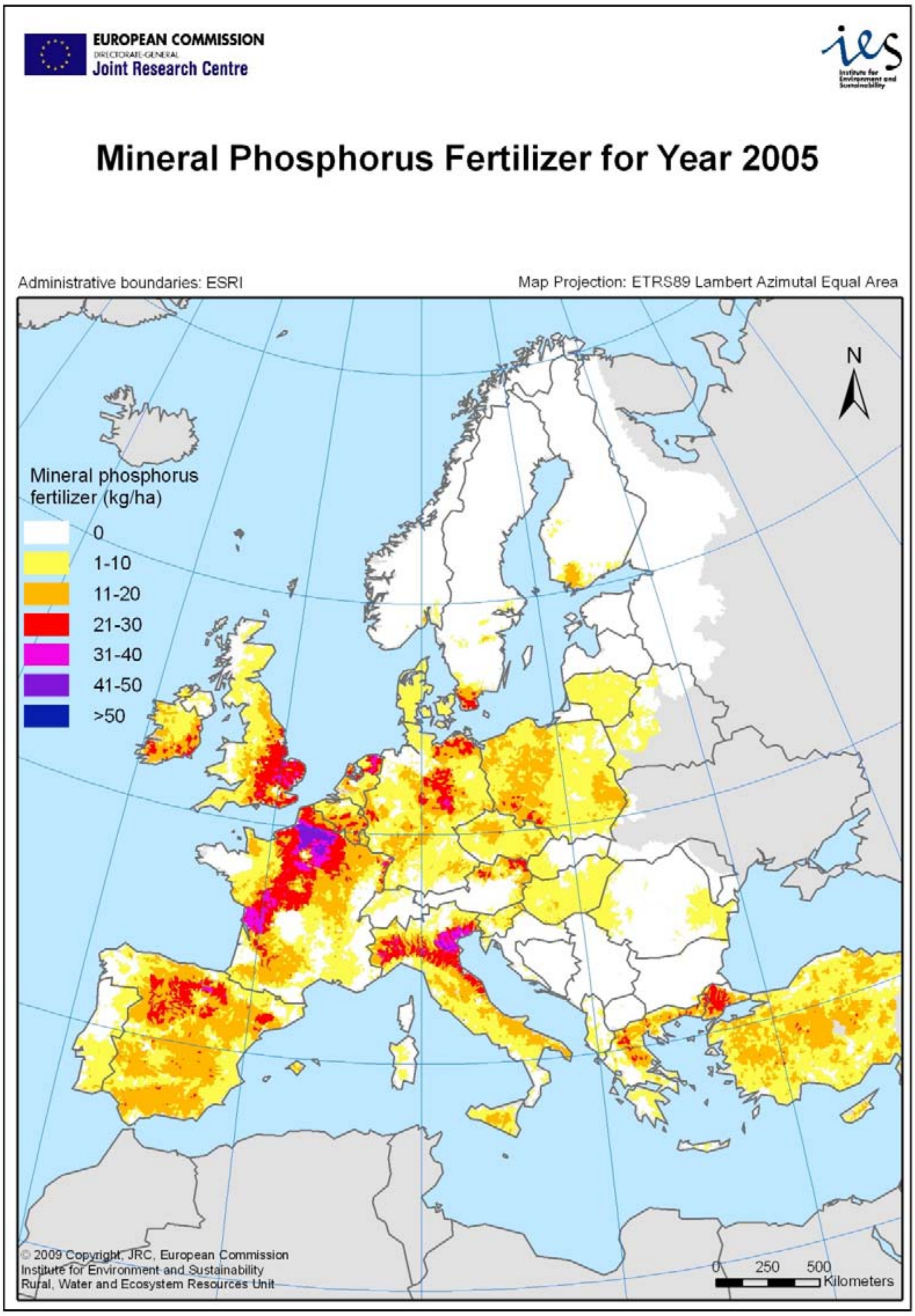


Figure 7. Map of mineral phosphorus application (kg P/ha of total area) per sub-basin for year 2005

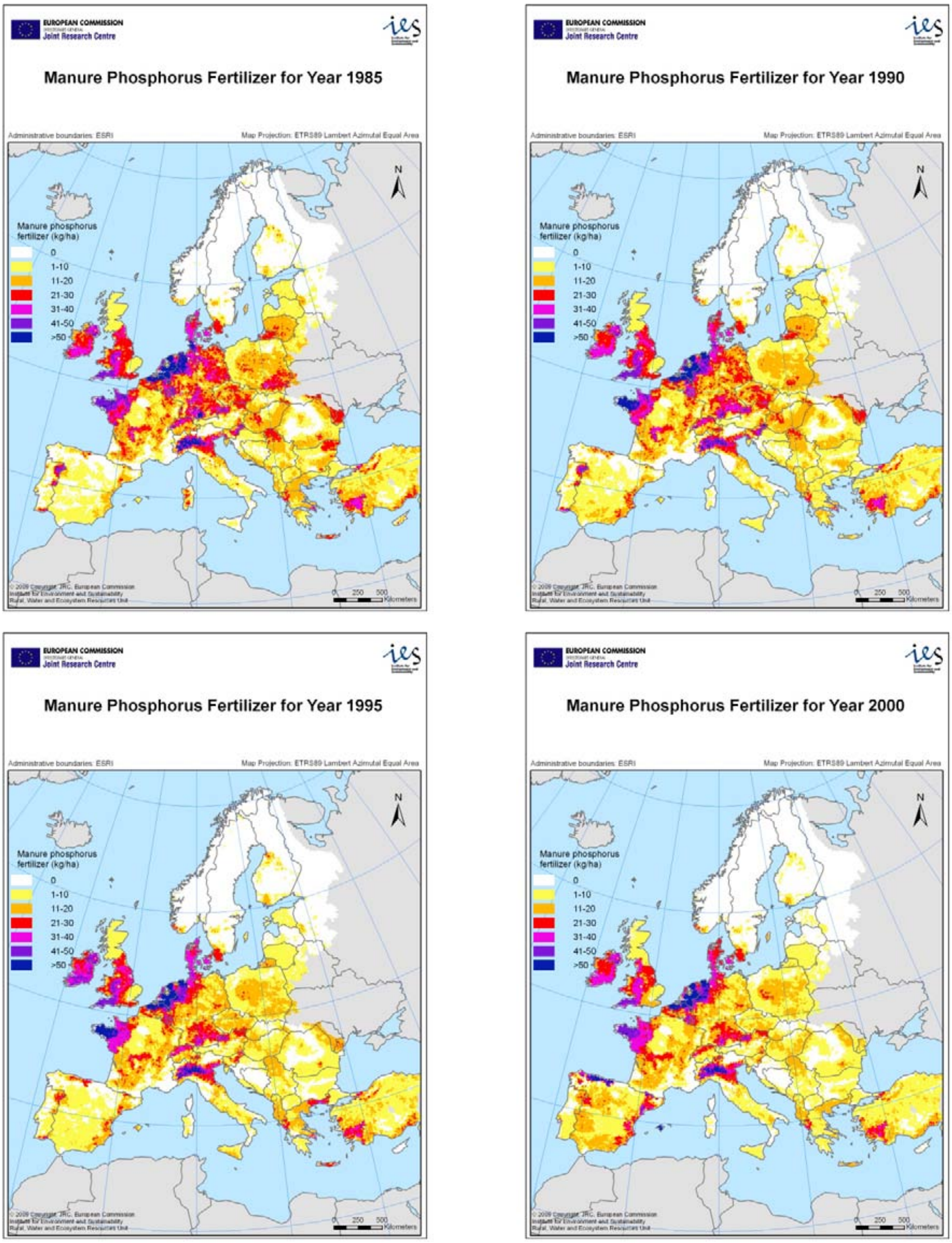


Figure 8. Map of manure phosphorus application (kg P/ha of total area) per sub-basin for the period 1985-2000

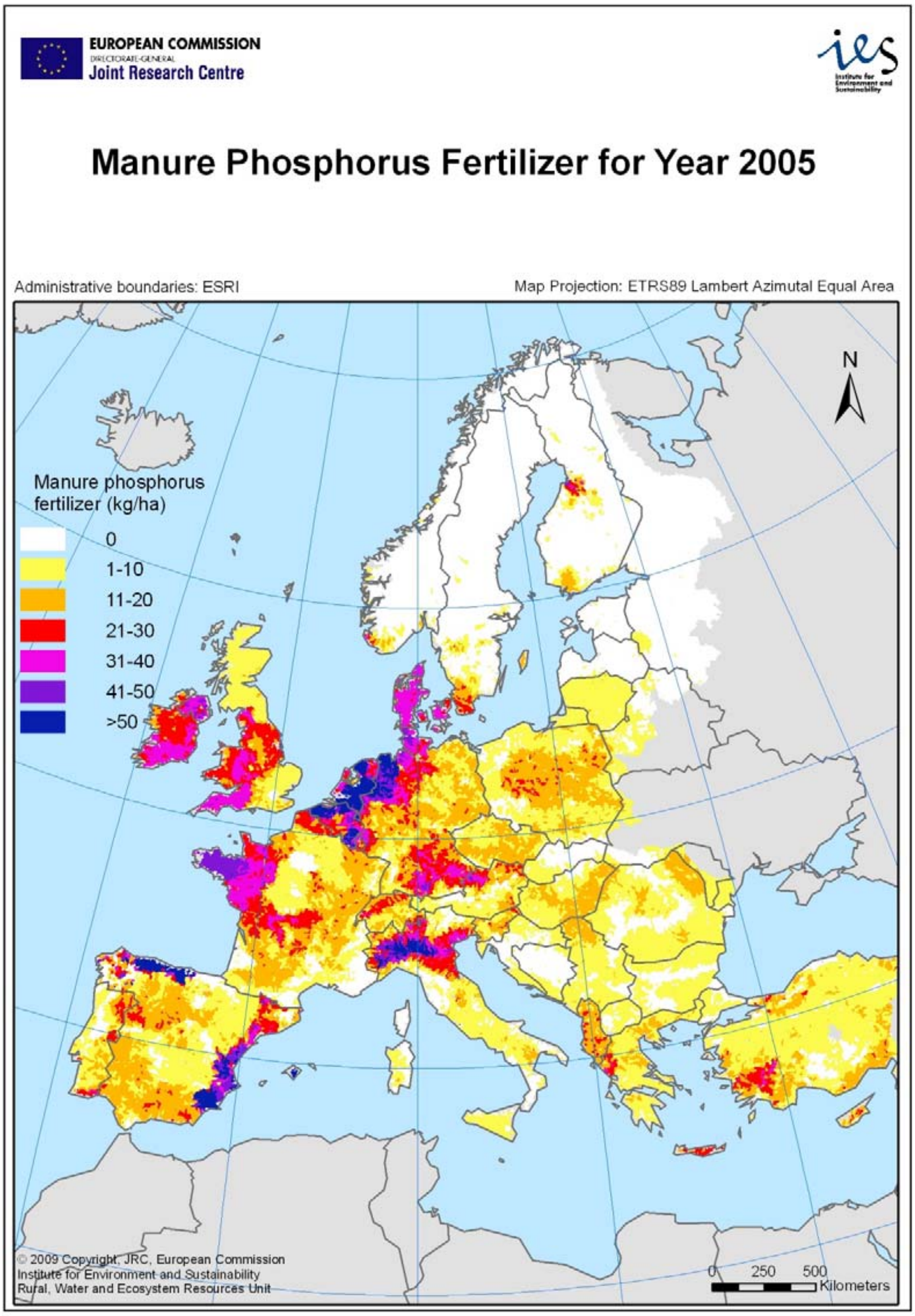


Figure 9. Map of manure phosphorus application (kg P/ha of total area) per sub-basin for year 2005

3.4 Point sources and scattered dwelling emissions

The estimation of N and P release from point sources from agglomeration is based on the population density, the percentage of population connected to the sewerage system, the level of treatment, the N and P abatement for each waste water treatment type, and the N and P emission factor per person. The population density was obtained from the HYDE database (Klein Goldewijk and Van Drecht, 2006). The HYDE database contains a time series of population density, providing an estimate every ten years on a 5 mn grid. For this study four time slices were considered: 1980, 1990, 2000, and 2005.

In the previous assessment, Bouraoui et al. (2009) estimated nutrient emission based on the GDP. For this present assessment a similar methodology to that used by Van Drecht et al. (2009) was developed, where the nutrient emission is calculated based on the protein intake. This change was introduced to allow the study of scenarios of the impact of human diet on nutrient loads. The N and P emission from human excretion was derived from a procedure developed by Jönsson & Vinnerås (2004), in which the N and P emissions are related to the human protein intake taken from the FAO database (2009) as follows:

$$Nemission = 0.11 * TFProtIntake \tag{4}$$

and

$$Pemission = 0.010 * (TFProtIntake + VegProtIntake) \tag{5}$$

where Nemission is the human emission of nitrogen (g N/yr/person), P emission is the human emission of phosphorus (g P/yr/person), TFProtIntake is the total food protein intake (g/yr/person) and VegProtIntake is the vegetable protein intake (g/yr/person). The data for total and vegetable protein intake was retrieved from the FAO (2009). The resulting emission coefficients are given in Table 2 and Table 3. The calculated mean value of human emission for all countries included in the study is about 4.5 kg per year for nitrogen and 0.5 kg per year for phosphorus, completely on line with the values given by Caldwell and Rosemarin (2008).

Little information about the amount of contribution of industry to the total load is available. The industries can contribute by discharging effluent directly into the water body, or indirectly through the connection a sewerage system. The calculation of the indirect industrial load was based on data published by UNEP (2000) on the domestic and industrial discharges for eleven European countries for year 1995 (Table 4). When available the data from UNEP (2000) was used, otherwise the indirect emissions were estimated to be 40% of the human emission.

Table 2. Annual and daily N emission based on the protein intake for the studied countries.

	N emission kg N/year/capita					N emission g N/day/capita				
	1985	1990	1995	2000	2003	1985	1990	1995	2000	2003
Albania	3.09	3.25	3.69	3.69	3.93	8.47	8.91	10.12	10.12	10.78
Austria	3.81	4.06	4.18	4.38	4.42	10.45	11.11	11.44	11.99	12.10
Belarus	4.05	4.09	3.81	3.49	3.45	11.09	11.19	10.45	9.57	9.46
Belg-Lux	4.10	4.14	4.10	4.18	4.18	11.22	11.33	11.22	11.44	11.44
Bosn_Herz	2.97	3.03	3.21	2.77	2.85	8.13	8.29	8.80	7.59	7.81
Bulgaria	4.26	4.42	3.41	3.45	3.61	11.66	12.10	9.35	9.46	9.90
Croatia	2.51	2.56	2.73	2.69	2.93	6.87	7.00	7.48	7.37	8.03
Cyprus	3.49	3.85	4.10	4.14	4.18	9.57	10.56	11.22	11.33	11.44
Czech Rep	4.38	4.51	3.73	3.61	3.77	11.99	12.35	10.23	9.90	10.34
Denmark	3.81	3.93	4.26	4.26	4.34	10.45	10.78	11.66	11.66	11.88
Estonia	4.55	4.60	3.93	3.57	3.53	12.47	12.59	10.78	9.79	9.68
Finland	3.69	3.97	3.89	4.02	4.10	10.12	10.89	10.67	11.00	11.22
France	4.66	4.62	4.62	4.70	4.70	12.76	12.65	12.65	12.87	12.87
Georgia	2.82	2.85	2.73	2.61	2.97	7.74	7.81	7.48	7.15	8.14
Germany	4.02	3.93	3.77	3.81	4.02	11.00	10.78	10.34	10.45	11.00
Greece	4.38	4.46	4.62	5.02	4.70	11.99	12.21	12.65	13.75	12.87
Hungary	4.18	4.06	3.41	3.77	3.81	11.44	11.11	9.35	10.34	10.45
Ireland	4.46	4.54	4.26	4.54	4.70	12.21	12.43	11.66	12.43	12.87
Italy	4.26	4.42	4.26	4.62	4.54	11.66	12.10	11.66	12.65	12.43
Jordan	3.09	3.01	2.89	2.85	2.77	8.47	8.25	7.92	7.81	7.59
Latvia	4.13	4.17	3.73	3.17	3.33	11.32	11.43	10.23	8.69	9.13
Lebanon	3.09	3.13	3.17	3.45	3.57	8.47	8.58	8.69	9.46	9.79
Lithuania	4.09	4.13	3.57	4.18	4.46	11.20	11.31	9.79	11.44	12.21
Malta	3.93	3.89	4.26	4.58	4.86	10.78	10.67	11.66	12.54	13.31
Moldova	3.58	3.62	2.65	2.45	2.61	9.82	9.91	7.26	6.71	7.15
Netherlands	3.85	3.85	4.14	4.34	4.18	10.56	10.56	11.33	11.88	11.44
Norway	4.02	3.89	4.02	4.18	4.30	11.00	10.67	11.00	11.44	11.77
Poland	4.06	4.02	3.89	3.97	3.97	11.11	11.00	10.67	10.89	10.89
Portugal	3.49	4.06	4.38	4.74	4.70	9.57	11.11	11.99	12.98	12.87
Romania	3.81	3.65	4.02	4.06	4.50	10.45	10.01	11.00	11.11	12.32
Russian Fed	3.84	3.87	3.57	3.45	3.65	10.51	10.61	9.79	9.46	10.01
Serbia Mon	3.68	3.75	3.57	3.13	2.97	10.08	10.27	9.79	8.58	8.14
Slovakia	3.81	3.93	3.13	3.09	3.05	10.45	10.75	8.58	8.47	8.36
Slovenia	3.26	3.32	3.85	4.22	4.02	8.93	9.11	10.56	11.55	11.00
Spain	3.93	4.18	4.18	4.42	4.54	10.78	11.44	11.44	12.10	12.43
Sweden	3.85	3.81	3.85	4.06	4.34	10.56	10.45	10.56	11.11	11.88
Switzerland	3.81	3.81	3.65	3.73	3.89	10.45	10.45	10.01	10.23	10.67
Syrian Repc	3.25	2.89	2.85	2.93	3.21	8.91	7.92	7.81	8.03	8.80
FYRM	2.97	3.03	2.81	2.73	2.89	8.13	8.29	7.70	7.48	7.92
Turkey	4.10	4.10	4.06	3.89	3.85	11.22	11.22	11.11	10.67	10.56
Ukraine	3.96	4.00	3.37	3.21	3.37	10.86	10.96	9.24	8.80	9.24
UK	3.73	3.77	3.73	3.97	4.22	10.23	10.34	10.23	10.89	11.55
mean value	3.78	3.84	3.72	3.76	3.86	10.36	10.51	10.18	10.31	10.57

Table 3. Annual and daily P emission based on the protein intake for the studied countries.

	P emission kg P/year/capita					P emission g P/day/capita				
	1985	1990	1995	2000	2003	1985	1990	1995	2000	2003
Albania	0.48	0.50	0.52	0.52	0.54	1.32	1.37	1.43	1.43	1.48
Austria	0.47	0.50	0.51	0.54	0.55	1.28	1.37	1.40	1.49	1.50
Belarus	0.53	0.53	0.51	0.47	0.46	1.45	1.45	1.39	1.29	1.26
Belg-Lux	0.51	0.52	0.51	0.51	0.51	1.41	1.42	1.40	1.41	1.41
Bosn_Herz	0.47	0.47	0.51	0.43	0.44	1.30	1.29	1.41	1.17	1.21
Bulgaria	0.59	0.61	0.48	0.47	0.49	1.62	1.67	1.32	1.29	1.35
Croatia	0.34	0.34	0.38	0.38	0.41	0.92	0.93	1.05	1.03	1.12
Cyprus	0.47	0.50	0.53	0.52	0.52	1.28	1.36	1.44	1.43	1.42
Czech Rep	0.53	0.55	0.48	0.46	0.49	1.45	1.50	1.32	1.26	1.35
Denmark	0.47	0.48	0.52	0.53	0.54	1.29	1.31	1.43	1.44	1.47
Estonia	0.53	0.53	0.51	0.46	0.46	1.45	1.45	1.40	1.26	1.25
Finland	0.46	0.49	0.47	0.50	0.51	1.25	1.35	1.30	1.38	1.41
France	0.56	0.56	0.56	0.57	0.58	1.54	1.53	1.54	1.57	1.58
Georgia	0.44	0.44	0.42	0.39	0.45	1.20	1.20	1.16	1.07	1.22
Germany	0.50	0.49	0.48	0.49	0.51	1.38	1.34	1.31	1.34	1.40
Greece	0.59	0.60	0.61	0.66	0.62	1.62	1.64	1.68	1.80	1.71
Hungary	0.55	0.53	0.45	0.50	0.51	1.50	1.46	1.24	1.37	1.39
Ireland	0.55	0.57	0.54	0.57	0.58	1.52	1.56	1.47	1.55	1.60
Italy	0.56	0.58	0.57	0.61	0.60	1.54	1.60	1.55	1.66	1.64
Jordan	0.46	0.47	0.44	0.44	0.43	1.27	1.29	1.21	1.20	1.17
Latvia	0.52	0.53	0.48	0.43	0.44	1.44	1.44	1.31	1.17	1.21
Lebanon	0.47	0.49	0.49	0.51	0.52	1.28	1.33	1.35	1.39	1.42
Lithuania	0.55	0.55	0.50	0.57	0.59	1.50	1.50	1.37	1.57	1.61
Malta	0.52	0.53	0.56	0.62	0.64	1.42	1.45	1.54	1.70	1.76
Moldova	0.53	0.53	0.39	0.37	0.38	1.44	1.44	1.08	1.00	1.05
Netherlands	0.47	0.47	0.49	0.52	0.53	1.29	1.28	1.33	1.42	1.44
Norway	0.49	0.49	0.50	0.53	0.54	1.35	1.34	1.37	1.44	1.49
Poland	0.54	0.53	0.53	0.54	0.54	1.47	1.46	1.46	1.48	1.47
Portugal	0.48	0.54	0.57	0.61	0.60	1.32	1.48	1.56	1.66	1.65
Romania	0.53	0.51	0.58	0.59	0.64	1.45	1.40	1.59	1.61	1.74
Russian Fed	0.52	0.52	0.49	0.47	0.50	1.41	1.41	1.34	1.30	1.37
Serbia Mon	0.49	0.49	0.47	0.40	0.38	1.34	1.34	1.30	1.10	1.04
Slovakia	0.49	0.51	0.42	0.42	0.42	1.35	1.39	1.15	1.16	1.14
Slovenia	0.44	0.44	0.50	0.54	0.51	1.20	1.21	1.37	1.49	1.41
Spain	0.51	0.54	0.53	0.55	0.56	1.40	1.47	1.44	1.50	1.53
Sweden	0.46	0.46	0.47	0.49	0.52	1.26	1.26	1.28	1.35	1.43
Switzerland	0.47	0.47	0.46	0.47	0.49	1.28	1.29	1.25	1.30	1.33
Syrian Rep	0.51	0.46	0.45	0.46	0.50	1.41	1.25	1.23	1.25	1.38
FYRM	0.45	0.45	0.42	0.40	0.43	1.25	1.24	1.14	1.09	1.17
Turkey	0.65	0.65	0.64	0.62	0.61	1.78	1.79	1.76	1.69	1.67
Ukraine	0.55	0.55	0.47	0.46	0.48	1.52	1.52	1.30	1.27	1.32
UK	0.48	0.49	0.49	0.52	0.55	1.32	1.34	1.33	1.43	1.50
mean value	0.50	0.51	0.50	0.50	0.51	1.38	1.40	1.36	1.38	1.41

Table 4. Population and industries connected to treatment plant in selected EU countries for 1995 in million pe (person equivalent), and estimated indirect industrial nutrient emission for nitrogen (g N/inh/day) and phosphorus (g P/inh/day)

	DE	DK	ES	FR	GR	IT	LU	NL	PT	FI	UK
Population	75.2	4.6	31.6	29	6.1	46.8	0.415	15	6.2	4	55.5
Industry	47.5	3.9	46.6	19.5	2	48	0.2	9	4.7	1.5	22.5
N industry	6.0	8.9	13.8	4.3	2.4	9.9	5.3	6.6	5.2	3.1	4.0
P industry	0.76	1.09	1.74	0.53	0.32	1.31	0.67	0.78	0.68	0.38	0.52

For phosphorus, the contribution of detergents was also considered in the estimation of emissions. In Europe, the two main uses of Phosphate-based (P-based) detergents are for laundry and dishwashing. P-based detergents contain sodium tripoliphosphates (STPP) as builders. The proportion of STPP in laundry P-based detergents varies between 20 and 50% depending on the type of detergent, and is about 50% in automatic dishwashing detergents (Wind, 2007). In this study we assumed an average concentration of STPP in phosphate detergents of 25% and we considered that the fraction of P in STPP is 0.2527 (RPA, 2006).

From the mid-1880s to the mid-1990s most of the European countries have reduced or banned the use of P-based detergents for laundry, by legislative actions or voluntary agreements, while no actions have been taken for P-based dishwashing detergents (RPA, 2006). Table 5 summarizes the level of phosphate-free in laundry detergents for EU25 countries.

In this study we estimated the per capita P emission for the year 2000 in European countries using the data reported by RPA (2006) for EU25 and by Schreiber et al. (2003) for the countries discharging in the Danube river basin (Table 6). To fill in the data gaps on P emission from detergents for the whole region of study some assumptions were made. For Belarus and Russian Federation (only a minor part of these countries is included in the study) we used the values available for Romania. For Switzerland and Norway we considered that P-based detergents were banned before 2000 (in 1986 for Switzerland and for Norway) and we assumed that the per capita consumption of P for dishwashing was the same as in Sweden. Finally, for Turkey we used the emission rate available for Bulgaria. The per capita P emissions from detergents for year 2000 used in the study are summarized in Table 6.

Data reported by WRC (2002) on trends in STPP consumption were used to estimate the P emission from detergents from 1985 to 1995. These data cover EU15 countries, Switzerland, Czech Republic, Hungary and Poland. For the missing countries we assumed that there were no reductions in P-based laundry detergents and the values of year 2000 were considered also for the past years. This is partially supported by the limited trends observed in the available accession countries. Regarding P emissions due to dishwashing detergents we assumed that there were no trends. For the year 2005 for all countries we used the information available for 2000, since updated values were not available. The P emissions from all detergents from 1985 to 2005 used in this study are reported in Table 7.

The human emission factors, the indirect industrial discharge, and the contribution of detergents to P emissions were combined with the maps of population density to estimate the nutrient sources generated by human settlements. These data were used in combination with information on connection to waste water treatment plants, and treatment level available from EUROSTAT at country level. However, this information was not always available for the study period (1985-2005), and to complete the dataset additional sources were used including OECD, EEA, WHO, and UNEP. However, some gaps remained and some assumptions were made such as using the data from the closest available year, etc. The population not connected to waste water treatment plants were considered as scattered dwellings. Maps of point source emissions of N and P are shown in Figure 10 to Figure 13.

Table 5 Degree to which EU25 countries are phosphate-free laundry detergents (RPA 2006).

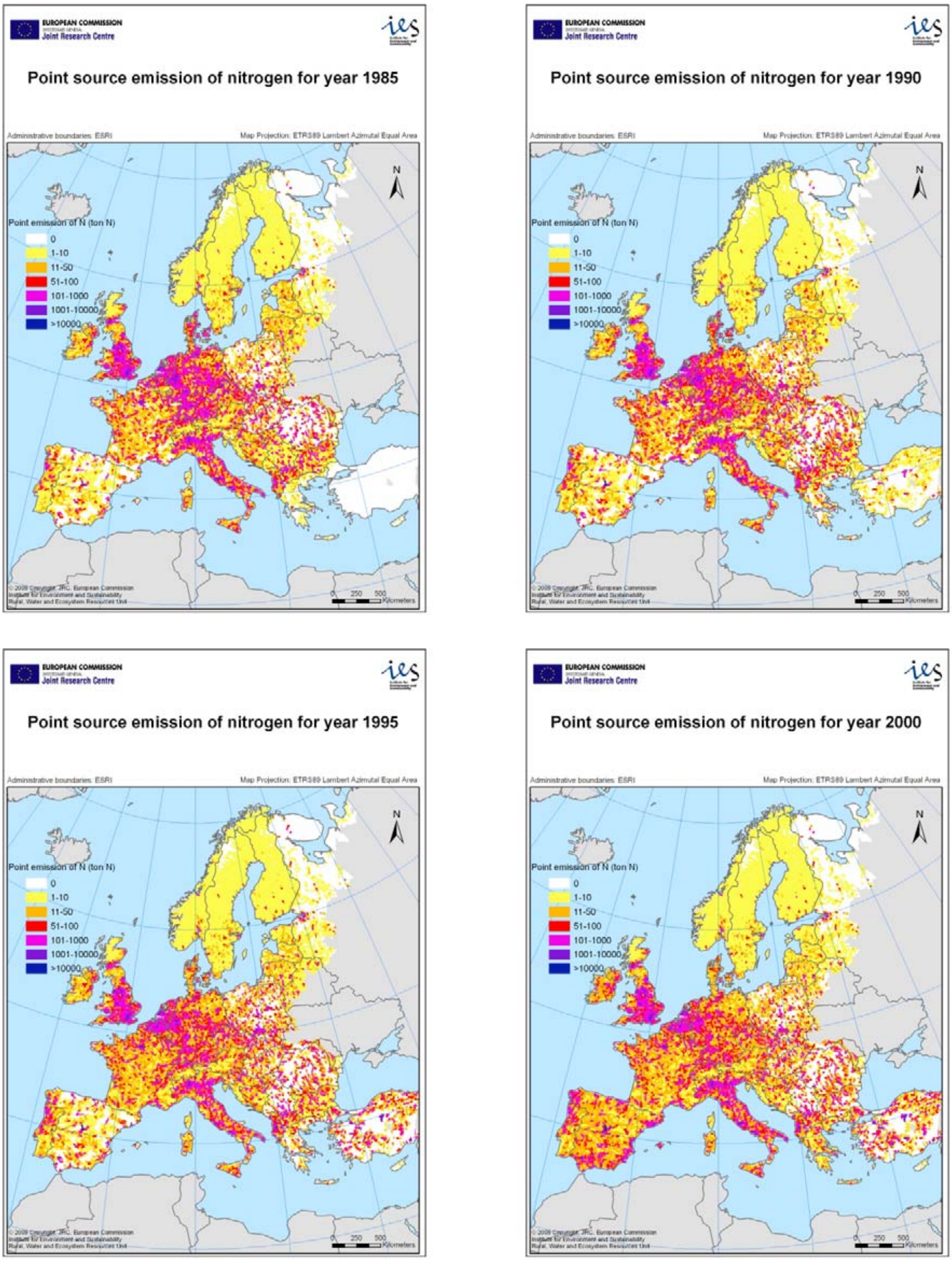
	Population (million)	% Phosphate free
Belgium	10.4	100
Czech Republic	10.2	35
Denmark	5.4	80
Germany	82.5	100
Estonia	1.3	20
Greece	11	50
Spain	42.2	40
France	59.9	50
Ireland	4	100
Italy	57.8	100
Cyprus	0.7	20
Latvia	2.3	20
Lithuania	3.4	20
Luxembourg	0.4	100
Hungary	10.1	30
Malta	0.4	20
Netherlands	16.2	100
Austria	8.1	100
Poland	38.2	15
Portugal	10.4	30
Slovenia	2	95
Slovakia	5.4	20
Finland	5.2	90
Sweden	9	85
United Kingdom	59.5	55
EU-25	456	66

Table 6. Phosphorus per capita consumption (kg P/person/yr) of laundry and dishwashing detergents.

	DATA source	P used in laundry detergents (kg P/pers yr)	P used in dishwashers detergents (kg P/pers yr)	P used in detergents TOTAL (kg P/pers yr)
Austria	RPA, 2006	0.0000	0.0948	0.0948
Belgium	RPA, 2006	0.0000	0.0821	0.0821
Cyprus	RPA, 2006	0.5054	0.0442	0.5496
Czech Republic	RPA, 2006	0.2717	0.0126	0.2843
Denmark	RPA, 2006	0.0695	0.1011	0.1706
Estonia	RPA, 2006	0.1706	0.0000	0.1706
Finland	RPA, 2006	0.0316	0.1011	0.1327
France	RPA, 2006	0.2780	0.0884	0.3664
Germany	RPA, 2006	0.0000	0.1074	0.1074
Greece	RPA, 2006	0.2464	0.0569	0.3032
Hungary	RPA, 2006	0.2211	0.0063	0.2274
Ireland	RPA, 2006	0.0000	0.0569	0.0569
Italy	RPA, 2006	0.0000	0.0632	0.0632
Latvia	RPA, 2006	0.1958	0.0000	0.1958
Lithuania	RPA, 2006	0.1832	0.0063	0.1895
Luxembourg	RPA, 2006	0.0000	0.0948	0.0948
Malta	RPA, 2006	0.3664	0.0126	0.3791
Netherlands	RPA, 2006	0.0000	0.0821	0.0821
Poland	RPA, 2006	0.5180	0.0063	0.5244
Portugal	RPA, 2006	0.3475	0.0569	0.4043
Slovakia	RPA, 2006	0.1516	0.0063	0.1579
Slovenia	RPA, 2006	0.0569	0.0505	0.1074
Spain	RPA, 2006	0.3348	0.0505	0.3854
Sweden	RPA, 2006	0.0442	0.1137	0.1579
United Kingdom	RPA, 2006	0.2590	0.0695	0.3285
Bulgaria	Schreiber et al., 2003	0.1153	0.0009	0.1162
Romania	Schreiber et al., 2003	0.0896	0.0002	0.0897
Belarus	Assumption	0.0896	0.0002	0.0897
Republic of Moldova	Schreiber et al., 2003	0.0459	0.0000	0.0459
Russian Federation	Assumption	0.0896	0.0002	0.0897
Ukraine	Schreiber et al., 2003	0.0433	0.0000	0.0433
Albania*	Schreiber et al., 2003	0.2350	0.0000	0.2350
Bosnia and Herzegovina	Schreiber et al., 2003	0.4417	0.0093	0.4510
Croatia	Schreiber et al., 2003	0.4843	0.0428	0.5271
Serbia and Montenegro	Schreiber et al., 2003	0.2350	0.0000	0.2350
TFYR of Macedonia	Schreiber et al., 2003	0.2350	0.0000	0.2350
Norway	Assumption	0.0000	0.1137	0.1137
Switzerland	Assumption	0.0000	0.1137	0.1137
Turkey	Assumption	0.1153	0.0009	0.1162

Table 7 Phosphorus per capita emissions from laundry and dishwasher detergents (kg P/person/yr) used in this study.

	1985	1990	1995	2000	2005
Austria	0.6782	0.4067	0.2508	0.0948	0.0948
Belgium	0.7017	0.3786	0.2303	0.0821	0.0821
Cyprus	0.5496	0.5496	0.5496	0.5496	0.5496
Czech Republic	0.6023	0.3273	0.2071	0.2843	0.2843
Denmark	0.9809	0.7515	0.4731	0.1706	0.1706
Estonia	0.1706	0.1706	0.1706	0.1706	0.1706
Finland	0.6745	0.4072	0.2785	0.1327	0.1327
France	0.8495	0.6255	0.5131	0.3664	0.3664
Germany	0.6768	0.1475	0.1275	0.1074	0.1074
Greece	0.6128	0.3532	0.3084	0.3032	0.3032
Hungary	0.5943	0.3191	0.2503	0.2274	0.2274
Ireland	0.5875	0.3411	0.1990	0.0569	0.0569
Italy	0.5520	0.1056	0.0844	0.0632	0.0632
Latvia	0.1958	0.1958	0.1958	0.1958	0.1958
Lithuania	0.1895	0.1895	0.1895	0.1895	0.1895
Luxembourg	0.6633	0.4106	0.2527	0.0948	0.0948
Malta	0.3791	0.3791	0.3791	0.3791	0.3791
Netherlands	0.5813	0.1071	0.0946	0.0821	0.0821
Poland	0.5957	0.3205	0.4181	0.5244	0.5244
Portugal	0.4675	0.4189	0.3351	0.4043	0.4043
Slovakia	0.1579	0.1579	0.1579	0.1579	0.1579
Slovenia	0.1074	0.1074	0.1074	0.1074	0.1074
Spain	0.7206	0.6032	0.4407	0.3854	0.3854
Sweden	0.6725	0.4198	0.2948	0.1579	0.1579
United Kingdom	0.5889	0.6114	0.4912	0.3285	0.3285
Bulgaria	0.1162	0.1162	0.1162	0.1162	0.1162
Romania	0.0897	0.0897	0.0897	0.0897	0.0897
Belarus	0.0897	0.0897	0.0897	0.0897	0.0897
Republic of Moldova	0.0459	0.0459	0.0459	0.0459	0.0459
Russian Federation	0.0897	0.0897	0.0897	0.0897	0.0897
Ukraine	0.0433	0.0433	0.0433	0.0433	0.0433
Albania	0.2350	0.2350	0.2350	0.2350	0.2350
Bosnia and Herzegovina	0.4510	0.4510	0.4510	0.4510	0.4510
Croatia	0.5271	0.5271	0.5271	0.5271	0.5271
Serbia and Montenegro	0.2350	0.2350	0.2350	0.2350	0.2350
TFYR of Macedonia	0.2350	0.2350	0.2350	0.2350	0.2350
Norway	0.8731	0.1900	0.1137	0.1137	0.1137
Switzerland	0.8731	0.1900	0.1137	0.1137	0.1137
Turkey	0.1162	0.1162	0.1162	0.1162	0.1162



Point source emission of nitrogen for year 1985

Point source emission of nitrogen for year 1990

Point source emission of nitrogen for year 1995

Point source emission of nitrogen for year 2000

Figure 10. Map of point source emission of nitrogen (ton N) per sub-basin for the period 1985-2000

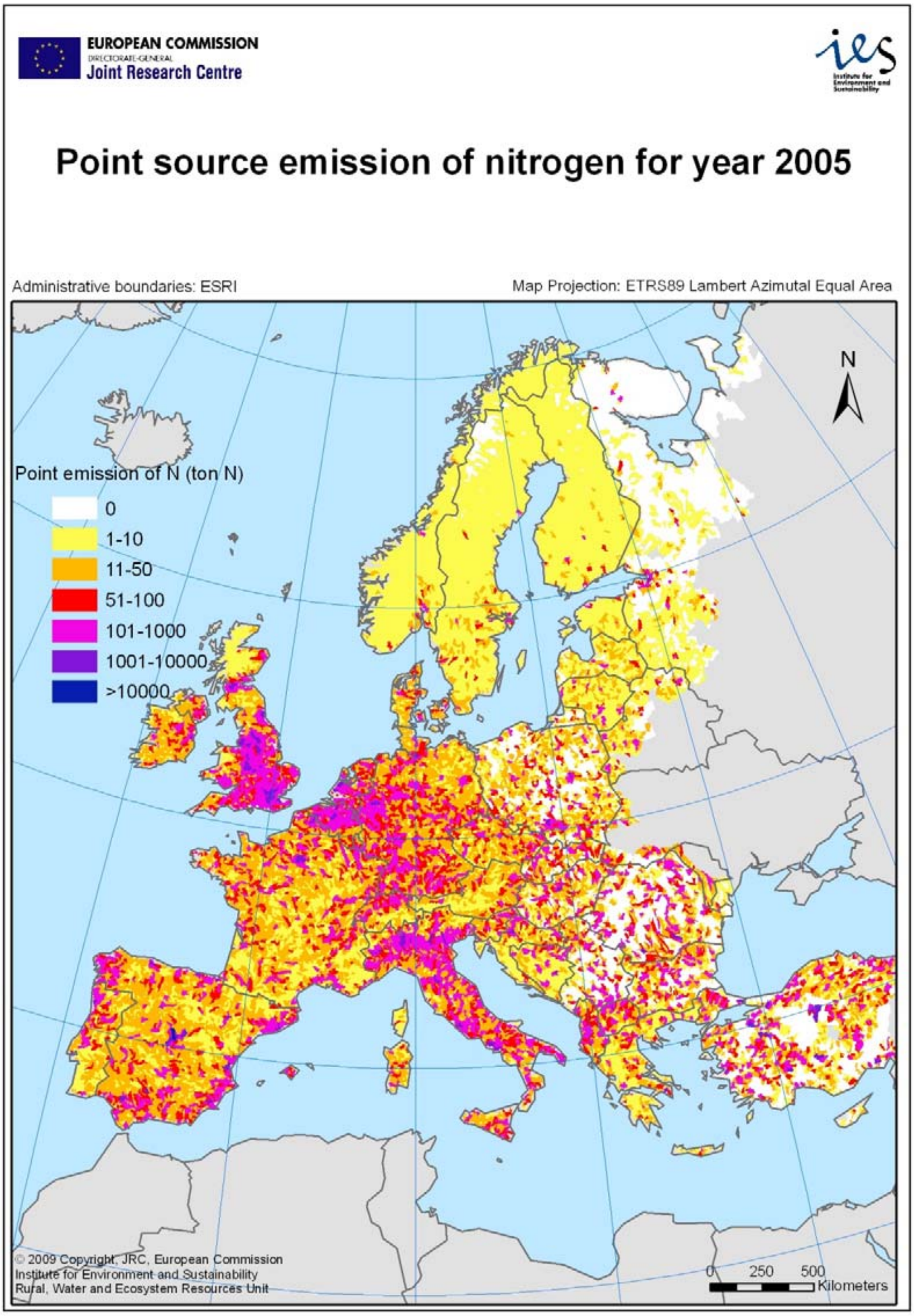


Figure 11. Map of point source emission of nitrogen (ton N) per sub-basin for year 2005

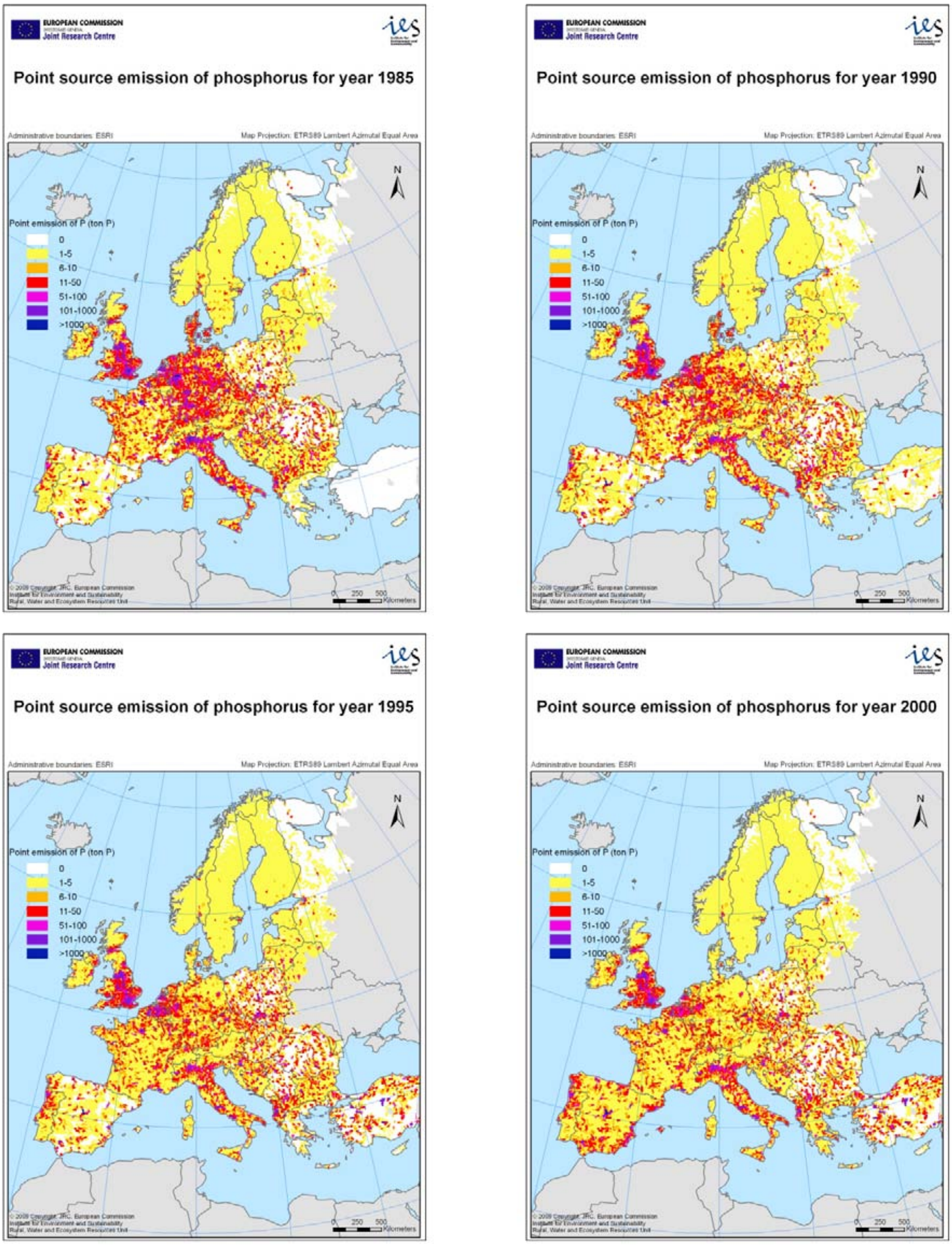


Figure 12. Map of point source emission of phosphorus (ton P) per sub-basin for the period 1985-2000

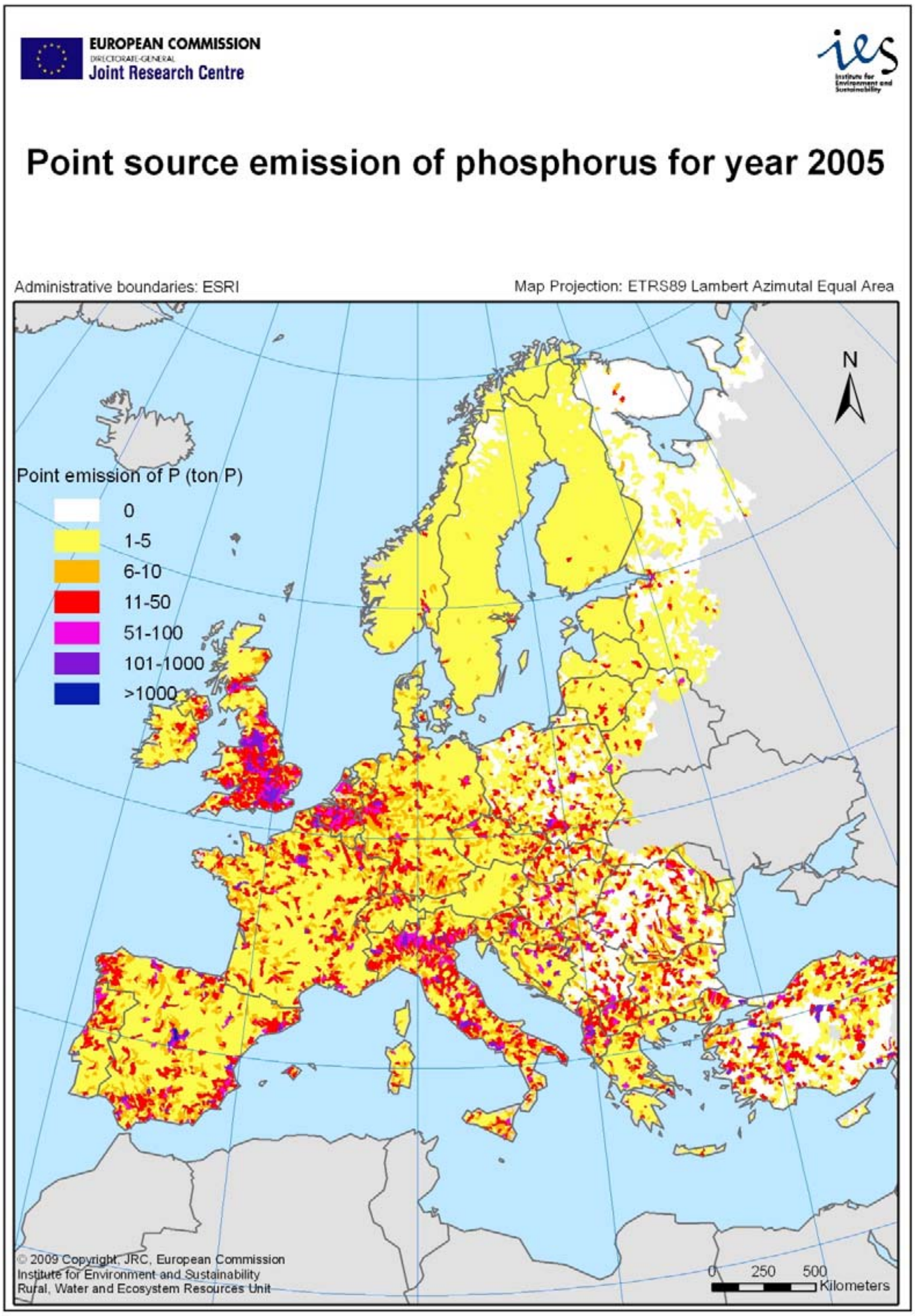


Figure 13. Map of point source emission of phosphorus (ton P) per sub-basin for year 2005

3.5 Climate and atmospheric deposition data

The atmospheric deposition data were taken from Cooperative Programme for the Monitoring and Evaluation of the Long- Range Transmission of Air Pollutants in Europe (EMEP) for the period 1985-2005 (EMEP, 2001) as detailed in Bouraoui et al. (2009). The climate database (Princeton Climate Database) was provided by Sheffield et al. (2006) for the period 1970-2006 as detailed by Bouraoui et al. (2009).

4. Nutrient balance

National nutrient balances are good indicators of the agriculture production intensity and inform on the efficiency of the nutrient use, helping to develop sustainable use of the resources. Nutrient balances have been used extensively as a proxy for environmental pressure, even though large surplus do not always coincide with high nutrient losses to the environment as hydro-geo-morphological and climatic factors have to be considered to convert nutrient surplus into a pressure on the environment (Grizzetti et al., 2008). Lord et al. (2002) reach a similar conclusions noting that the nitrogen surplus in the UK was weekly correlated to either nitrate concentrations or loads in the streams. An additional explanation between the lack of correlation between the nutrient surplus and concentrations in the streams is the time lag before the nitrogen excess actually reaches the streams. Indeed the travel time of nutrients from the soils surface to the streams range from days to several decades. Despite this serious limitation, nutrient balances are used on a routine basis because of their simplicity, allowing local, regional, and national comparison. Two types of balances are usually performed:

- the farm gate balance where the farm is taken as a working “black box” unit and all kind of nutrient entering and leaving the systems are considered.
- the soil surface balance takes into account all flows of nutrient reaching and leaving (Crop, fodder and grass removal) the soil surface

See Oenema et al. (2003) and Oborn et al. (2003) for an in depth discussion of the advantages and disadvantages of the two methods.

In this study, the national soil surface nutrient balances were computed as a screening to understand the time evolution of inputs coming from agriculture. These nutrient balances were then coupled to water quality concentrations at the river basins outlets reported from OECD or from data national monitoring databases. For nitrogen the national nutrient balances were computed as follows:

$$N_{Bal} = N_{Fert} + N_{Man} + N_{Dep} + N_{fix_{symb}} + N_{fix_{asymb}} - N_{Upt} \qquad 6$$

where N_{Bal} is the nitrogen balance, N_{Fert} is the mineral nitrogen fertilizer application, N_{Man} is the manure application, N_{Dep} is the nitrogen deposition, N_{Fix} is the nitrogen fixation, and N_{Upt} is the nitrogen uptake and all units can be tons or kg/ha. For phosphorus the balance was computed using a similar equation however no phosphorus deposition was considered. The balance was computed from 1965 to 2005. No emphasis was put on getting crop and animal excretion coefficients specific to each countries as this task was outside the scope of the study.

The total N and P fertilizer consumptions were retrieved from FAOSTAT and used unmodified. The head stocks of ducks, chicken, buffaloes, camel, cattle pigs, geese, and horses were also retrieved from the

FAO (FAOSTAT) and were then converted in manure production using excretion coefficients summarized in Table 8 for the major animal groups.

Table 8. Excretion coefficients used in the calculation of the nutrient balances (kg/head/year)

	Cattle Horse-Camels		Chicken Ducks-Geese		Goat-Sheep		Pigs	
	N	P	N	P	N	P	N	P
Albania	50	8	0.5	0.2	11	4.46	10	2.5
Austria	65	10	0.5	0.2	11	4.46	10	2.5
Belgium-Luxembourg	65	10	0.5	0.2	11	4.46	10	2.5
Belarus	50	8	0.5	0.2	11	4.46	10	2.5
Bosnia & Herzegovina	50	8	0.5	0.2	11	4.46	10	2.5
Bulgaria	50	8	0.5	0.2	11	4.46	10	2.5
Croatia	50	8	0.5	0.2	11	4.46	10	2.5
Cyprus	65	10	0.5	0.2	11	4.46	10	2.5
Czech Republic	50	8	0.5	0.2	11	4.46	10	2.5
Denmark	65	10	0.5	0.2	11	4.46	10	2.5
Estonia	50	8	0.5	0.2	11	4.46	10	2.5
Finland	65	10	0.5	0.2	11	4.46	10	2.5
France	65	10	0.5	0.2	11	4.46	10	2.5
Georgia	50	8	0.5	0.2	11	4.46	10	2.5
Germany	65	10	0.5	0.2	11	4.46	10	2.5
Greece	65	10	0.5	0.2	11	4.46	10	2.5
Hungary	50	8	0.5	0.2	11	4.46	10	2.5
Ireland	65	10	0.5	0.2	11	4.46	10	2.5
Italy	65	10	0.5	0.2	11	4.46	10	2.5
Latvia	50	8	0.5	0.2	11	4.46	10	2.5
Lithuania	50	8	0.5	0.2	11	4.46	10	2.5
Malta	50	8	0.5	0.2	11	4.46	10	2.5
Moldova	50	8	0.5	0.2	11	4.46	10	2.5
Netherlands	65	10	0.5	0.2	11	4.46	10	2.5
Norway	65	10	0.5	0.2	11	4.46	10	2.5
Poland	50	8	0.5	0.2	11	4.46	10	2.5
Portugal	65	10	0.5	0.2	11	4.46	10	2.5
Romania	50	8	0.5	0.2	11	4.46	10	2.5
Russian Federation	50	8	0.5	0.2	11	4.46	10	2.5
Serbia & Montenegro	50	8	0.5	0.2	11	4.46	10	2.5
Slovakia	50	8	0.5	0.2	11	4.46	10	2.5
Slovenia	50	8	0.5	0.2	11	4.46	10	2.5
Spain	65	10	0.5	0.2	11	4.46	10	2.5
Sweden	65	10	0.5	0.2	11	4.46	10	2.5
Switzerland	65	10	0.5	0.2	11	4.46	10	2.5
The FYR Macedonia	50	8	0.5	0.2	11	4.46	10	2.5
Turkey	50	8	0.5	0.2	11	4.46	10	2.5
Ukraine	50	8	0.5	0.2	11	4.46	10	2.5
United Kingdom	65	10	0.5	0.2	11	4.46	10	2.5

Crop yield was taken from FAO (FAOSTAT database) and was converted from biomass yield into nutrient yield using conversing coefficients specific to each crop as summarized in Table 9.

Table 9. Nutrient content of the major crops in Europe

crop/crop group	N content g/kg	P content g/kg
Bananas	2	0.4
Barley	17	1.4
Citrus fruit, nec	1	0.2
Cottonseed	29	4.4
Fibres	81	12.4
fodder	3	0.4
Fruits exc melons	1	0.2
Groundnuts, with shell	40	3.2
Maize	14	1.6
Millet	15	2.1
Nuts	2	0.1
Oilcrops	30	6.1
other cereal	16	1.3
Potatoes	3	0.3
Pulses	35	7.1
Rapeseed	35	7.1
Rice, paddy	13	1.2
root crop	3	0.3
Rubber, gums, waxes +	0	0.1
Sesame seed	33	6.7
Sorghum	15	2.4
Soybeans	35	4.9
spice	4	1.5
Sugar beet	2	0.3
Sugar cane	2	0.3
Sunflower seed	34	5.5
Sweet potatoes	3	0.3
Tobacco +	3	0.3
Vegetables inc melons	2	0.3
Wheat	19	4.1

The microbial nitrogen fixation was taken at 5 kg/ha of arable land while symbiotic fixation was calculated apart for fixing leguminous crops and clover. Atmospheric nitrogen wet and dry were taken from EMEP at national level and reduced according to the ratio of the arable land and the total country area.

The results for nitrogen are presented in Figure 14 for all countries included in the study area. A reference line corresponding to year 1991 was drawn to illustrate the starting date of implementation of the Nitrates Directive. A second reference line was added in 2002 to indicate the deadline of implementation of a maximum application of manure N at 170kg N/ha.

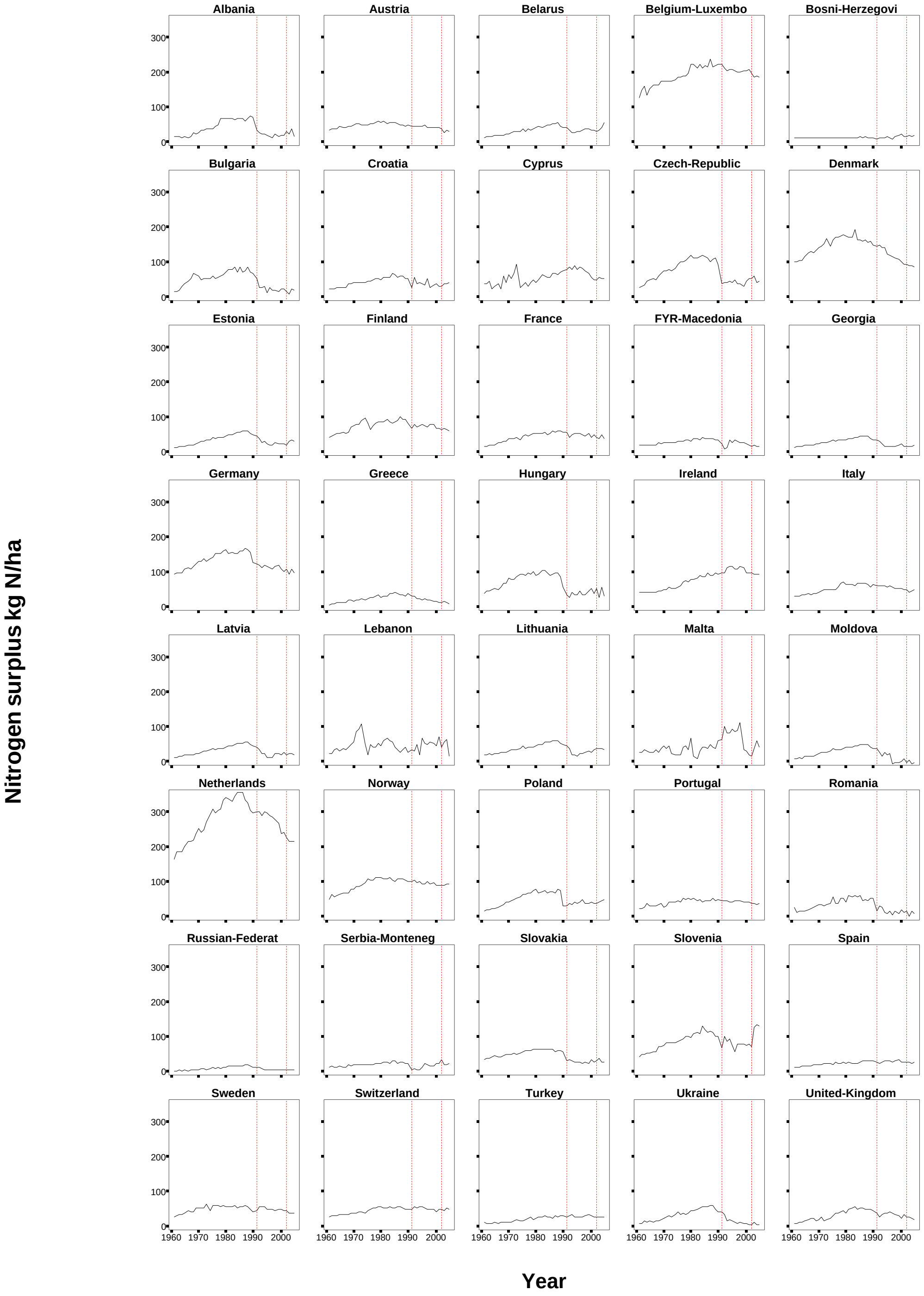


Figure 14. National nitrogen balance for the period 1960 – 2005.

It is interesting to note that in several EU 15 countries there is a significant decrease of nitrogen surplus prior to the implementation of the Nitrates Directive. Several reasons might explain this decrease including: (1) the reform to limit milk production and control production surplus in the 1980's in order to accommodate the new Members joining the EU, (2) the introduction of set aside, (3) the increase of nitrogen use efficiency due to better management practices and better selection of crop variety used, (5) the rise of the price of fertilizers, (6) the increase use of fixing crop (Eckhout, 2006). Only Spain and Ireland show a different trend with a continuous increase for Spain and a slight decrease for Ireland only from 2000. The introduction of the Nitrates Directive accelerated the decrease of N surplus such as for Denmark (Kyllingsbæk and Hansen, 2009). With the introduction of limit of application of 170 kg manure nitrogen per hectare in 2002, several countries have seen a sharper drop in the nitrogen surplus, including Austria, Belgium, and Sweden (Figure 14).

The phosphorus balance is shown in Figure 15. The decrease in the P surplus started much earlier and was not based on environmental regulation (for instance in Denmark, see Kyllingsbæk and Hansen, 2009). This decrease is largely due to the fact that P was no longer a limiting factor to optimum crop yield, while this stage was reached later for nitrogen. It is important to stress that the reduction in phosphorus is not due to the implementation of environmental regulation as in Europe only a limited number of countries have legislation limiting the amount of applied P, including The Netherlands, Ireland, Norway and Sweden (for more details see De Clerq et al., 2001).

The spatialised nitrogen balances using the database developed in this project for the period 1985 to 2005 are shown in Figure 16 and Figure 17.

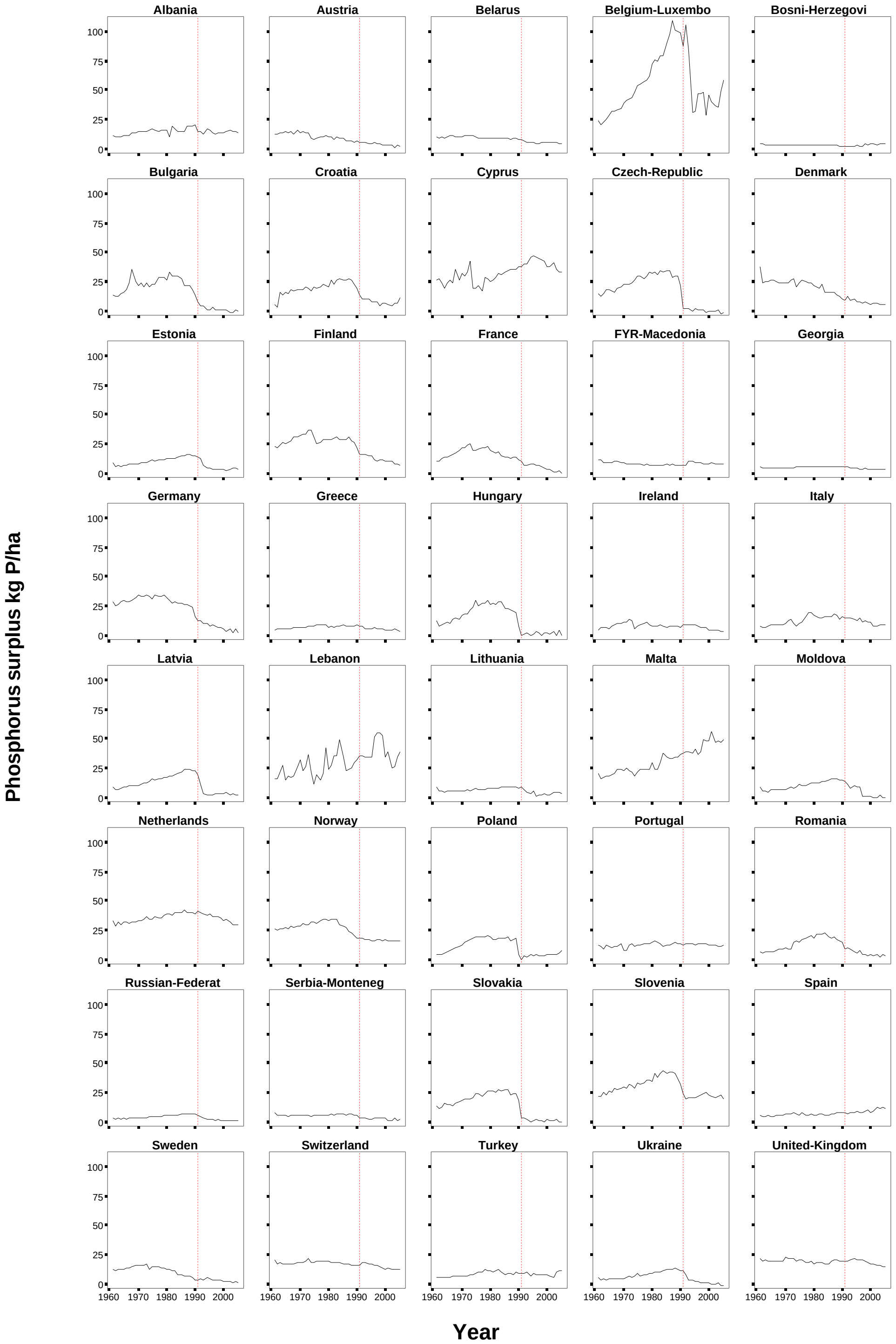


Figure 15. National phosphorus balance for the period 1960 – 2005.

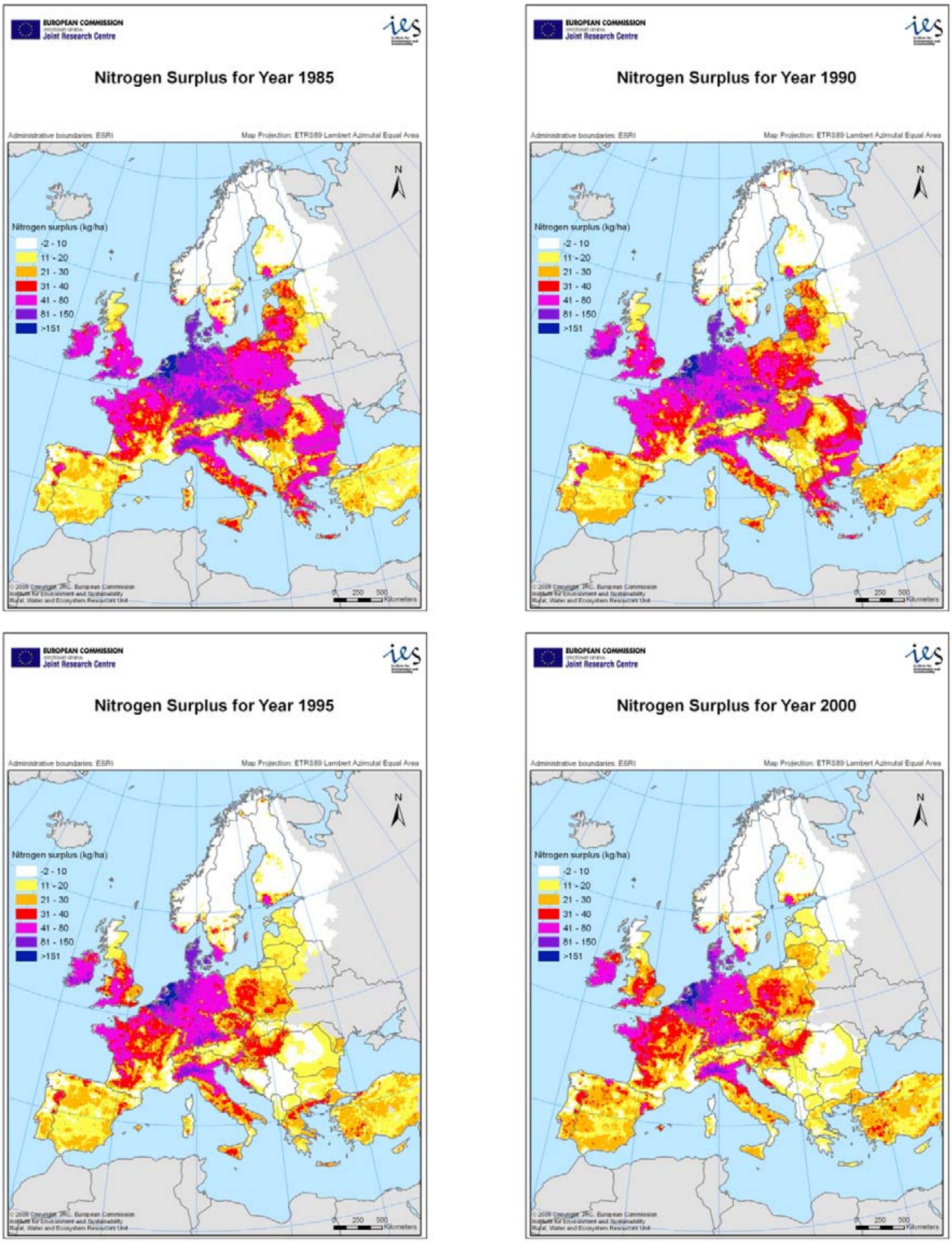


Figure 16. Map of nitrogen surplus (kg N/ha of total area) per sub-basin for the period 1985-2000

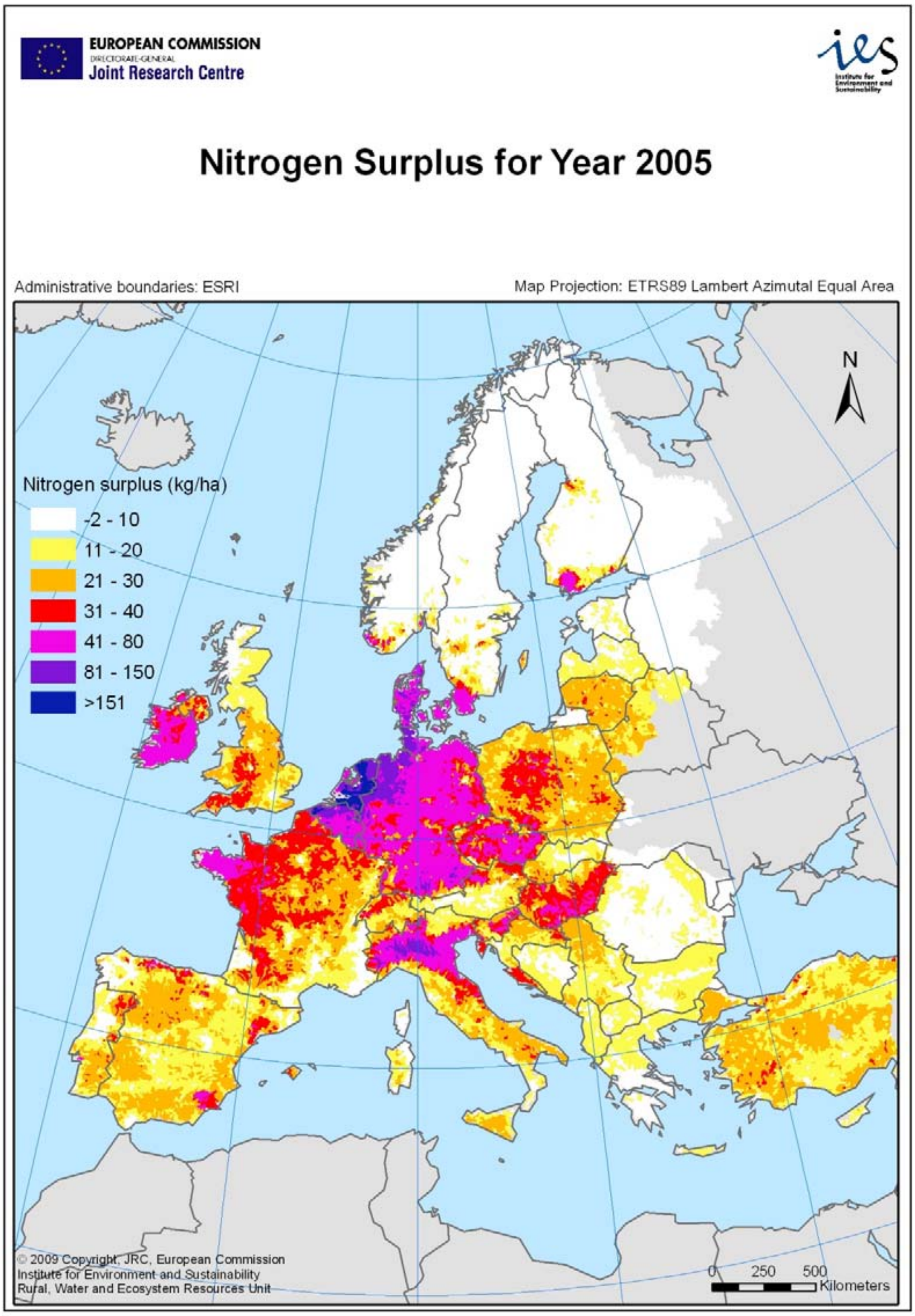


Figure 17. Map of nitrogen surplus (kg N/ha of total area) per sub-basin for the year 2005

5. Analysis of long term water quality in Europe

Changes in N balances are expected to produce impacts on water quality. In this study we investigated the relation between the decrease of N surplus observed in parts of Europe and the time evolution of water quality over large river basins for the past two decades. Two trend analysis were performed, one on measured nutrient concentration at the river basin outlets, the other one on the nutrient entering the system via point sources and fertilizer application.

5.1 Trend analysis of water quality and nutrient inputs

The trend analyses were conducted using the non-parametric test of Mann-Kendall (Hirsh et al., 1991). This test does not make any assumption regarding the data distribution and deals with incomplete, seasonal data with serial dependence, and any type of trend (linear and non-linear). The first step of the test is to determine the sign of the n(n-1)/2 differences between the pairs (x_j;x_k) with j>k and to compute the Mann-Kendall S with the following convention:

$$S=\sum_{k=1}^{n-1}\sum_{j=k+1}^{n}s(x_j-x_k) \text{ where } \quad \begin{cases} s(x_j-x_k)=1 & if\, x_j-x_k>0; \\ s(x_j-x_k)=0 & if\, x_j-x_k=0; \\ s(x_j-x_k)=-1 & if\, x_j-x_k<0. \end{cases} \qquad 7$$

where $x_1,...,x_n$ are the climate variables ordered in a chronological way, and n is the number of points to be analyzed. For large data sets (n>40), the Z test statistics is then computed as follows:

$$\begin{aligned} Z &= \frac{S-1}{VAR(S)^{0.5}} \quad if \quad S>0; \\ Z &= 0 \quad if \quad S=0; \\ Z &= \frac{S+1}{VAR(S)^{0.5}} \quad if \quad S<0. \end{aligned} \qquad 8$$

where VAR(S) is the variance of S. If the null hypothesis of no trend (H_0) is true, Z follows a standard normal distribution. The Mann-Kendall test was modified by Hirsh et al. (1982) to perform a trend analysis in presence of seasonality. For seasonal data sets, the value of S and its variance are determined for each season (week, month, etc.) respectively. The global value for S is obtained by summing all seasonal S, while the global variance is obtained by summing all seasonal variances plus the covariance terms. The trend is then tested using the Z test statistics described. Additional details about the test can be found in Hirsh et al. (1982) and Gilbert (1987).

For the trend analysis of nutrient concentrations at the basins outlets, data was retrieved from OECD (2008) as it was assumed that the data quality was thoroughly checked and had a wide spatial coverage. From the original 77 stations available from OECD, only the ones corresponding to a watershed outlet to the sea were kept, resulting in 39 stations with annual measurements of NO3 and NH4 concentrations. Data for dissolved inorganic nitrogen (DIN) concentration for the Baltic area from HELCOM (2009) were also used, resulting in an additional 50 stations. Concentrations of DIN for the Danube were taken from the updated Transboundary Diagnostic Analysis (ICDPR, 2009). In total, 90 stations were available for DIN and total phosphorus, and 39 stations (OECD stations) for nitrate and ammonium.

The time series of NO3, NH4, and total phosphorus concentrations are shown in Figure 18, Figure 19, and Figure 20, respectively. The calculated trends for NO3, NH4, dissolved inorganic nitrogen (calculated as the sum of NO3 and NH4 for the OECD countries), and total phosphorus concentrations are shown in Figure 21. The analysis shows that the nitrate concentration is decreasing only in a limited number of catchments. Out of the 39 basins analyzed, 23% exhibit decreasing trend while 21% have an increasing trend (0.99 level of significance). For ammonium 56% of the basins have a decreasing trend and only 5% an increasing trend. These results indicate that ammonium, which is mostly linked to point sources, is decreasing while nitrates, originating mostly from diffuse sources, do not decrease with time. This highlights that the policies to reduce point source emissions of nutrients have been more successful in the short-medium term than those dealing with diffuse sources of nutrients.

When performing the trend analysis for dissolved inorganic nitrogen for the 90 monitoring stations described previously, 30% of the stations exhibit a decreasing trend and 22% an increasing trend. Nitrate seem to be dominant in many of the streams and the lack of trend in nitrate concentration impacts negatively the dissolved inorganic nitrogen concentration, which exhibit lower decreasing trend than that of ammonium when analyzed singularly. Concerning total phosphorus, a decreasing trend is detected for about 48% of the OECD stations and 51% of the whole dataset. Again, this seems to indicate that the contribution of point sources of nutrient loads tends to decrease with time in a significant way, while this is not the case for diffuse sources, where the response to implementation of the Nitrates Directive in the short term may not be significant due to the various retardation processes and storage of nitrates in soils and aquifers.

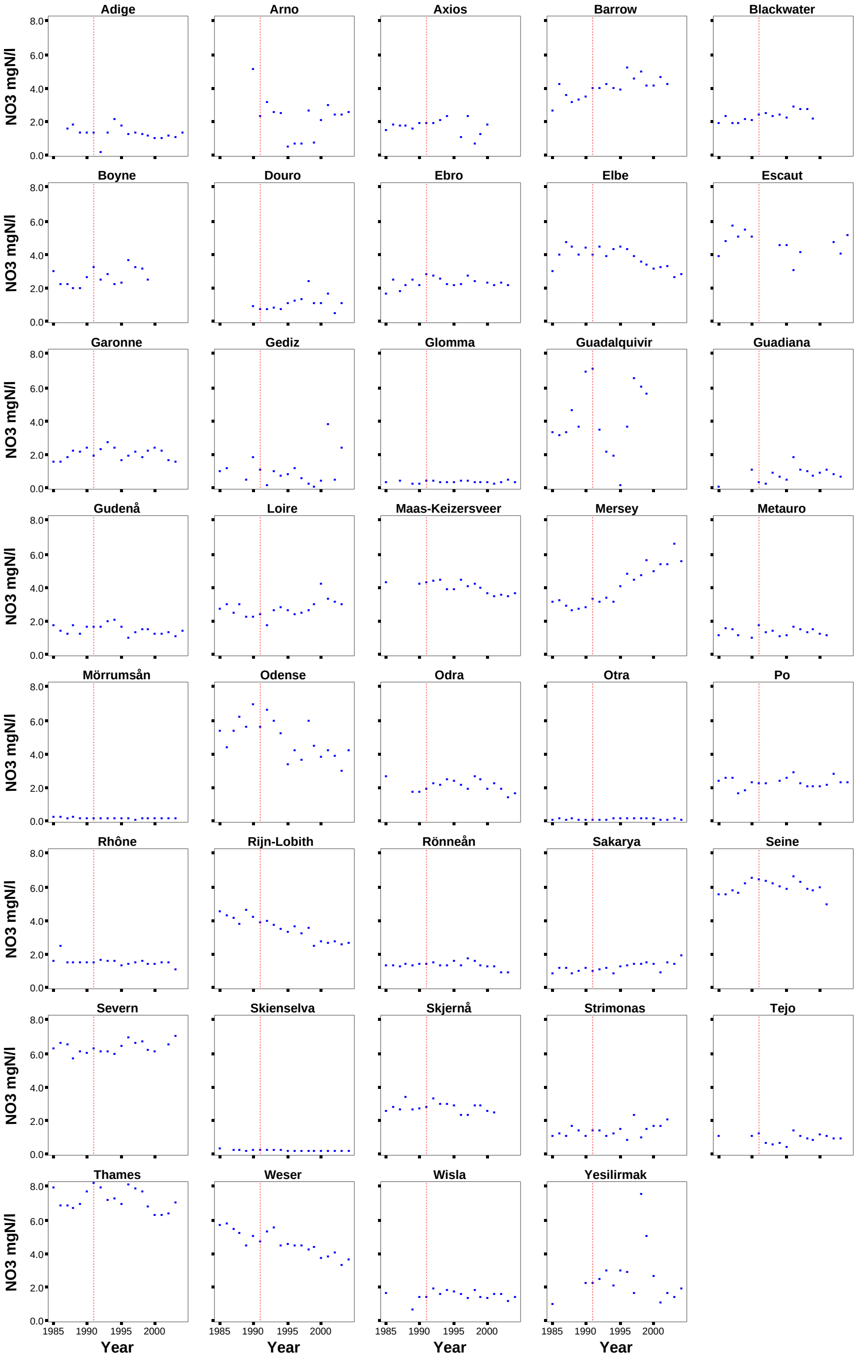


Figure 18. Nitrate concentration reported by OECD for the period 1985-2004.

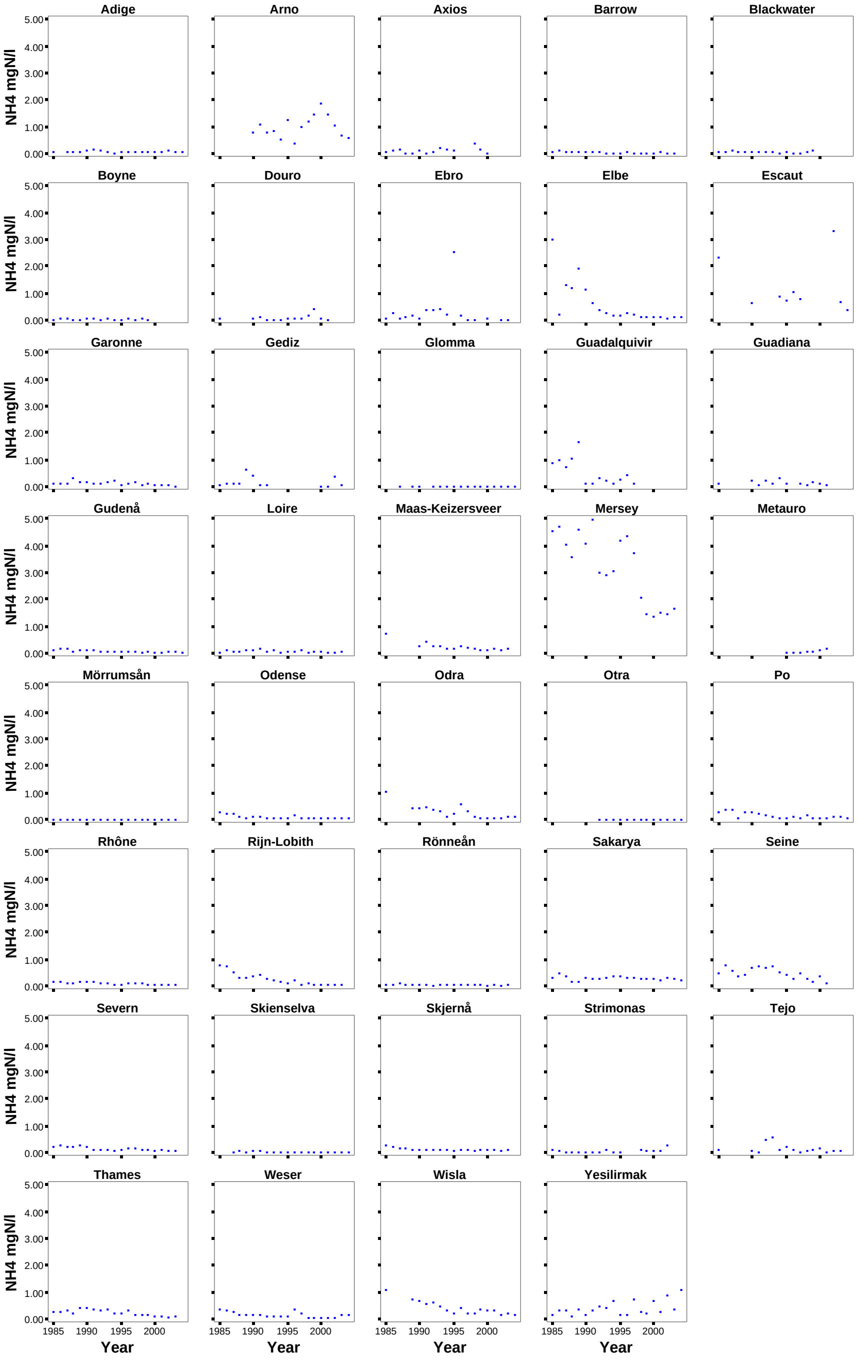


Figure 19. Ammonium concentration reported by OECD for the period 1985-2004.

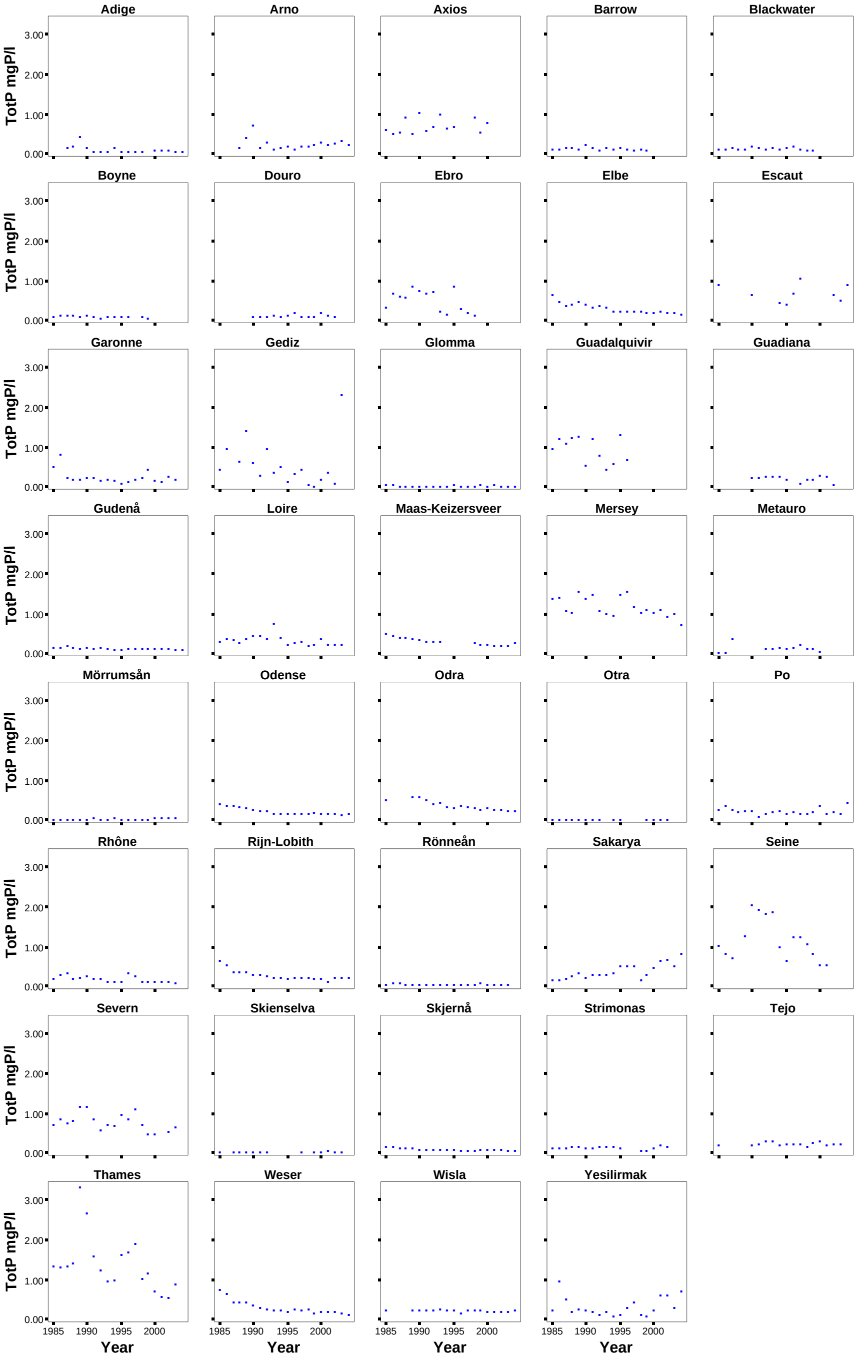


Figure 20. Total P concentration reported by OECD for the period 1985-2004 (for UK rivers data refers to orthophosphate).

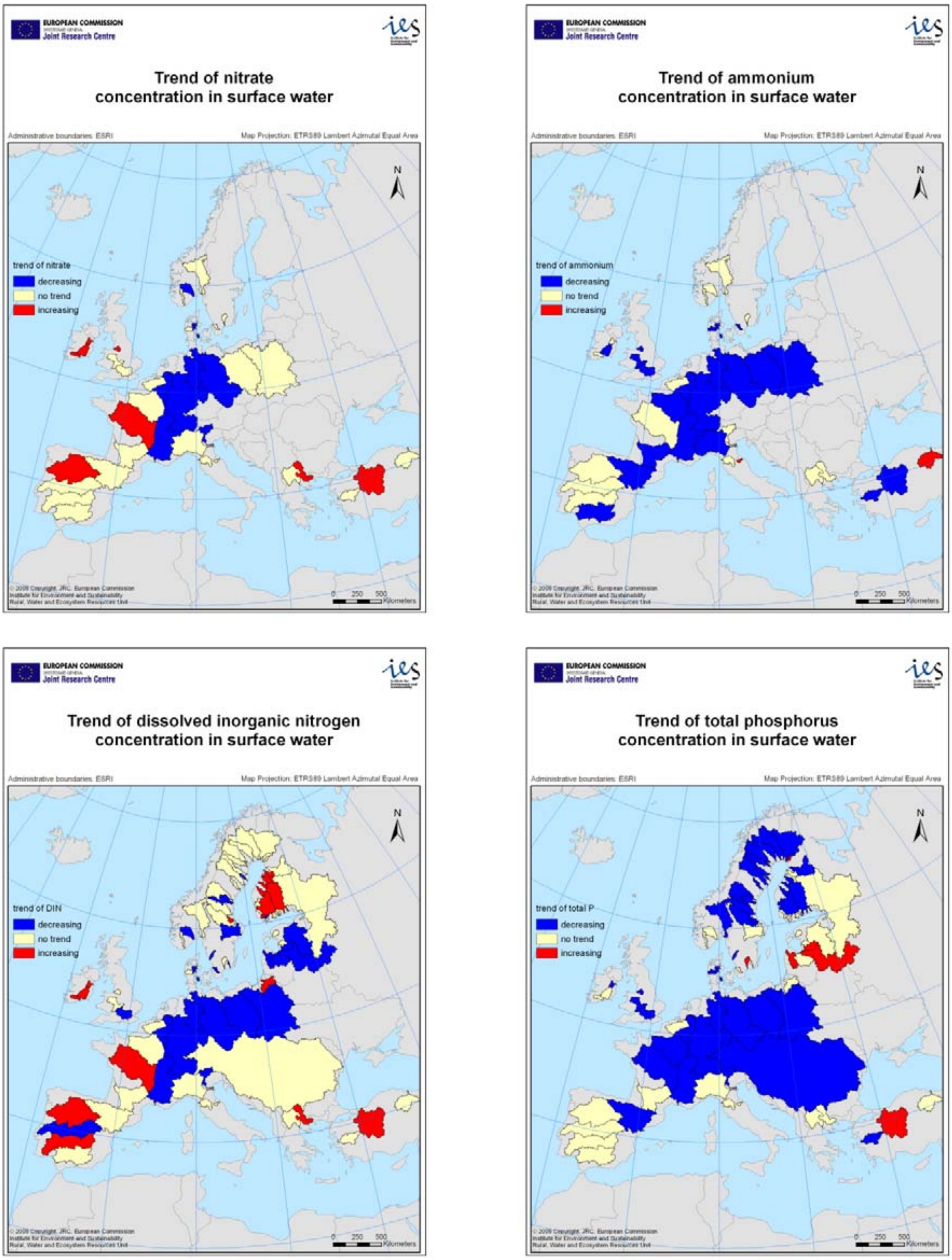


Figure 21. Trend analysis for NO3, NH4, DIN, and total P concentrations at the river basin outlet for the period 1985-2004.

A second trend analysis was performed on a basin level to understand whether the quantity of nutrients entering via point or diffuse sources the European waters have significantly decreased and to understand if possible trends are correlated to water quality. All nutrient sources available at the sub-basin level (about 33,000 sub-basins) were summarized at the river basin level (about 2,200 river basins). First a trend was determined for the period 1985-2005 for both point source and of fertilizer application for nitrogen and phosphorus. In addition, the difference of the amount of nutrient input in 2005 and 1990 was calculated. This latest approach provides a snapshot of an increase, decrease, or no change between two fixed periods, but does not give an indication on the presence or not of a trend. In fact, a significant trend indicates the persistence in a certain direction of change, while the difference just expresses the change between two periods.

The results for nitrogen are shown in Figure 22. Between 1985 and 2005 the significant trend of fertilizer application are rather limited to few basins, while an increasing trend can be noticed for the whole of Spain. Similarly the trend of nitrogen emission through point sources is not covering the whole Europe indicating that in many places the implementation of waste water treatment plants took place after 1990: so there was an increase of point emission until 1990 and then a decrease. This is clearly shown in the figures about the changes of nitrogen from point sources between 2005 and 1990, where a decrease is characterizing most of Europe (but Spain, UK, Greece and Turkey). The results for UK should be taken with care as only one yearly value was used for the connection of population to waste water treatment plants and the level of treatment as no other value was reported or could be found in the literature. So in the case of UK, the increase in point emission of nitrogen might simply be linked to an increase in population. A decrease of nitrogen fertilizer application between 2005 and 1990 is characterizing large parts of Europe but Spain, parts of France and the Po valley in Italy. In conclusion the significant trends of input through fertilizer application or point source emission are rather limited in Europe for the period 1985-2005. When using the difference between 2005 and 1990, there is a large portion of Europe where point source emissions of nitrogen and fertilizer application are decreasing. This decrease in point source emission had an immediate effect of nitrogen concentration in many parts of Europe (as seen previously by a decrease in ammonium concentrations).

The results of trend analysis for phosphorus inputs are shown in Figure 23. Decreasing trend of phosphorus fertilizer application extends over large parts of Europe but for Spain. The maps of trends and change are rather similar indicating that there has been a continuing decrease of P application since 1985. Concerning point source emissions of P, a large part of Europe is characterized by a significant decreasing trend of emission. Between years 1990 and 2005 most of Europe has seen a decrease in emission of phosphorus but for Spain where there is an increase in the emission. In the case of phosphorus, these changes in inputs had a significant impact on water quality. Indeed, many streams in Europe have seen a decrease in the concentration of phosphorus.

To further analyze the impact of these changes on water quality, and the contribution of various sectors of activities to the nutrient loads to European Seas, the model GREEN was applied for the time period 1985-2005

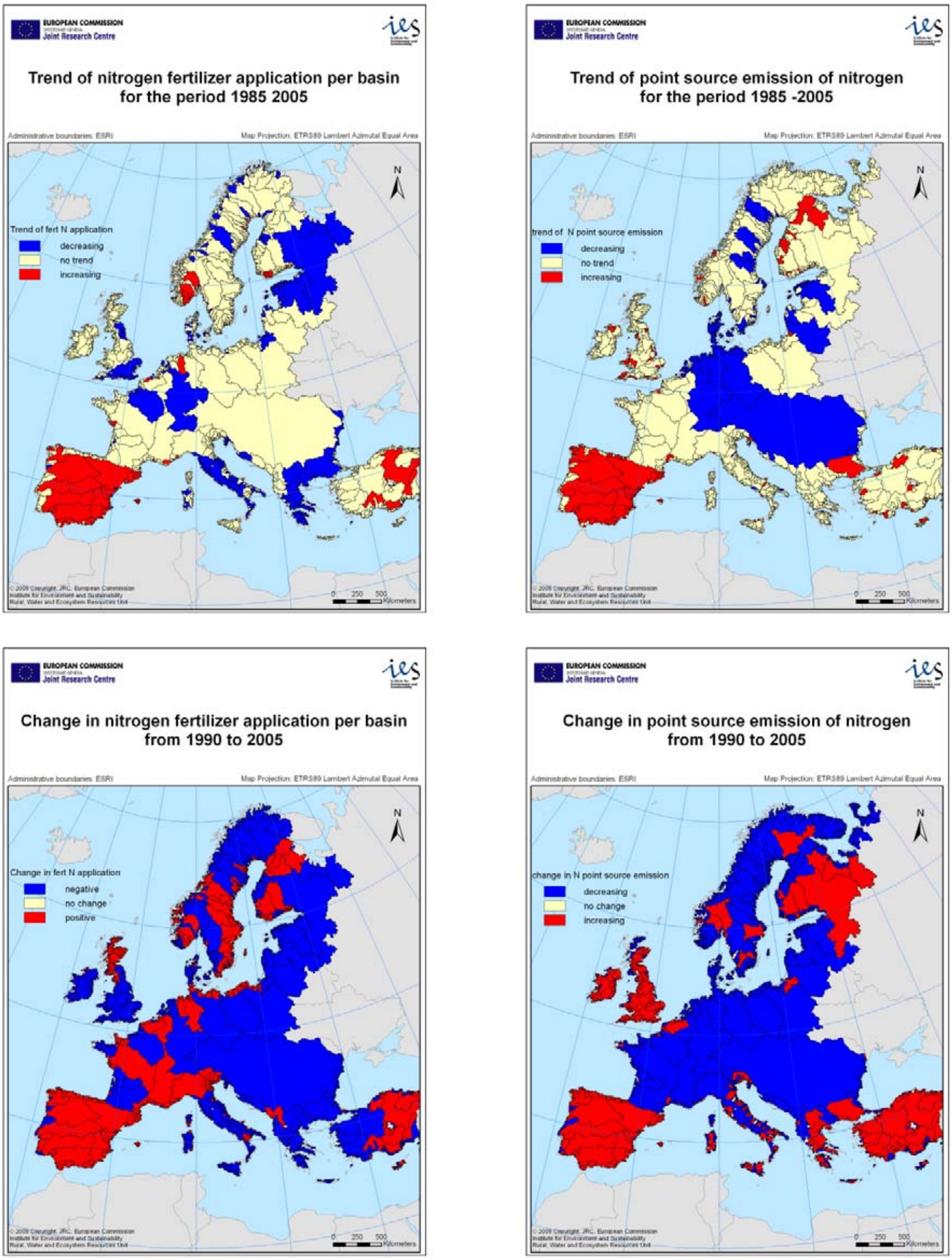


Figure 22. Trend analysis for nitrogen fertilizer application and point source emission of nitrogen for the period 1985-2005, and change of nitrogen application and point source emission between years 2005 and 1990.

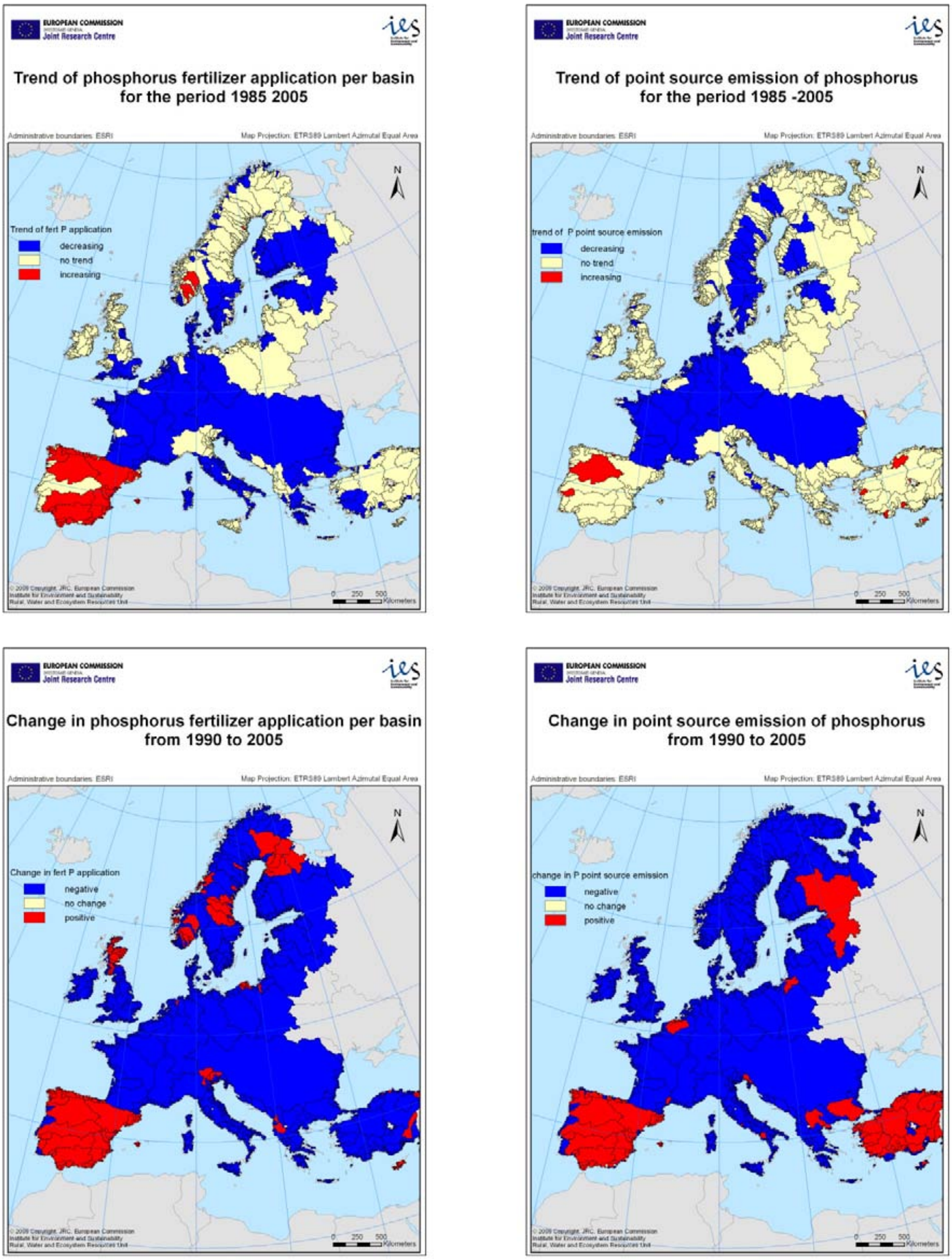


Figure 23. Trend analysis for phosphorus fertilizer application and point source emission of phosphorus for the period 1985-2005, and change of phosphorus application and point source emission between years 2005 and 1990.

5.2 Predictions of nutrient loads

The model GREEN described in details in Grizzetti et al. (2008) and summarized in Section 2 was used to calculate the load of total nitrogen and total phosphorus for all the study area for the period 1985 to 2005. The model is used at the sub-basin level along a routing structure in order to provide nutrient fluxes and source apportionment on an annual basis anywhere in a river basin. The model was calibrated using all available monitoring data of total N and P loads for a total of more than 4500 points covering almost all Europe (Bouraoui et al., 2009). The results of model calibration for N and P are shown in Figure 24. The results are extremely satisfactory with an overall efficiency of 92% and 71% for nitrogen and phosphorus, respectively. There is not temporal bias in the estimation of the total nitrogen and total phosphorus loads and the efficiencies remain extremely high from one year to the other (see Figure 25 and Figure 26). For the nitrogen predictions, the yearly efficiency ranges from 76% to 97%. For phosphorus, it ranges between 50% and 87%. No significant systematic deviation could be detected for the whole simulation period. The model was thus assumed to be properly calibrated and suitable for performing source apportionment and calculating the diffuse emissions of nutrients.

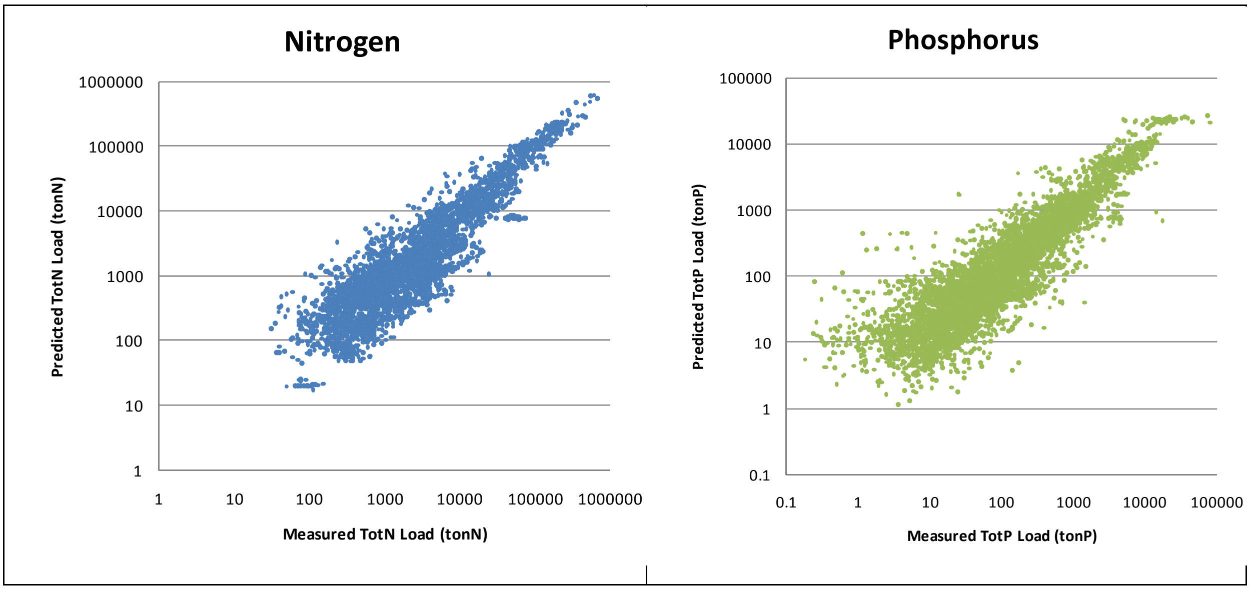


Figure 24. Measured and estimated total nitrogen and phosphorus loads for the period 1985-2005.

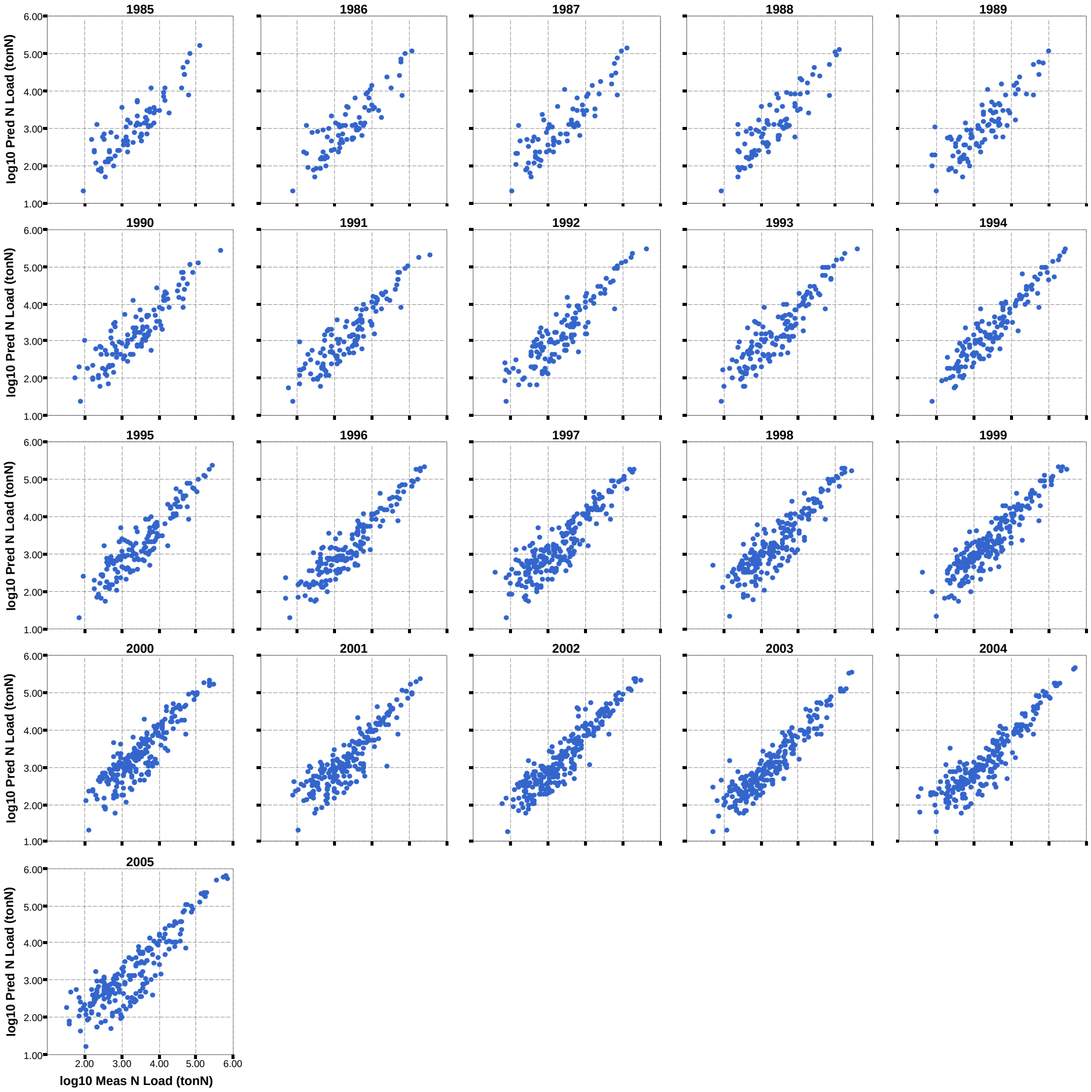


Figure 25. Measured and estimated total nitrogen loads for the period 1985-2005 on annual basis.

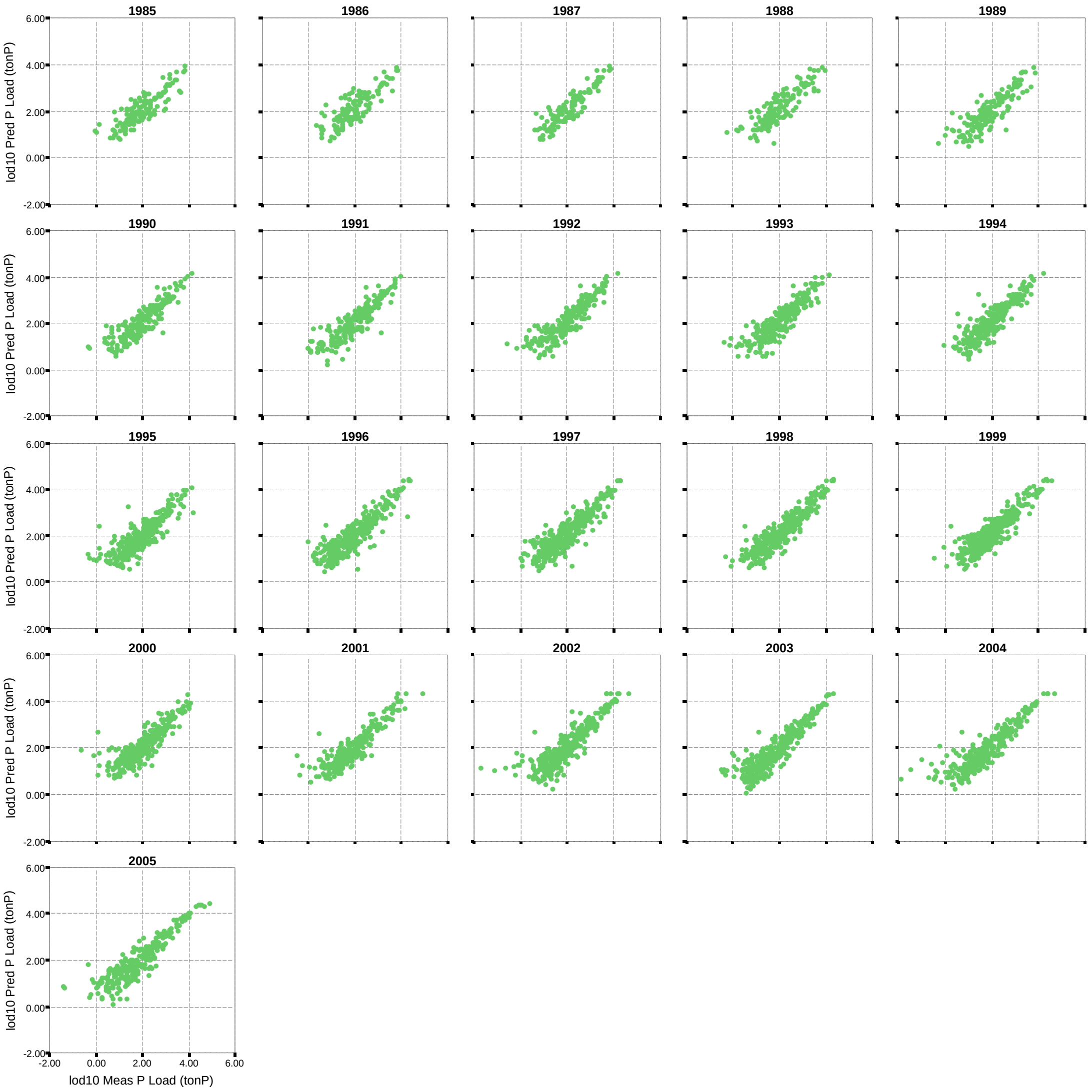


Figure 26. Measured and estimated total phosphorus loads for the period 1985-2005 on annual basis.

6. Nutrient loads into European Seas for the period 1985-2005

The calibrated model (Section 5) was used to estimate the load of nutrients entering the regional European Seas between 1985 and 2005 and to analyse the respective contribution of the different nutrient sources to the total export.

We estimated that between 1985 and 2005 the total nitrogen load entering the European seas varied between 3700 ktN/yr and 5300 ktN/yr with fluctuations following the water discharge (Figure 27). Agriculture represents the major source (1800-3100 ktN/yr), followed by point sources (920-1030 ktN/yr). The other contributions originate from atmospheric deposition, scattered dwellings and biological fixation (800-1200 ktN/yr). Similarly, we estimated that during the period 1985- 2005 the total phosphorus load into the European seas ranged between 215 kt P and 328 kt P (Figure 28), with point sources contributing the most (131-175 ktN/yr) and agriculture and background losses accounting for the rest.

Comparing the estimates for 2005 with those of 1991, at European continental scale the total nitrogen export has decreased by 9%, while the total phosphorus load has decreased by around 15%, mainly due to a decrease in point sources emission. The figures partially change when looking at the regional seas, showing the effectiveness of measures undertaken in the different regions. The annual estimates of nitrogen and phosphorus loads from 1985 to 2005 into the Atlantic Sea, Mediterranean Sea, North Sea, Baltic Sea and Black Sea are shown in Figure from Figure 29 to Figure 38. Apart for the North Sea and partially for the Baltic Sea, annual nutrient exports from land to the sea have not changes significantly in spite of the implementation of measures to reduce the nutrient sources. In the North Sea and in the Baltic Sea, the decrease of nutrient loads from the values of the ‘90ies is mainly related to the reduction of point sources due to the implementation of advanced waste water treatment. Similar results were found by Hartmann et al. (2007) for the Rhine River and by Radach and Parsch (2007), who analysed the annual nutrient loads into the North Sea from Belgium, the Netherlands and Germany for the period 1977-2000. Concerning nutrient loads from agriculture we observed that the export is strictly related to the water discharge fluctuation, as highlighted also by Grimvall et al. (2000) and Radach and Parsch (2007). This means that apparent decreases in nutrient load, such as in the Atlantic Sea during the recent years, are not determined by the effectiveness of measures, but rather related to lower precipitation and water discharge. This is confirmed also by the annual variation of N:P ratio, which has increased from 1985 to 2005 in the Atlantic Sea, Mediterranean Sea and North Sea, indicating an intensification of land use. Scientific evidences in agreement with our results were found by Artioli et al. (2008), who showed that the adopted policies to reduce anthropogenic nutrient inputs to European seas were more effective in abating point sources than diffuse sources and more successful for phosphorus rather than for nitrogen, leading to the increase of N:P ratio in anthropogenic inputs.

When analysing the nutrient pressures on water, both the temporal and spatial variation are important. Figure 39 Figure 46 show the estimated contribution of the different sources to the total nutrient load at river basin and sub-catchment level for the whole Europe from 1985 to 2005 and pressures of diffuse nutrient emission from agriculture on inner freshwater (Figure 47 to Figure 48).

Assessing policy effectiveness in reducing loads of nitrogen is controversial and presents regional differences. This is related to the diffuse nature of the sources, the tight connections with lifestyles, notably human diet, and the economic implications due to the links with agriculture and livestock production. Moreover, long-retention times of groundwater may retard the system recover (Artioli et al., 2009). In Denmark, the implementation of targeted regulations and nitrogen efficiency measures has reduced nitrogen load to water by 32%, while maintaining the crop yield and increasing the livestock production (Kronvang et al., 2008). In large part of England, the effect of actual measures on water quality is not evident and a time lag is expected because of the specific soils-aquifers characteristics (Jackson et al., 2008). In Finland, no clear reduction of nutrient loads or water quality improvements were observed although a large scale program to reduce nutrient emissions from agriculture has been introduced since 1995 (Ekholm et al., 2007). According to OSPAR (2008), in the areas under the OSPAR Convention, the nitrogen and phosphorus sources reduction of 50% (compared to the level of 1985) have been met for phosphorus, but not completely for nitrogen. In fact, the target for nitrogen source reduction was achieved only by Denmark (in 2003), Germany and the Netherlands (both in 2005), although progresses in this direction have been made also by the other Contracting Parties. The assessment report on the implementation of the Baltic Sea Action Plan, under the HELCOM Convention, indicates that since 1990 nitrogen and phosphorus diffuse and point source loads have been slightly decreasing in the Baltic Sea catchment, however the target input levels foreseen in the Action Plan have not been met and additional reductions are needed.

As much as the Urban Waste Water directive have been successful in resulting in a decrease of emission of nitrogen and phosphorus (EC, 2009), the effectiveness of implementation of controlling diffuse losses of nutrients have been far less evident (De Clercq e al., 2001). Even though the Nitrates Directive was successful in reducing emissions of nitrogen through limitations in application, achieving the environmental objective of the Nitrates Directive will still require years to decades due to the different transport mechanisms involved and the storage of nitrates in soils and aquifers, process which do not take place in the case of point sources which are released directly into rivers, lakes and coastal waters (EC, 2010).

Analysing data from France using a statistical stratification technique, the EEA (2007) concluded in a similar way that the UWWTD was very successful in achieving a very significant decrease in N and P emission from point sources, and in particular from urban areas, while the Nitrates Directive does not seem to have reached its objectives in France. Csatho and Radimsky (2009) recognized the effectiveness of the UWWTD in reducing nutrient loads to surface waters, however they formulated a very critical opinion on the implementation of the nitrate and suggested few mandatory improvements to be incorporated in order to improve the state of water quality in Europe. Among the improvement they strongly suggest to take into account the amount of applied nitrogen in form of manure in the recommendation of fertilizer application rates, and they underline that combined application of more than 200kg N/ha/yr cannot be agronomically justified and should be totally banned (Csathó and Radimszky, 2009). However, it must be noted that in specific cases such as intensive grassland, nitrogen uptake can exceed the 200 kg/ha mentioned by (Csathó and Radimszky, 2009).The Nitrates Directive limits the amount of applied manure nitrogen, however it leaves flexibility in the amount of applied mineral fertilizer leading to large difference level of implementation of the Directive, even in similar environmental conditions (De Clercq et 2001., Nimmo Smith et al., 2007). Similar conclusions are reported in Finland by Raike et al. (2003) when analyzing long term water quality monitoring data (1975-2000): efficient reduction of nutrient load due to improved waste water purification, no clear reduction of decreased nonpoint source loading could be detected. Granlund et al. (2005) Analyzing the implementation of the Finnish Agri-environmental Programme reported no significant reduction of nutrient loads despite huge investments, due again to the inertia of the soil-water system in responding to changes.

The results of the study presented have indicated that policies controlling point source emission of nutrients have been successful in reducing the inputs in Europe’s surface water. Despite a decrease of the amount of used fertilizer in Europe, no improvement could be detected over large areas in Europe. It seems that future drastic control over the total amount of applied nitrogen will be required to significantly improve surface water quality. It is important to stress that in EU reducing fertilizer application is possible without endangering agricultural production and farmers' income. For instance, the successful reversal of high nitrate concentration in Danish water is due in large part to the fact that Denmark implemented stricter measures than those required by the Nitrates Directive (Nimmo Smith et al., 2007). It is however, important to stress that reductions in point source emissions in the stream have immediate effects, while reduction in fertilizer application might take years to decades before its impacts are seen (AlvarezCobelas et al., 2008). However, it is important to invest in both for long term sustainability.

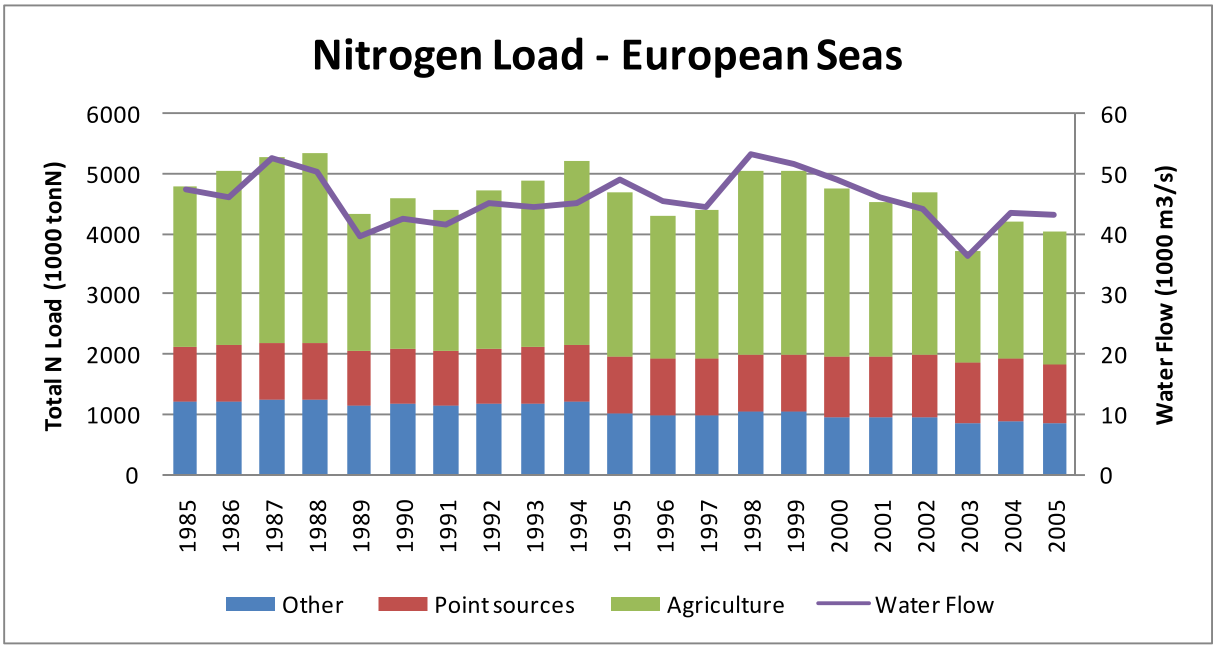


Figure 27. Estimated annual total nitrogen load per source and annual water discharge entering European Seas.

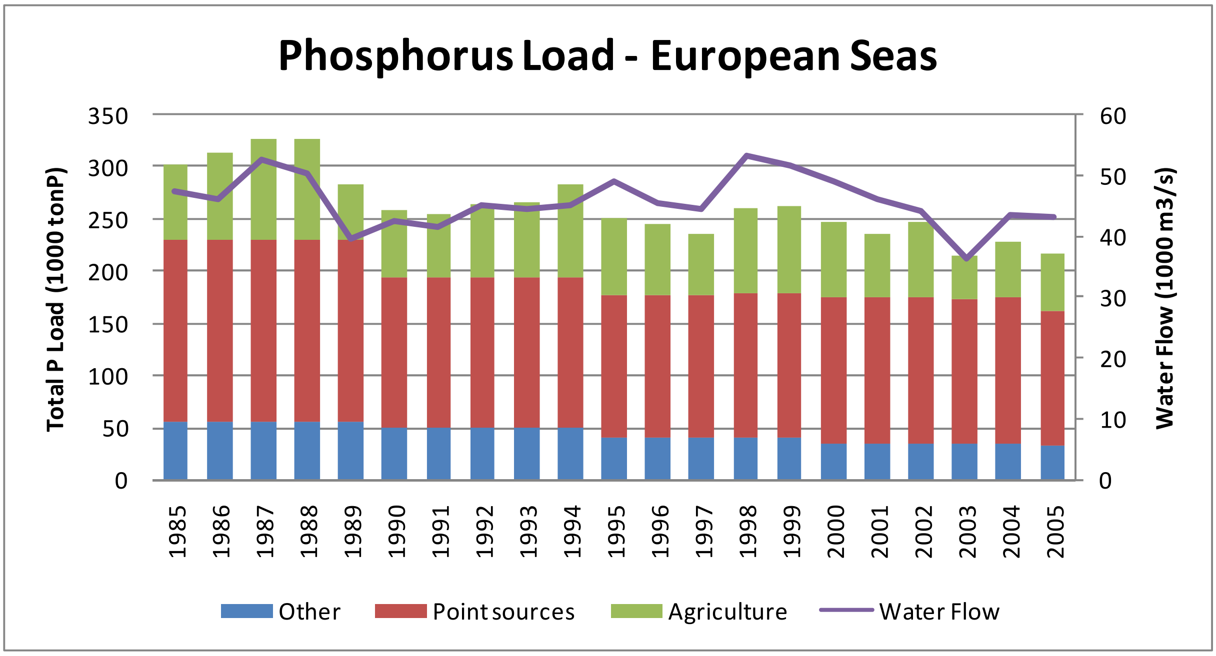


Figure 28. Estimated annual total phosphorus load per source and annual water discharge entering European Seas.

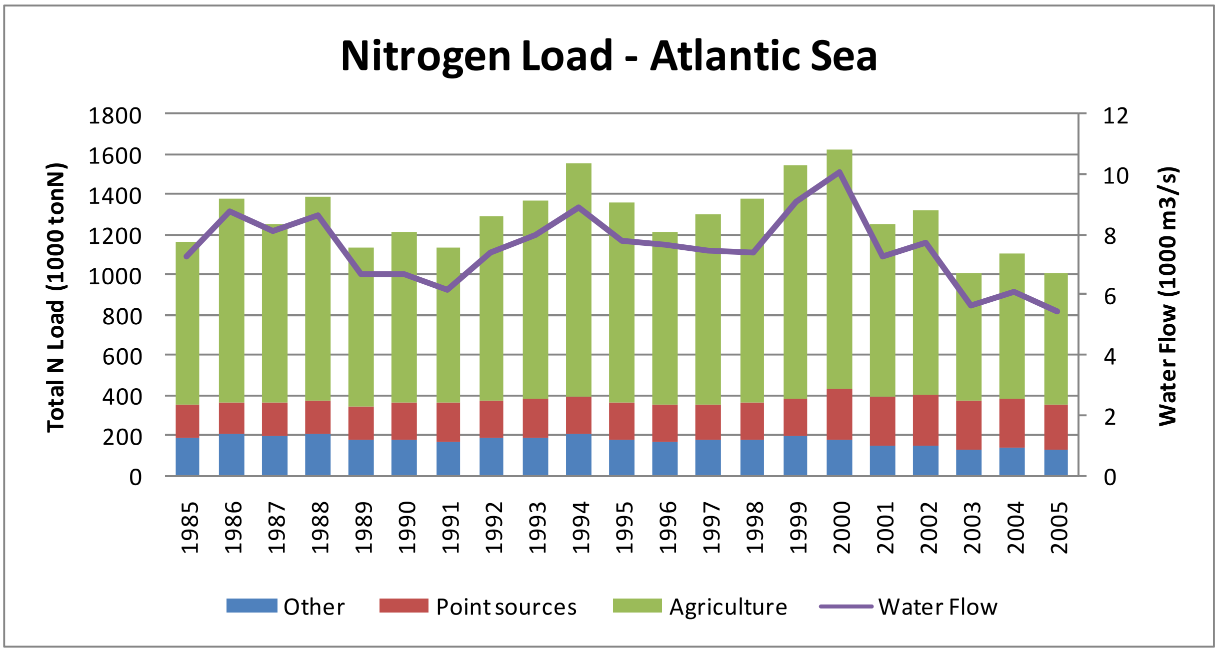


Figure 29. Estimated annual total nitrogen load per source and annual water discharge entering the Atlantic Sea.

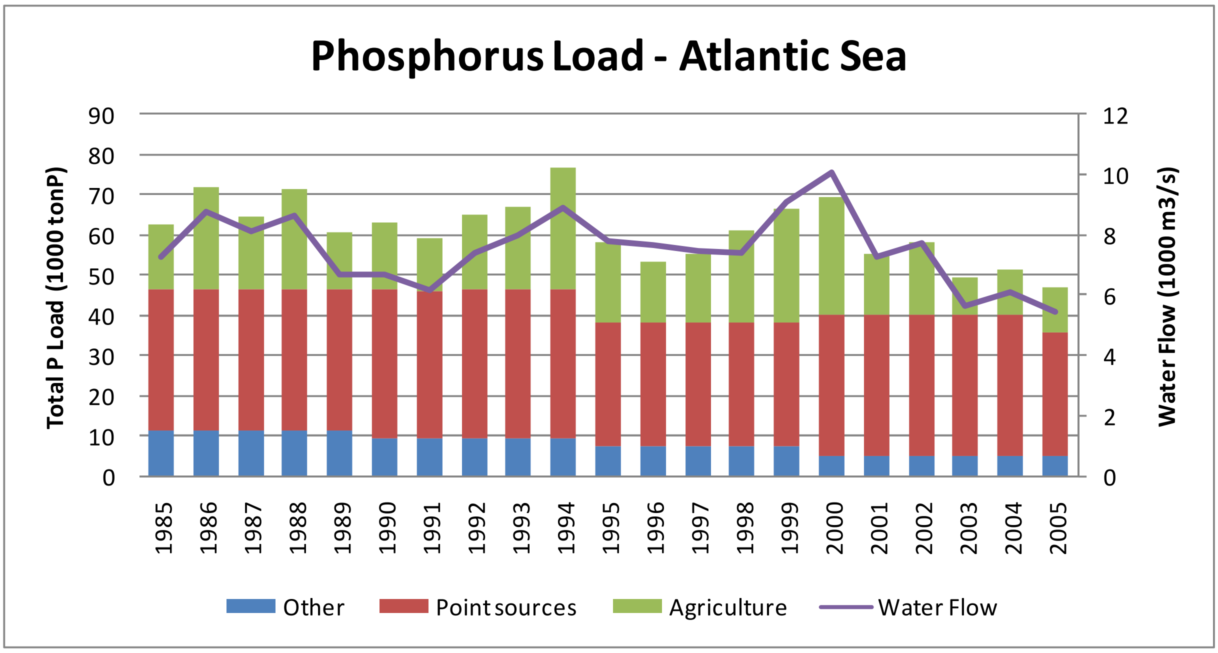


Figure 30. Estimated annual total phosphorus load per source and annual water discharge entering the Atlantic Sea.

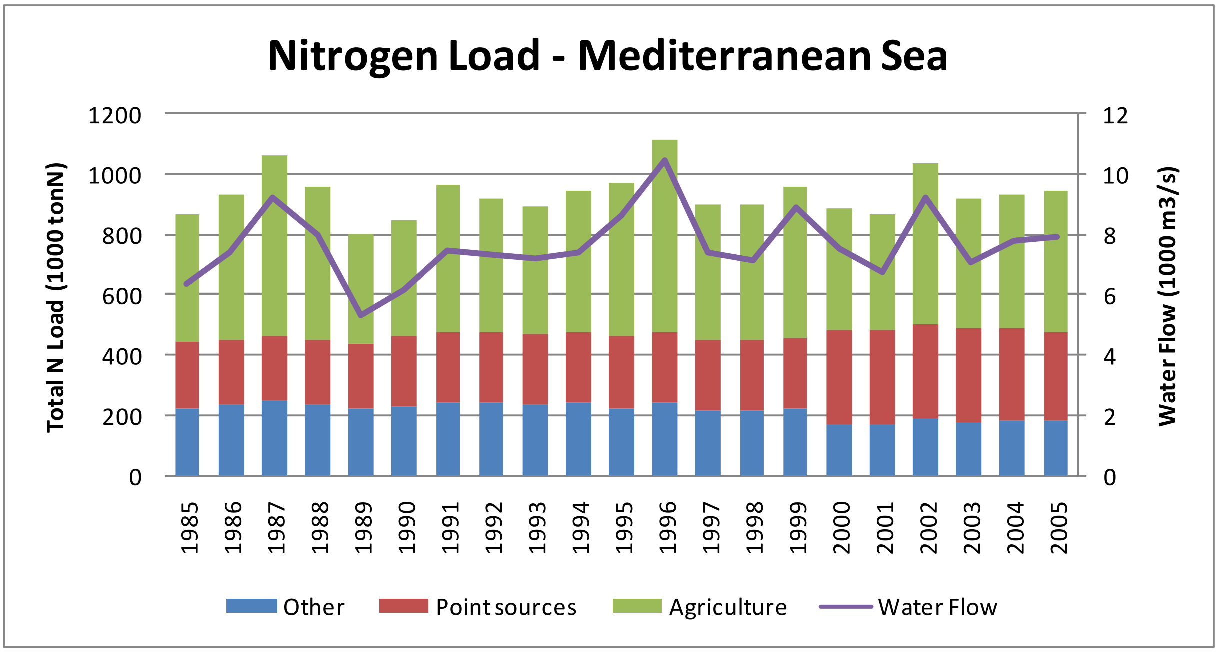


Figure 31. Estimated annual total nitrogen load per source and annual water discharge entering the Mediterranean Sea.

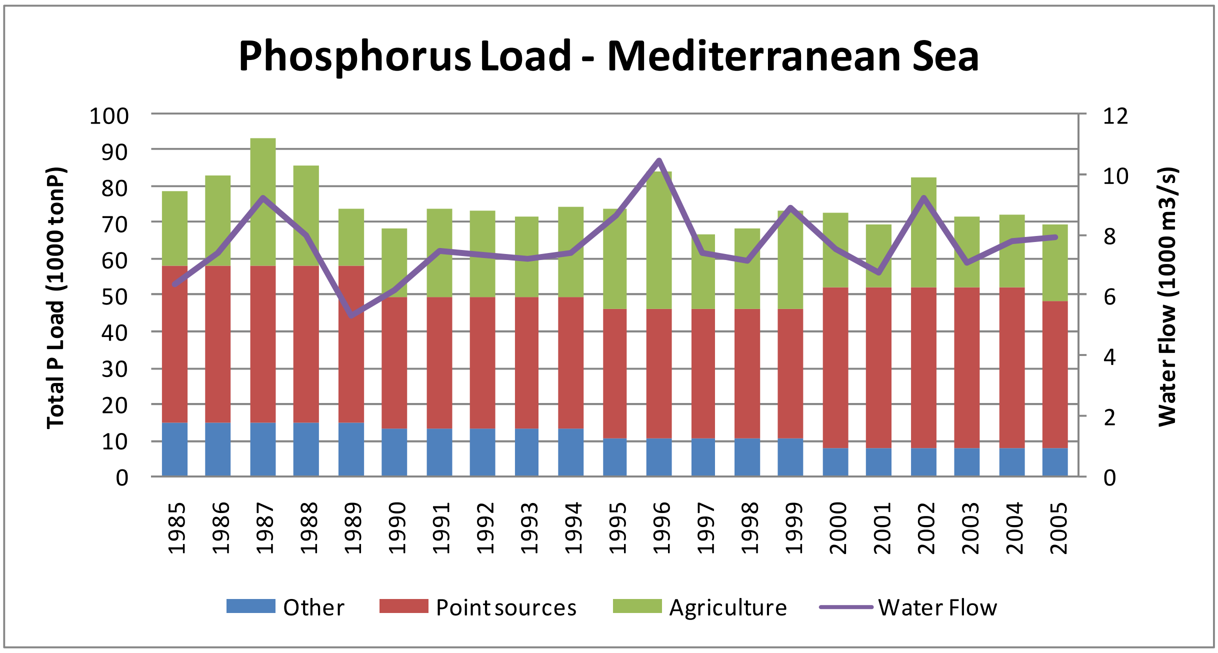


Figure 32. Estimated annual total phosphorus load per source and annual water discharge entering the Mediterranean Sea.

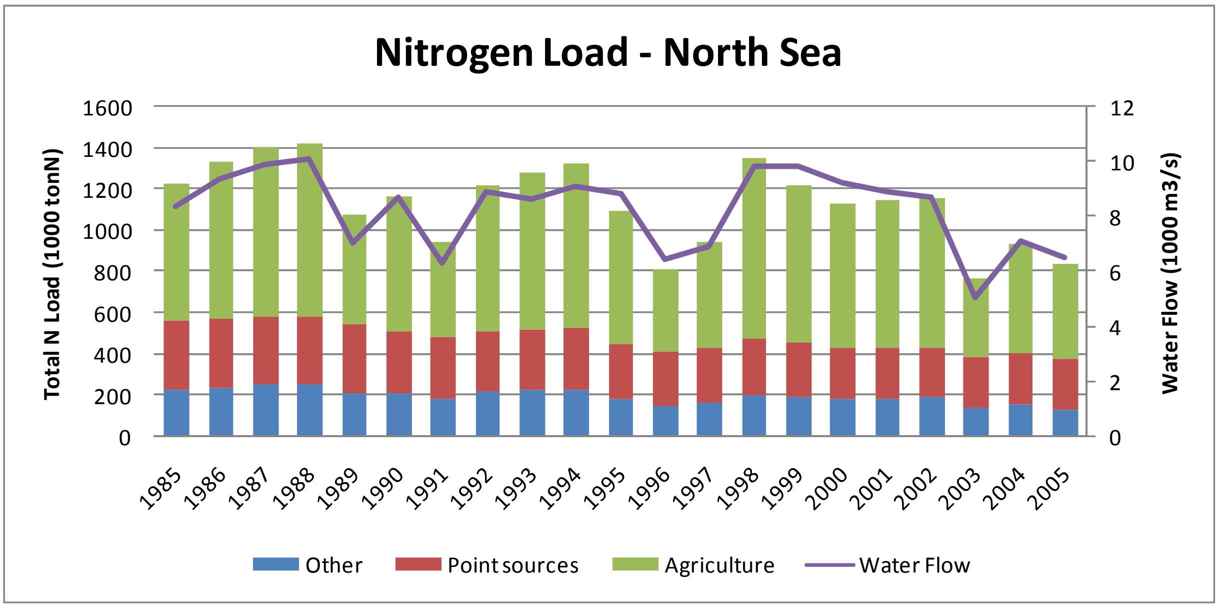


Figure 33. Estimated annual total nitrogen load per source and annual water discharge entering the North Sea.

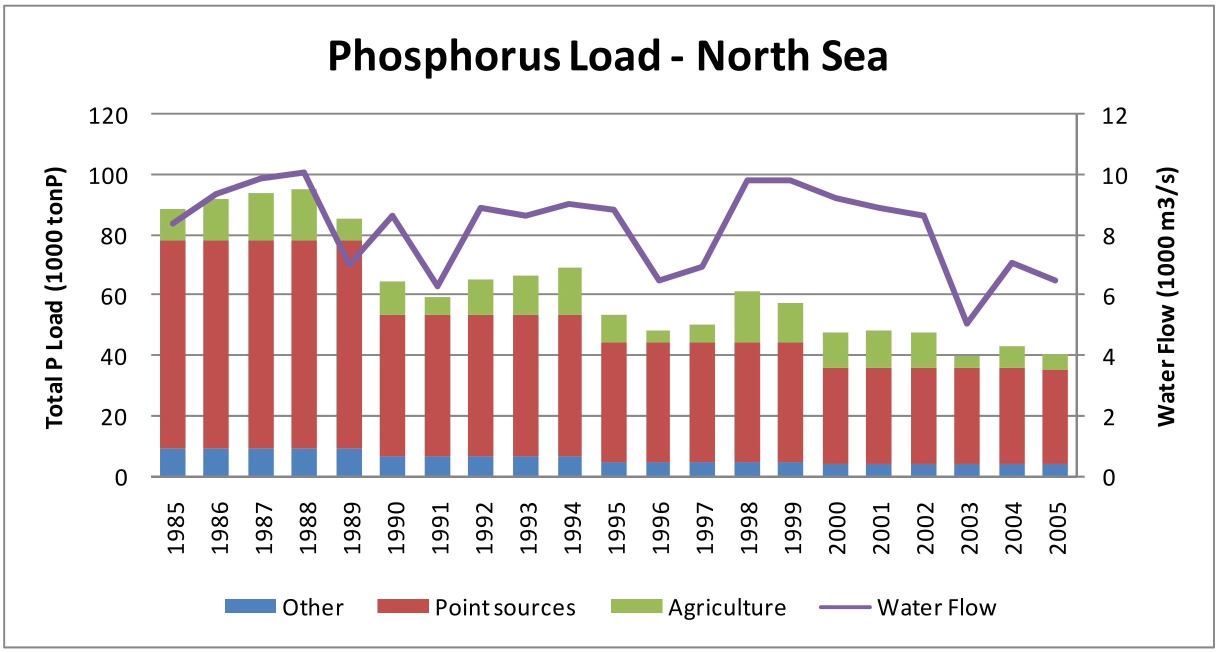


Figure 34. Estimated annual total phosphorus load per source and annual water discharge entering the North Sea.

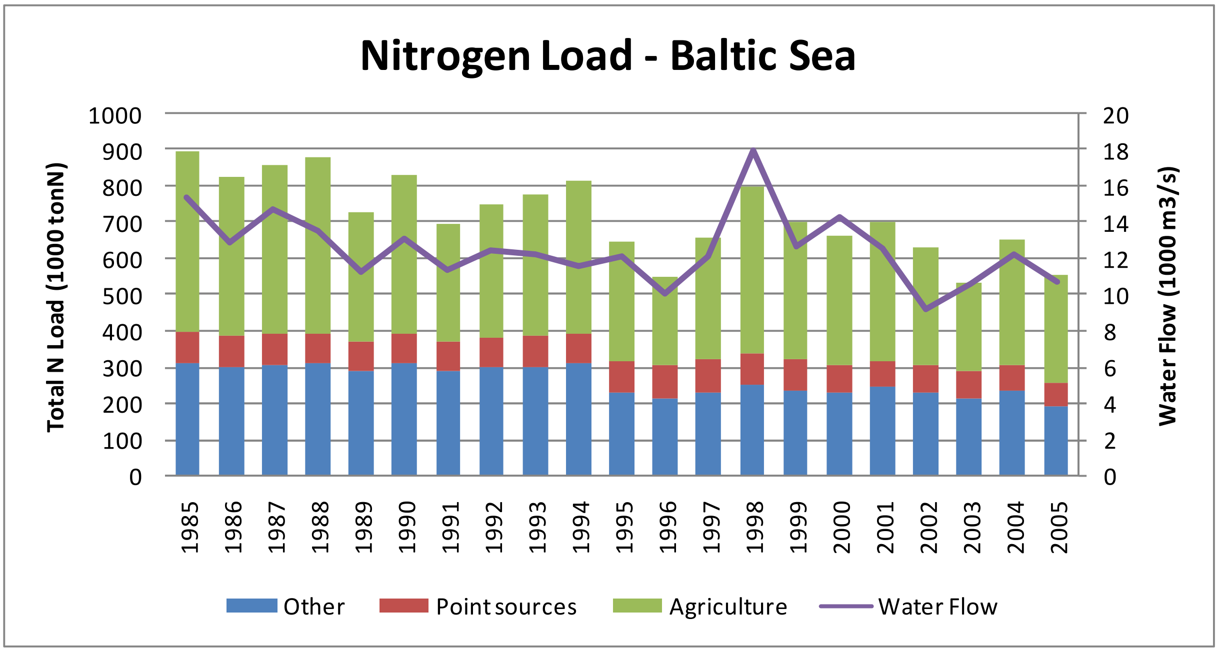


Figure 35. Estimated annual total nitrogen load per source and annual water discharge entering the Baltic Sea.

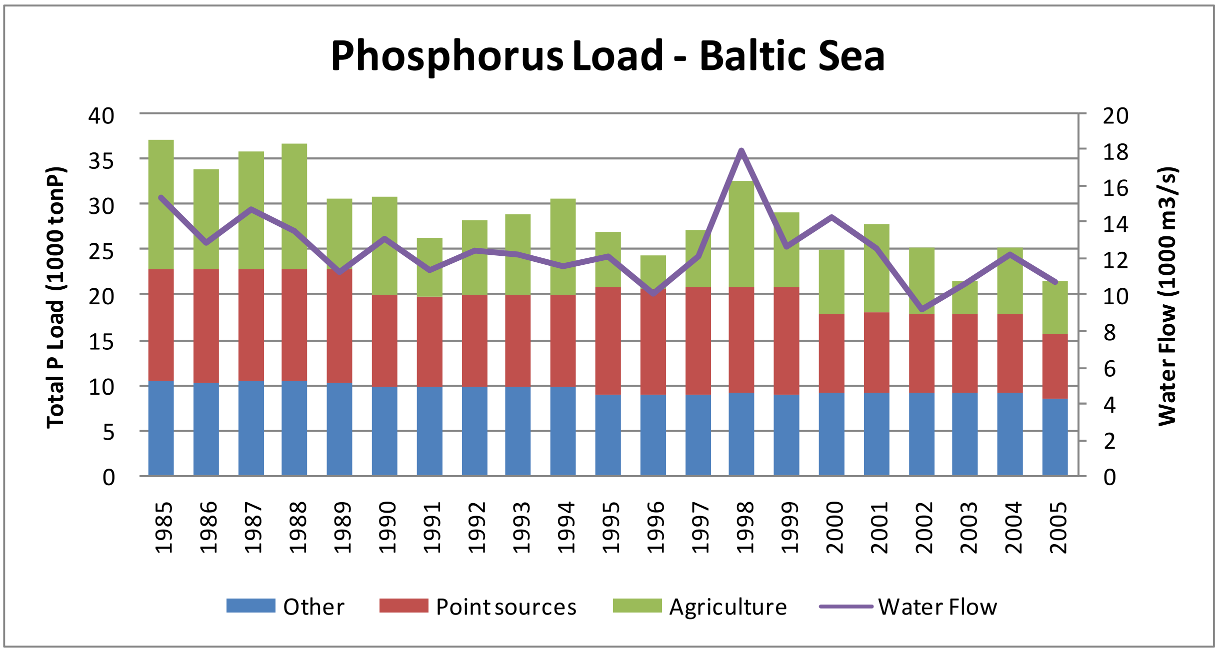


Figure 36. Estimated annual total phosphorus load per source and annual water discharge entering the Baltic Sea.

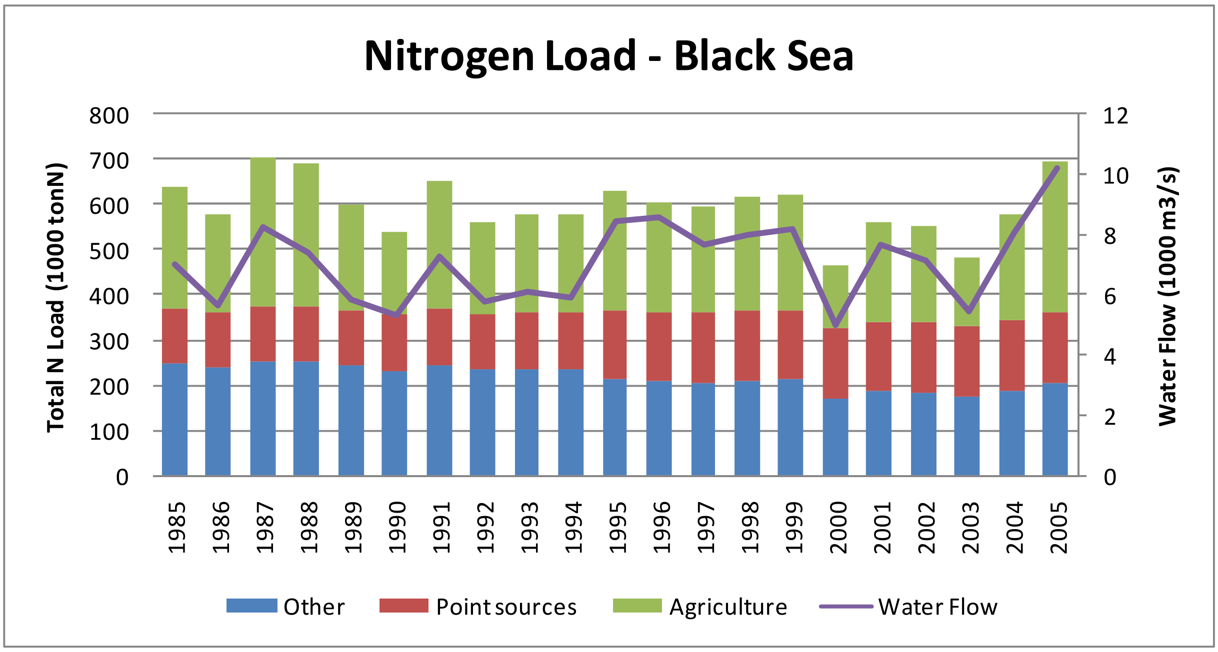


Figure 37. Estimated annual total nitrogen load per source and annual water discharge entering the Black Sea.

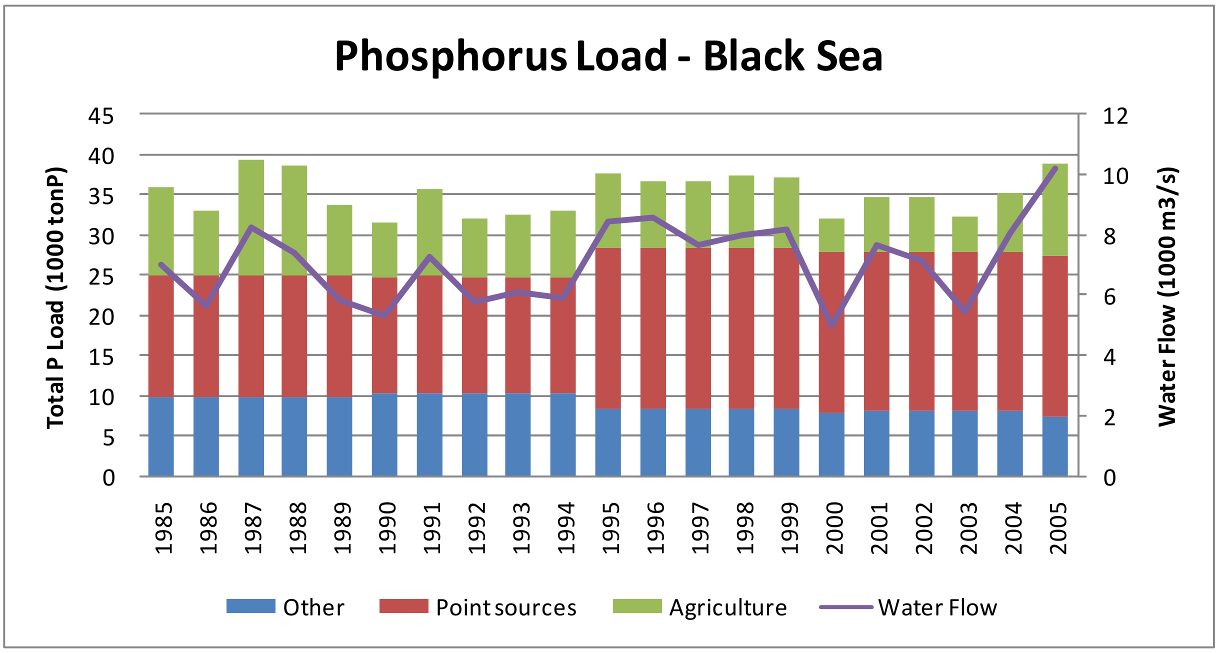


Figure 38. Estimated annual total phosphorus load per source and annual water discharge entering the Black Sea.

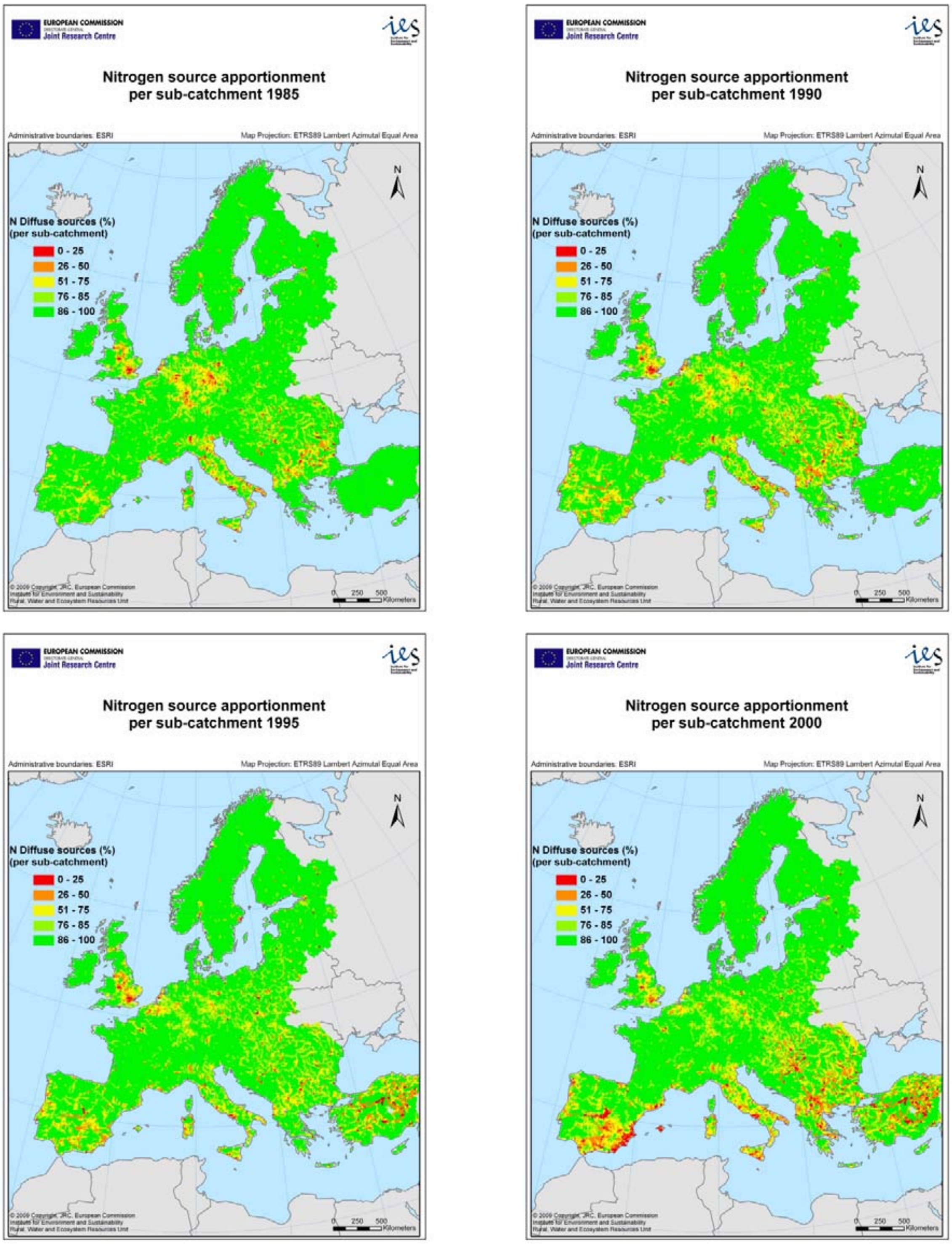


Figure 39. Nitrogen load source apportionment for the period 1985-2000 on a per sub-catchment basis.

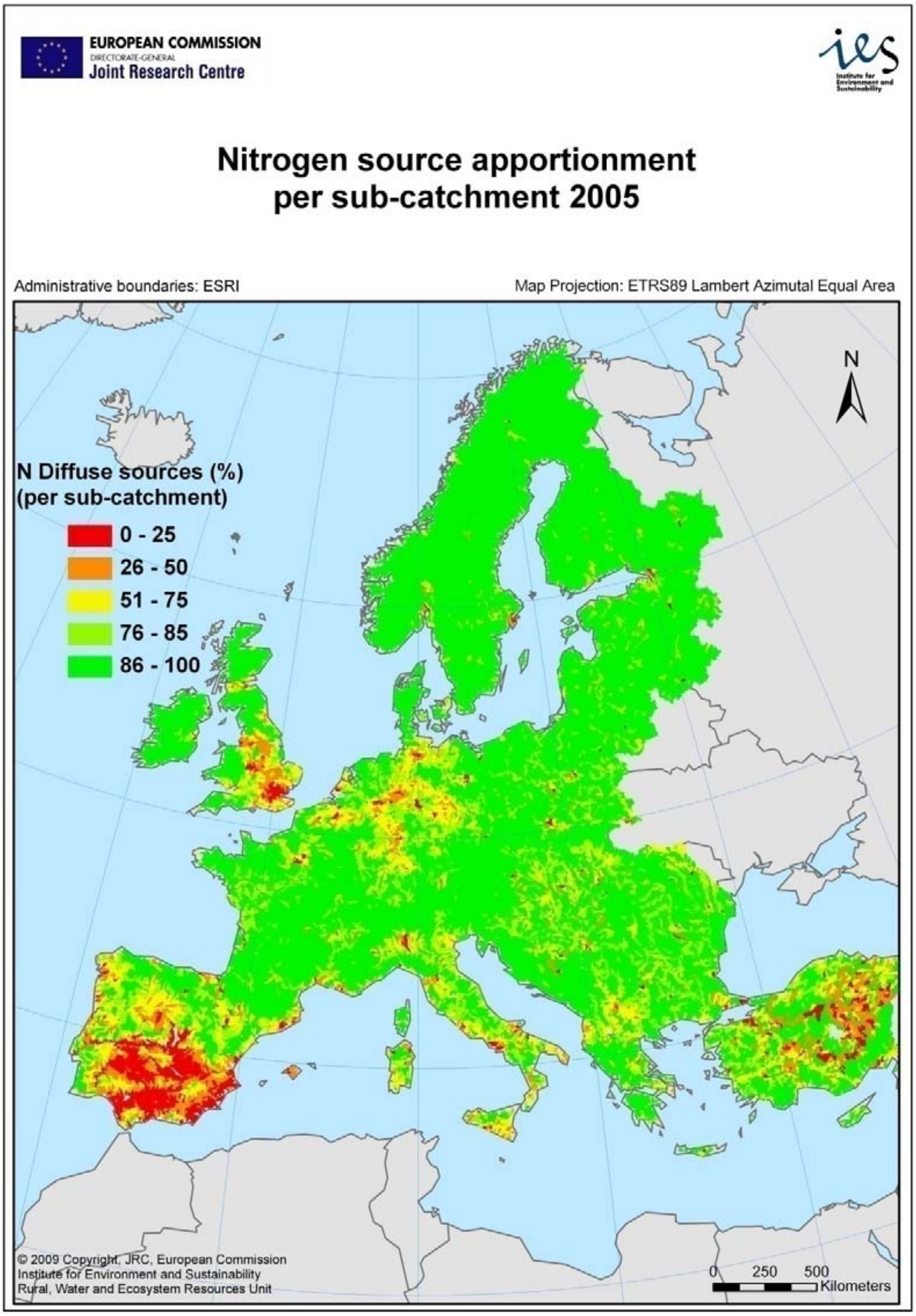


Figure 40. Nitrogen load source apportionment for year 2005 on a per sub-catchment basis.

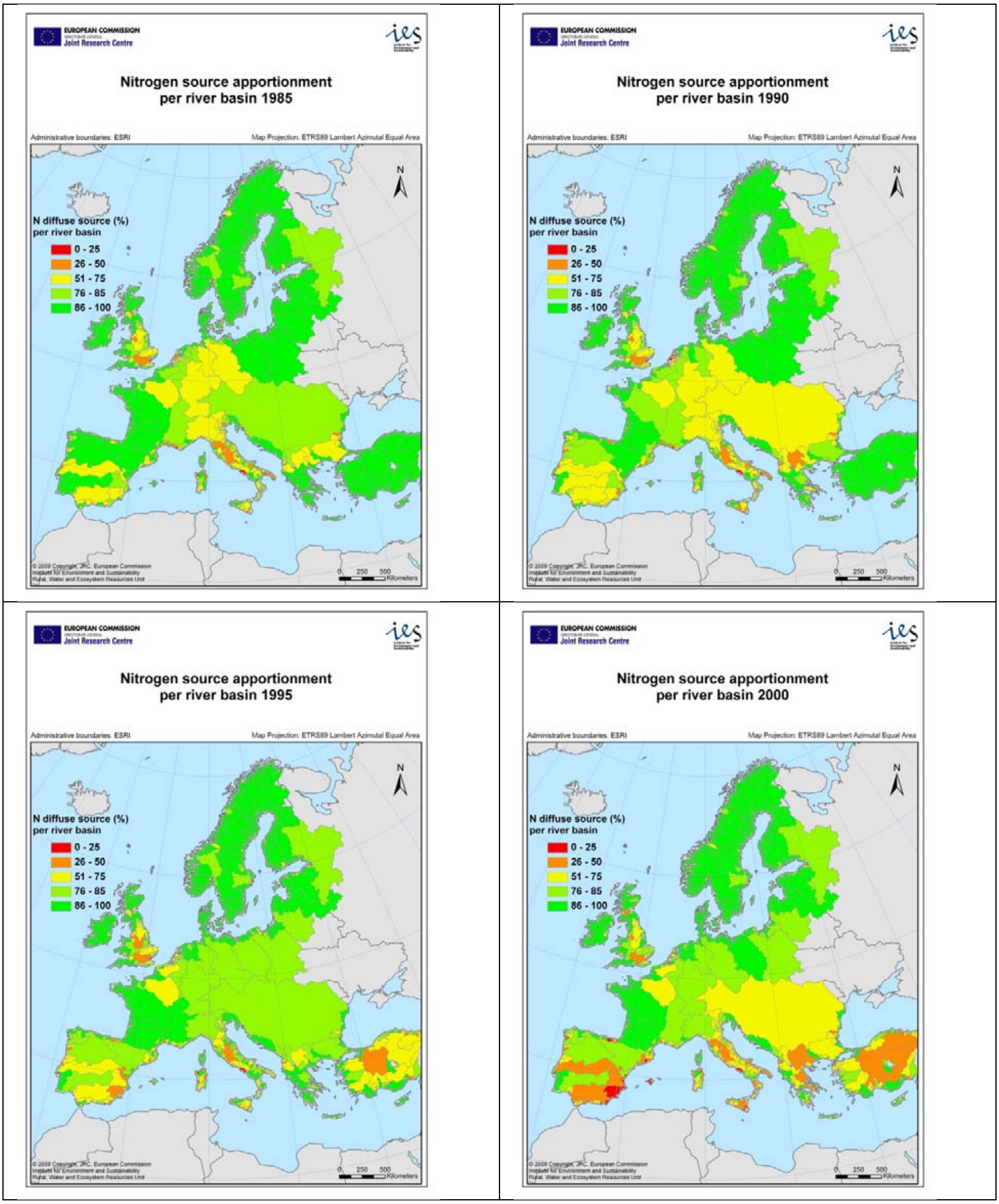


Figure 41. Nitrogen load source apportionment for the period 1985-2000 on a per river basin basis.

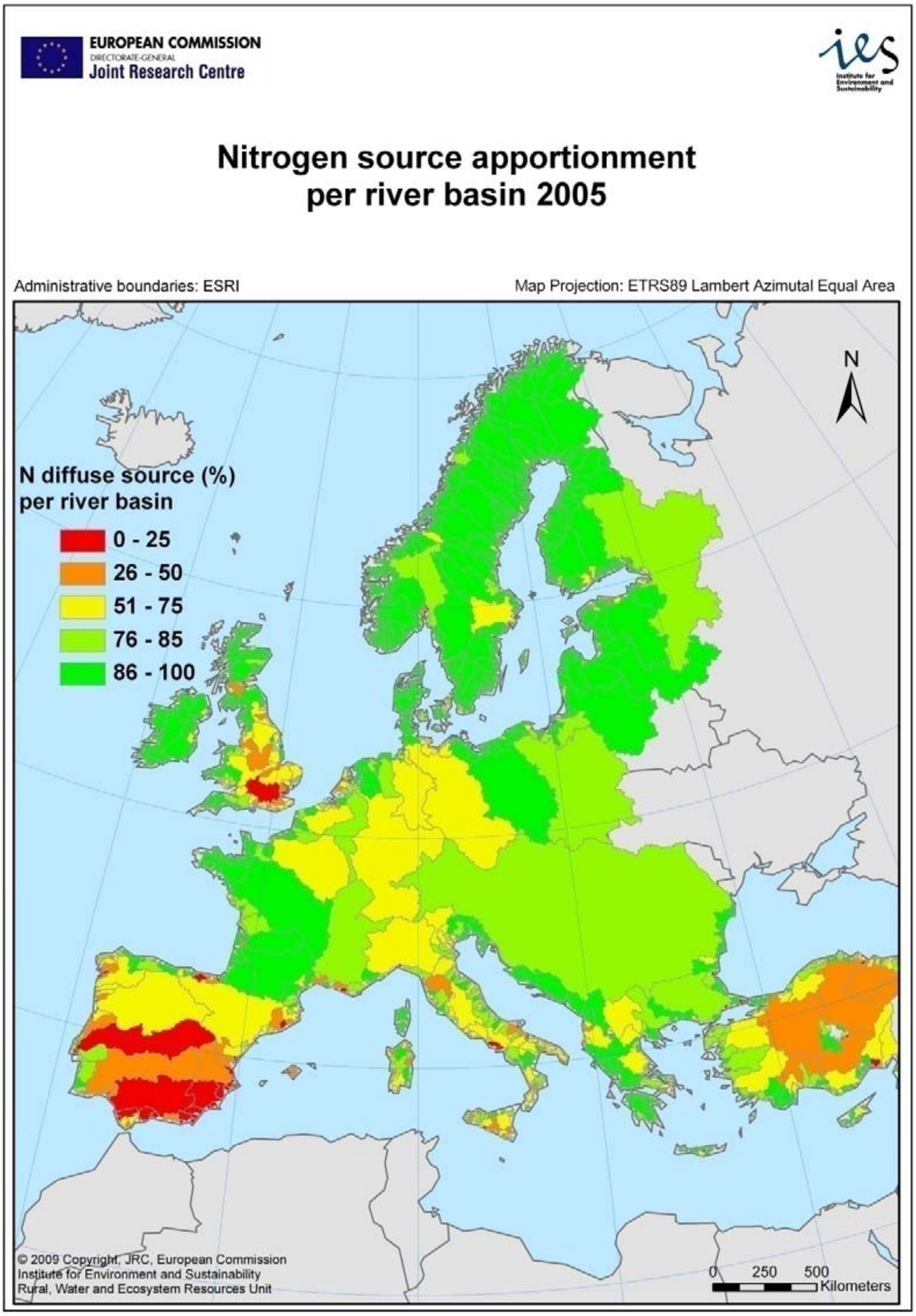


Figure 42. Nitrogen load source apportionment for year 2005 on a per river basin basis.

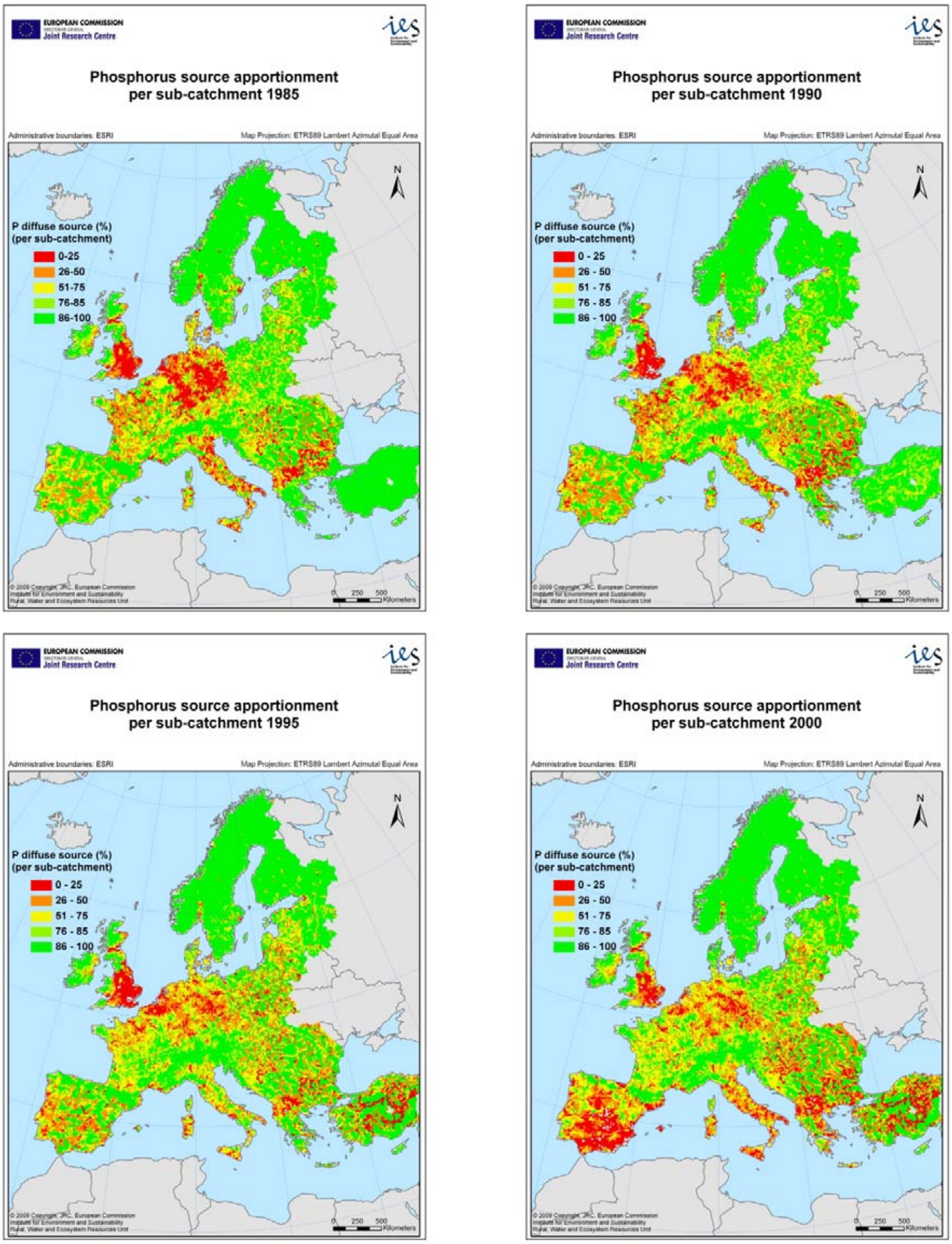


Figure 43. Phosphorus load source apportionment for the period 1985-2000 on a per sub-catchment basis.

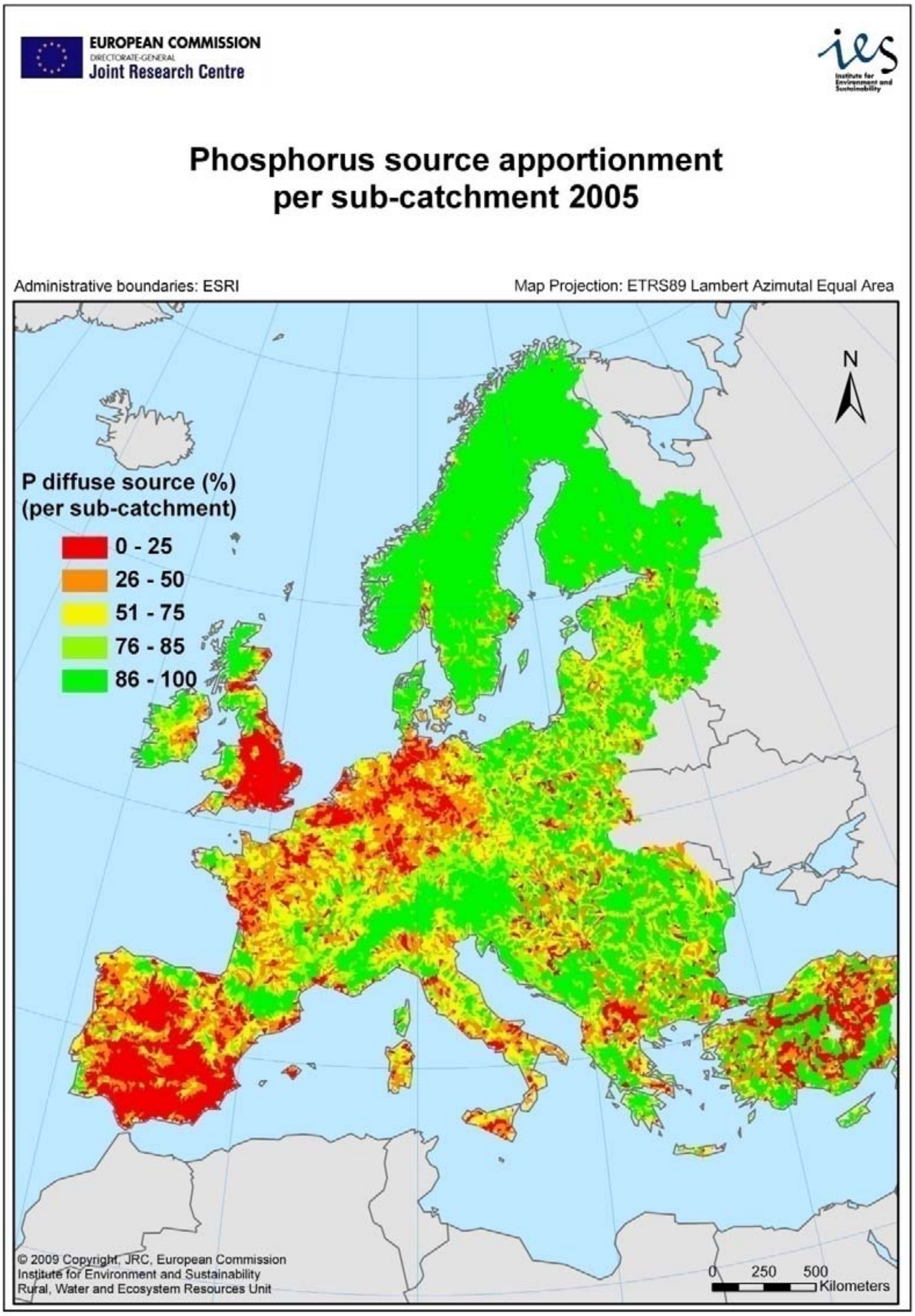
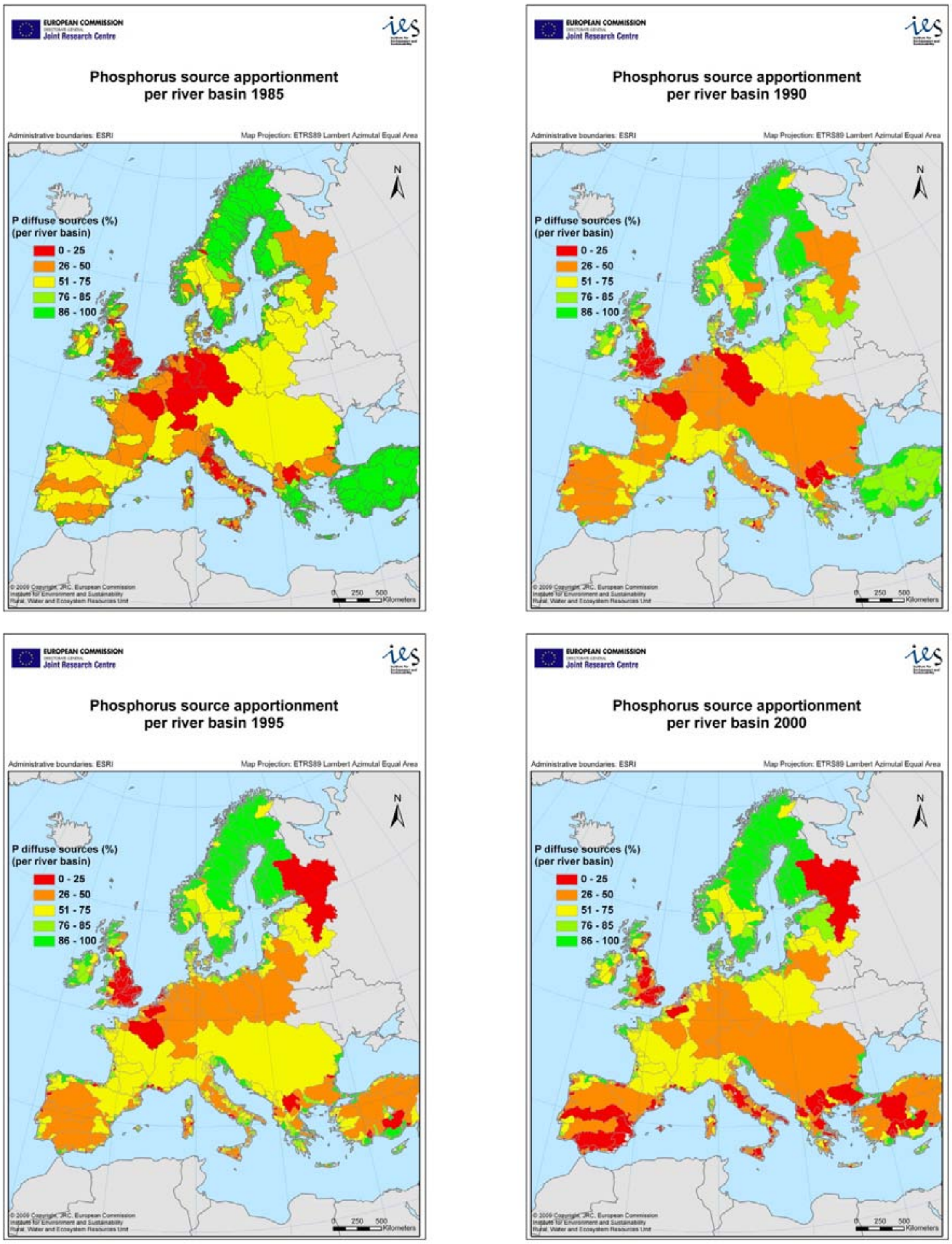


Figure 44. Phosphorus load source apportionment for year 2005 on a per sub-catchment basis.


Phosphorus source apportionment per river basin 1985

Phosphorus source apportionment per river basin 1990

Phosphorus source apportionment per river basin 1995

Phosphorus source apportionment per river basin 2000

Figure 45. Phosphorus load source apportionment for the period 1985-2000 on a per river basin basis.

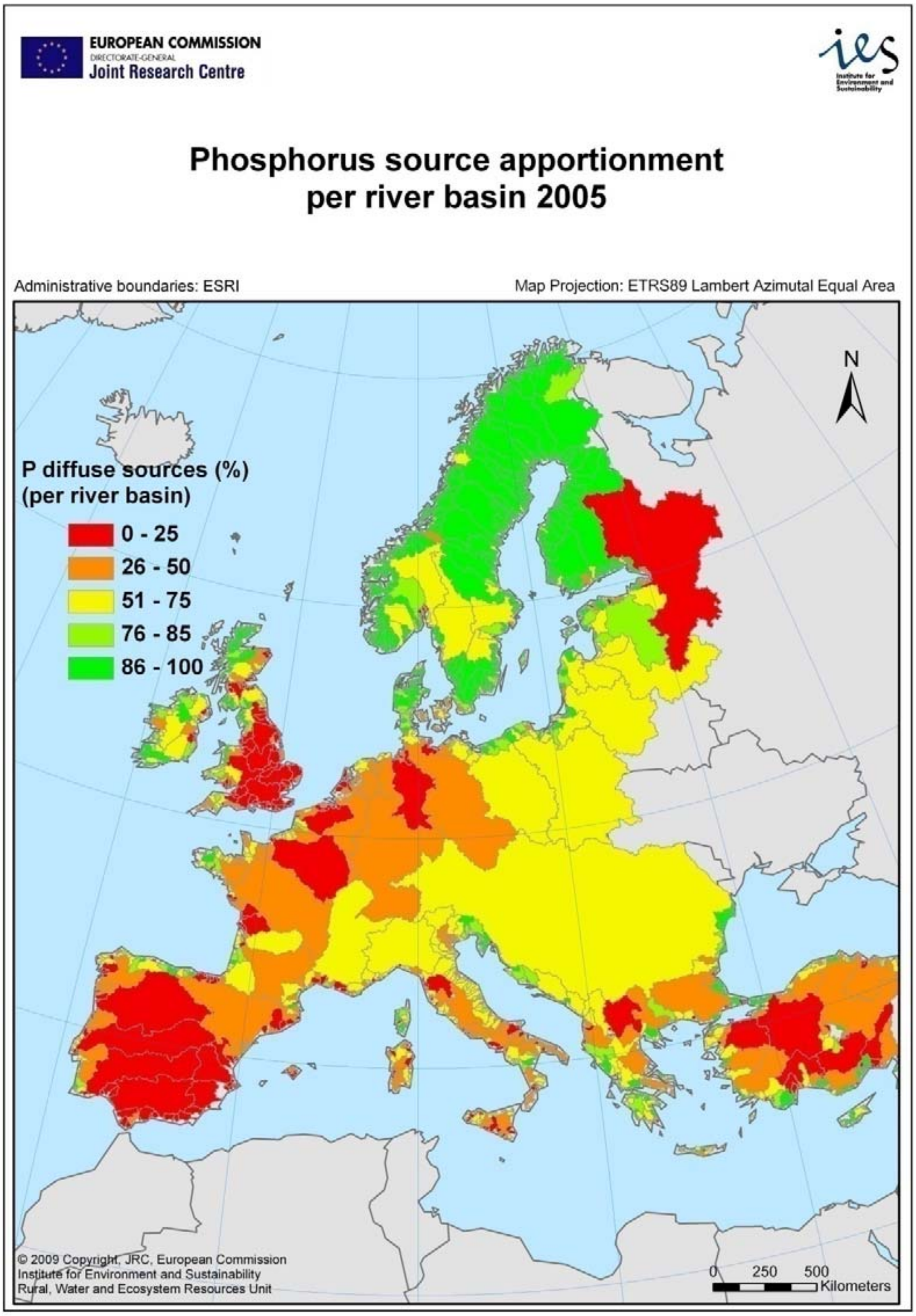


Figure 46. Phosphorus load source apportionment for year 2005 on a per river basin basis.

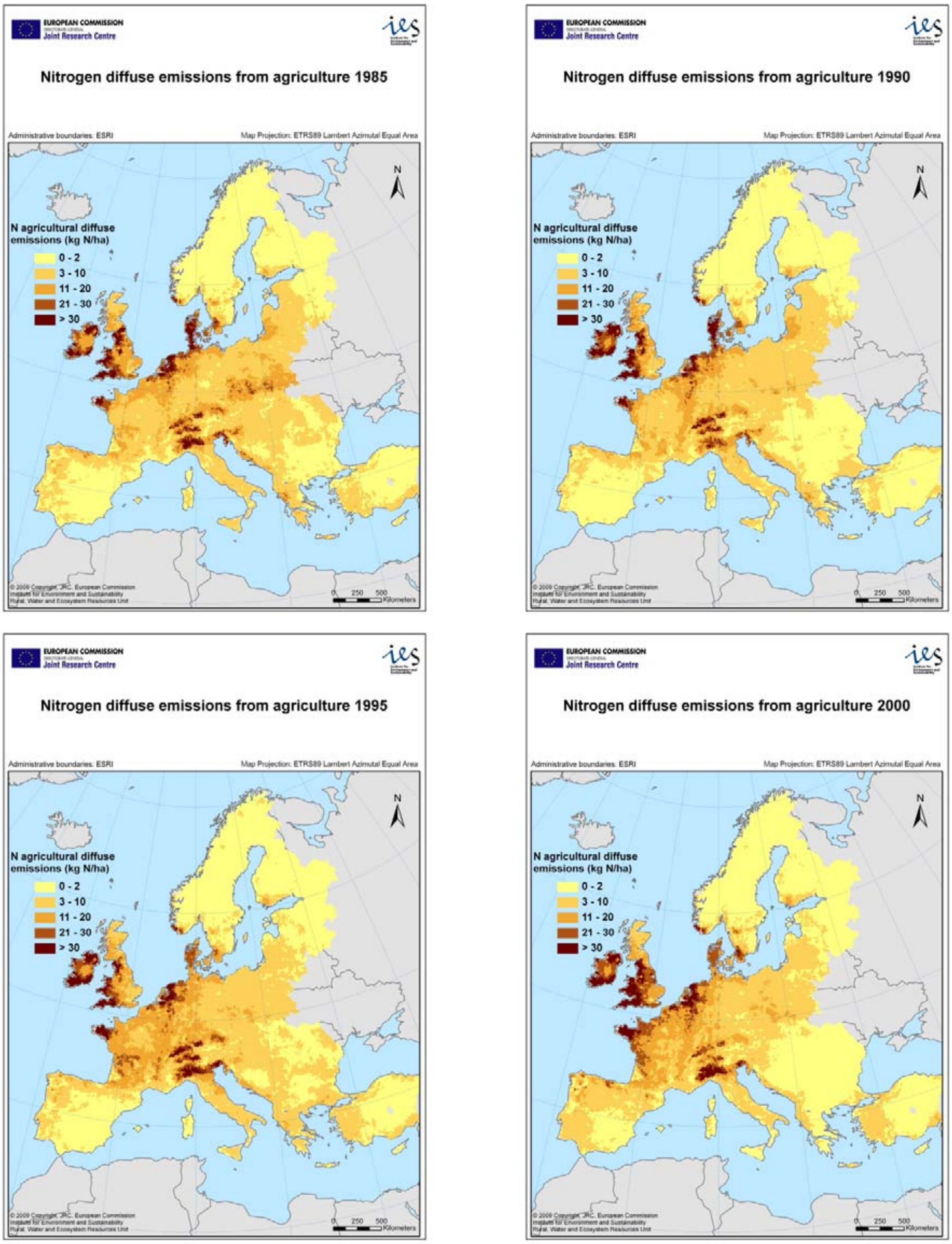


Figure 47. Nitrogen diffuse emission from agriculture for the period 1985-2000 on a per sub-catchment basis.

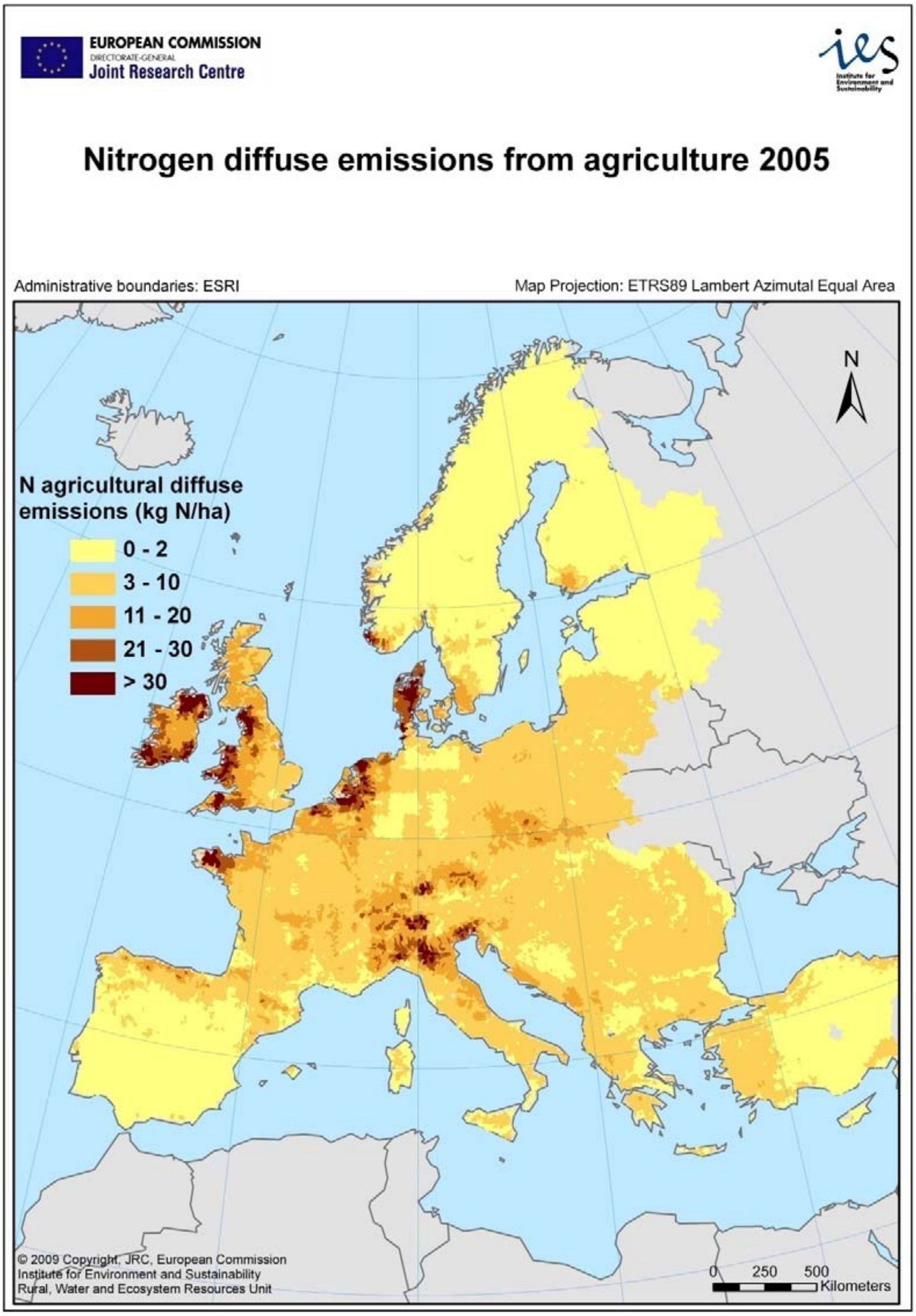


Figure 48. Nitrogen diffuse emission from agriculture for year 2005 on a per sub-catchment basis.

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Abstract

In 2008, DG ENV invited the JRC to conduct a three year study on the impact of EU environmental legislation on nutrient loads to European Seas. The objective of the study was to perform a long term retrospective analysis (20 years) of land based nutrient loads in European Seas to assess the effectiveness of the EU environmental policies and other management plans adopted by countries with rivers discharging in European Seas, and assess future scenarios linked to alternative management plans different policies to control nutrient loading. The focus is both on the nutrient loading to the sea and the inland response to various policies. The first phase of the study focused on setting up the methodology for year 2000. The work concentrated on data collection and model development. The present report focused on the retrospective analysis including trend analysis (1985-2005). The report describes the change in time of the nutrient loads and their origin, entering European Seas.

The mission of the JRC is to provide customer-driven scientific and technical support for the conception, development, implementation and monitoring of EU policies. As a service of the European Commission, the JRC functions as a reference centre of science and technology for the Union. Close to the policy-making process, it serves the common interest of the Member States, while being independent of special interests, whether private or national.

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