Nitrogen deposition to Danish waters 1989 to 1995

Estimation of the contribution from Danish sources

NERI Technical Report no. 215

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Ministry of Environment and Energy
National Environmental Research Institute
November 1997

Data sheet

Title:	Nitrogen deposition to Danish waters 1989 to 1995
Subtitle:	Estimation of the contribution from Danish sources
Author(s):	Ole Hertel and Lise Frohn
Department(s):	Department of Atmospheric Environment
Serial title and no.:	NERI Technical Report no. 215
Publisher:	Ministry of Environment and Energy National Environmental Research Institute ©
URL:	http://www.dmu.dk
Date of publication:	November
Referee(s):	Henrik Skov, Thomas Ellermann
Layout:	H. R. Fomsgaard
Computer graphic:	Ole Hertel, Lise Frohn, Thomas Ellermann
Please quote:	Hertel, O. & Frohn, L. (1997):Nitrogen deposition to Danish waters 1989 to 1995. Estimation of the contribution from Danish sources. National Environmental Re search Institute, Denmark. 54pp. - NERI Technical Report, no. 215

Abstract:

The presented work is a demonstration of various types of assessment studies that can be performed with e.g. the transport-chemistry models developed at NERI. Model calculations with NERI's ACDEP-model show that in total the atmospheric load is about half of the total nitrogen load of Danish marine waters. About 2/3 of this atmospheric load is from deposition of ammonia and ammonium, which is related to emissions from agricultural activities. The remaining 1/3 is from emissions related to various combustion processes. The results show also that the Danish emissions to the atmosphere only contribute to about 16% of the total atmospheric load of Danish marine waters. For coastal waters, like e.g. fjord systems, bays and creeks, the contribution from Danish sources is considerably higher. The main contribution is in this case from ammonia emissions from local agricultural activities. However, for these waters the atmospheric load is in general low compared to the contributions from streams and point sources.

Keywords:	Keywords: nitrogen deposition to Danish marine waters, assessment of the impact of Danish emissions, transport-chemistry models
ISBN:	87-7772-359-7
ISSN:	0905-815x
Paper quality:	Cyclus Offset, 100% genbrugspapir
Printed by:	Hvidovre Kopi ApS
Number of pages:	54
Circulation:	200
Price:	DKK 70,- (incl. 25% VAT, excl. freight)
For sale at:	National Environmental Research Institute PO Box 358 Frederiksborgvej 399 DK-4000 Roskilde Denmark Tel.: +45 46 30 12 00 Fax: +45 46 30 11 14
	Miljøbutikken Information and Books Læderstræde 1 DK-1201 Copenhagen K Denmark Tel.: +45 33 37 92 92 Fax: +45 33 92 76 90

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Preface

The present report is carried out within the framework of the National Environmental Research Institute (NERI) project "Integrated Environmental Information Systems" (In Danish: "Integrerede Miljøinformationssystemer" - IMIS). The aim of the IMIS project is to develop a model hierarchy after the so-called DPSIR concept (Driving forces, Pressures, State, Impact and Respons), which is based on the relations between economical factors, emissions, loads and levels, and impacts on the environment. The intention of the model hierarchy is to establish a tool for performing various impact assessment studies.

The IMIS - Sea subproject concerns the establishment of an integrated environmental information system for the Danish marine waters. Within this subproject, the Atmospheric Chemistry and Deposition (ACDEP) model (Hertel et al. 1995) is used for different assessment studies of the atmospheric nitrogen load of Danish marine waters. The calculated nitrogen depositions will serve as input data for a water quality model for Danish marine waters. The water quality model is under development at NERI in the department for Marine Environment and Microbiology. Also this work is carried out as a part of the NERI IMIS project.

In the present report, the ACDEP-model is used to estimate the contribution from Danish atmospheric sources to the nitrogen deposition to Danish marine waters. This work is a demonstration of the possibilities for various impact assessment studies using the mathematical models in the IMIS-project.

In the present report, the surface areas of the Danish marine (water) are identical to the ones used in Skov et al. (1996). There are some inconsistencies regarding the methods used by different authorities for estimating these areas and therefore they may be updated in the future. This will however not change the overall conclusions of the report.

The authors would like to thank the NERI senior scientists Thomas Ellermann and Henrik Skov for reviewing the report and giving valuable suggestions to the content and structure.

A considerable amount of data was produced in the model calculations prepared for the present report. In order to make the report more readable, many figures and tables are therefore placed in the Appendixes in the back of the report.

1 Introduction

Atmospheric load of marine waters

The pollution in the atmosphere contributes significantly to the total nitrogen load of coastal marine waters, and serve therefore as an important source of nutrients for algae growth in these regions. The ACDEP-model (Hertel et al. 1995) was originally developed within the Danish Marine Research Programme Sea90. The model calculations within the Sea90 showed that the atmospheric contribution is about 30% of the total nitrogen load of the Kattegat Strait between Denmark and Sweden (Asman et al. 1993; 1994).

Monitoring programme

The air pollutant concentrations at 7 monitoring stations and wet depositions at 17 monitoring stations of a number of chemical compounds are continuously measured within the Danish Background Monitoring Programme (Ellermann et al. 1996; Skov et al. 1996). The monitoring network has a rather coarse resolution, and in order to increase the geographical resolution in the deposition estimates routine calculations with the ACDEP model have been introduced as a supplement to the measurements (Skov et al. 1995; 1996).

Use of previous calculations

The ACDEP calculations of nitrogen depositions to Danish open waters, fjord systems, bays and creeks, performed under the Danish Background Monitoring Programme, have formed the basis for the present work concerning the impact of Danish atmospheric emissions. Detailed information about the total nitrogen depositions to Danish marine waters in the period 1989 to 1995 is presented in (Skov et al. 1996).

Uncertainties in calculations

Analyses of the ACDEP calculations and comparison of the model results to measurements from the monitoring stations have shown that the model is fairly well able to reproduce observed gas phase concentrations and sulphur and nitrogen contents in atmospheric aerosols. Based on the comparisons, the uncertainties in the calculated nitrogen depositions on yearly basis have been estimated to be in the order of 40% for the open waters and 60% for the coastal waters (Skov et al. 1996).

Contributions from Danish sources to atmospheric load

The model calculations within the Sea90 programme showed that Danish pollution sources contribute with about 20% of the atmospheric nitrogen load of the Kattegat Strait. However, the contribution from Danish sources is considerably higher for the waters along the coastline including fjords, bays and creeks, since these waters are close to the sources on land. The present report gives an estimation of the contribution from Danish sources to nitrogen deposition to all the Danish marine waters. Emphasis is on the geographical distribution and on possible trends over the period 1989 to 1995 revealed by the model calculations.

Results presented as yearly mean values

The uncertainties in calculated nitrogen depositions are in general high (see the discussions in Hertel, Vignati 1996; Skov et al. 1996; Hertel et al. 1997) and therefore the uncertainties in estimates of the contribution from Danish atmospheric emissions are high, especially considering shorter averaging times (such as hourly or daily mean values). Therefore, the estimates of the impact of Danish atmospheric emissions on nitrogen deposition to Danish waters are mainly presented on a yearly basis in the report.

2 Calculation procedure

In this chapter a very brief introduction to the used transport-chemistry model is given. Furthermore the applied calculation procedure and the most important input data for the calculations are described.

2.1 The applied model and calculation procedure

The ACDEP-model

The ACDEP-model is a Lagrangian transport-chemistry model in which an air parcel is followed along 96 hours transport to a given receptor point. The air parcel is represented by 10 grid points in a vertical column from the surface and up to 2 km's height. During the transport the air parcel receives emissions and vertical diffusion, chemical transformation and dry and wet deposition take place, see Figure 2.1. The chemical mechanism of the model includes 37 species and about 80 reactions. For details on the model structure and the parameterizations in the model see (Hertel et al. 1995) and (Asman et al. 1993), and the shorter description in (Ellermann et al. 1996) in which also a description of the calculation procedure is given.

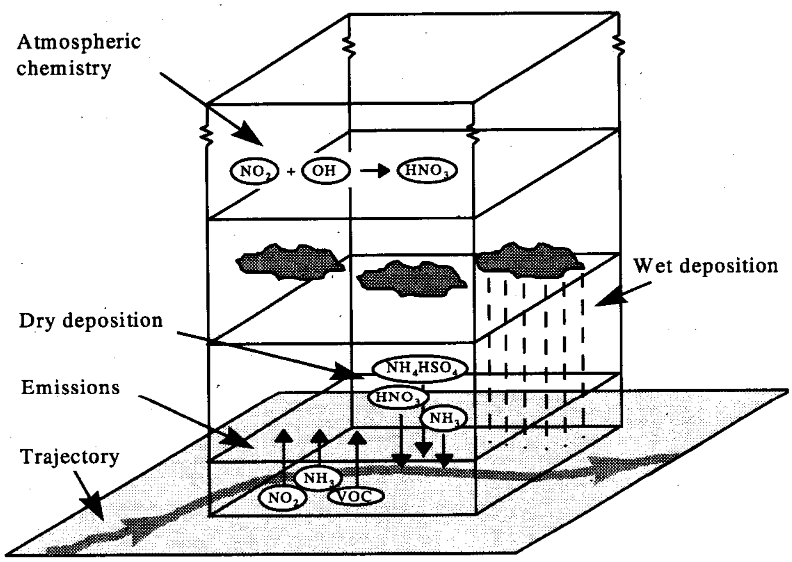


Figure 2.1 Illustration of the concept in the ACDEP-model. A one dimensional vertical air column is advected along 96 h back-trajectories. During the advection the column receives emissions, vertical mixing takes place, species are chemically transformed and/or removed by dry and wet deposition.

Calculation procedure

The ACDEP calculations under the Danish Background Monitoring programme provide information regarding the spatial distribution of the nitrogen deposition to Danish marine waters. Model calculations have been performed for 212 receptor points in a 30 km x 30 km grid covering all Danish marine waters (Figure 2.2) for the period 1989 to 1995. The nitrogen deposition has subsequently been divided into deposition to Danish open waters, fjord systems, creeks and bays based on information about the area and position of these waters. In total 84 different Danish marine waters are included in these calculations (i.a. the tables in Appendix D).

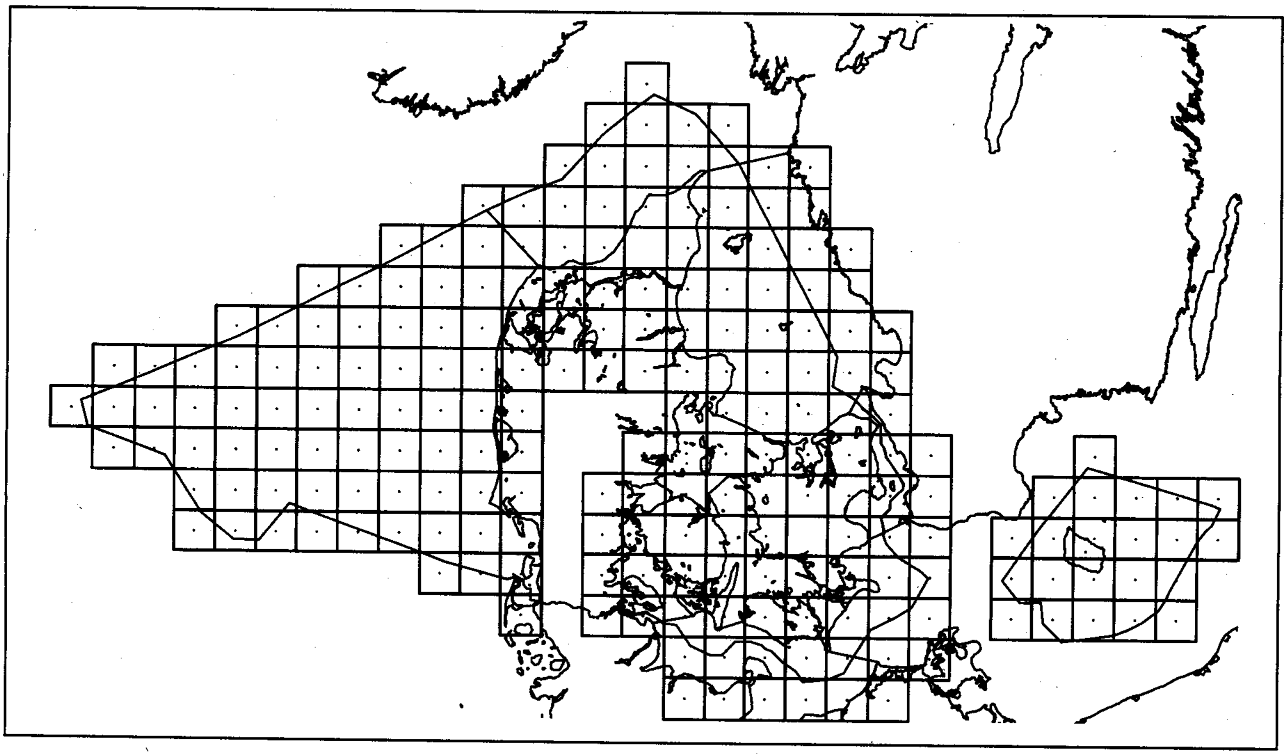


Figure 2.2 The used calculation grid with a horizontal resolution of 30 km x 30 km for the Danish marine waters. Borders for the open Danish waters are indicated in the figure. Information about the placement of the different open waters related to the calculation grid has been compiled by Henning Steen Hansen NERI-SYS by use of GIS-ArcInfo, based on data from Denmark's Geological Research Institute. The position of fjord systems, creeks and bays have been obtained from manual reading of maps. The surface areas of these waters were provided by the Danish counties.

Two model versions

The computations have been performed using two different versions of the ACDEP-model, with respectively two and ten vertical layers. The results for the open Danish waters have been shown to be rather unattached by changes in the vertical resolution of the model (Hertel et al. 1997), and calculations for these waters are therefore performed with a version of the model with only two vertical layers; one for the boundary layer and one for the free troposphere. Calculations for fjord systems, creeks and bays have been made using the original version of the model with ten vertical layers. Both versions of the model cover a vertical domain from the surface and up to 2 km's height.

Time resolution in calculations

The model calculations are performed with arrival time every 6 hours: 0000, 0600, 1200 and 1800 hour. Depositions for the 6 hour intervals are obtained from linear interpolation between the values at the arrival times. For each arrival time air concentrations, dry and wet depositions are stored and afterwards averaged for longer time periods to give e.g. monthly and yearly mean values.

2.2 Input data

Meteorological data

The ACDEP calculations are performed using meteorological data on EMEP grid (150 km x 150 km) that where kindly made available by Helge Styve, The European Monitoring and Evaluation Programme, Meteorological Synthesising Centre - West at the Norwegian Meteorological Institute (EMEP MSC-W at DNMI). The air mass trajectories were calculated using a programme developed for the EMEP Lagrangian model (Iversen et al. 1990). The meteorological parameters are further used for the calculation of dispersion, dry and wet deposition and chemical transformations (for further details see Hertel et al. 1995; Asman et al. 1994; Ellermann et al. 1996).

Emission data

The model needs input data for the emissions of sulphur dioxide (SO_2), nitrogen oxides (nitrogen monoxide (NO) and nitrogen dioxide (NO_2)), non-methane hydrocarbons (NMHC) and ammonia (NH_3) for the EMEP area (most of Europe) distributed on a grid. In connection with the Danish Marine Research Programme Sea90, a detailed emission inventory on a 15 km x 15 km grid was compiled for Denmark and closest surroundings for the year 1985 (and afterwards upgraded for 1990) (Asman et al. 1994; 1995). The EMEP inventory on 150 km x 150 km grid was used for the rest of the EMEP area (Mylona 1996). For the calculations under the Danish Background Monitoring Programme, the gridded inventory was updated by simple scaling of the annual emissions on national basis. The figures are reported by EMEP in (Mylona 1996) for the period 1989 to 1995 (see also the description of the handling of emissions in (Ellermann et al. 1996)). This procedure means that the geographic distribution in the inventory for 1985 was not changed. Simple expressions were applied for the seasonal variation in the emissions (Hertel et al. 1995; Ellermann et al. 1996). The EMEP emission inventories on annual basis were kindly made available on digital media by Sophia Mylona, EMEP MSC-W at DNMI. The Danish emission inventories for the period 1989 to 1995 are shown in Table 2.1.

Table 2.1 Total yearly Danish emissions in the period 1989 to 1994 (Mylona 1996). The 1995 emissions are assumed unchanged from 1994.

Year	NO_x [A] ktonnes N	NH_3 ktonnes N	SO_2 [B] ktonnes S
1989	83	120	97
1990	82	115	90
1991	97	110	121
1992	83	107 [c]	95
1993	80	104	79
1994	83	104	78
1995	83	104	78

A) 95% nitrogen monoxide and 5% nitrogen dioxide. B) 95% sulphur dioxide and 5% sulphate. C) Average value between the emission in 1991 and 1993.

Danish emissions set to zero

In order to estimate the impact of Danish emissions, the calculation procedure from the Danish Background Monitoring Programme was repeated but this time with the Danish emissions set to zero. Subsequently an indication of the impact of Danish emissions is found by comparison of the results obtained from calculations with and without Danish emissions for the period 1989 to 1995.

3 Results

This chapter presents the model results, for the impact of Danish emissions to the atmosphere on the nitrogen depositions to Danish Marine waters.

3.1 The total nitrogen load of Danish Marine waters

Year to year variation

The relative contributions from Danish sources to the total nitrogen deposition to Danish marine waters show only a minor year to year variation. The contribution from Danish sources to total, dry and wet depositions of nitrogen compounds to the 212 receptor points in the 30 km x 30 km grid covering Danish marine waters are shown for 1995 in Figure 3.1 (for the other years see Figures A.1 to A.21 in Appendix A). The presented results are taken from the ratio:

$$R_{dk} = \frac{dep - dep_{-dk}}{dep} \cdot 100\%$$

where R_{dk} is the contribution from Danish sources, whereas dep and dep_{-dk} are the total nitrogen depositions calculated with and without Danish emissions, respectively.

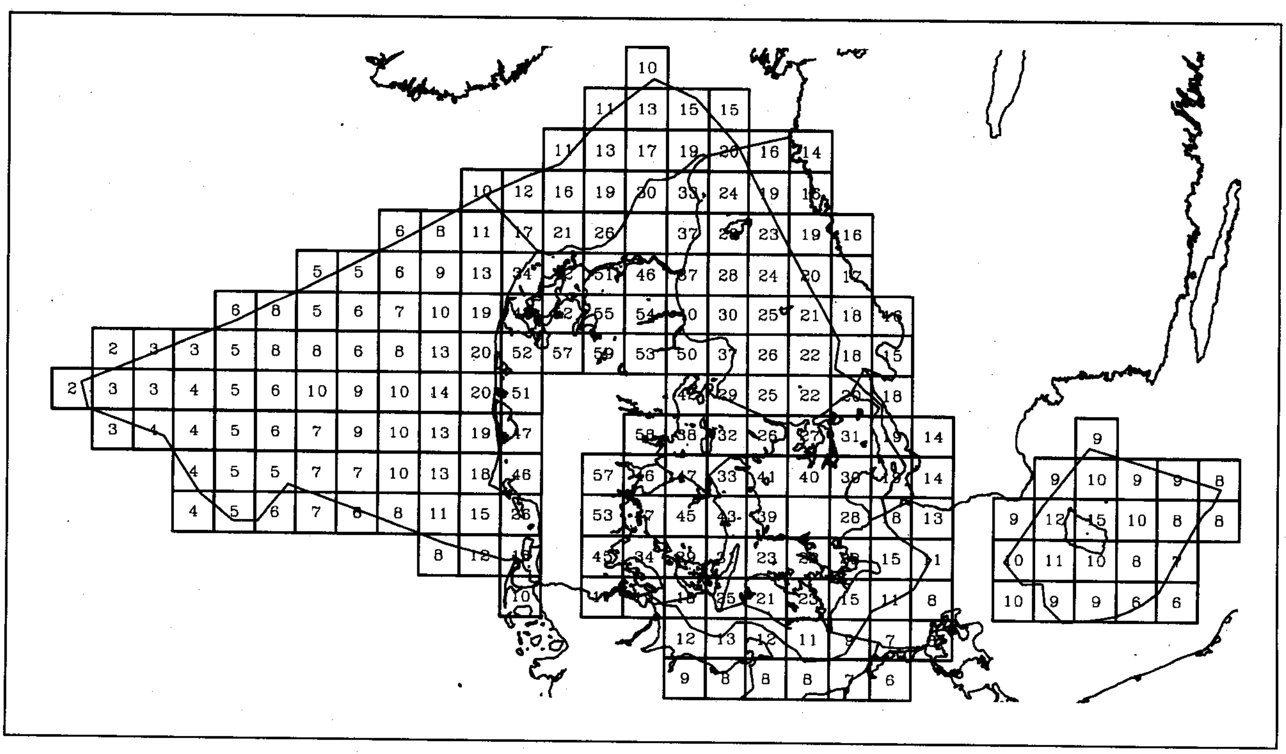


Figure 3.1 The relative impact of Danish pollutant emissions on the total nitrogen deposition to Danish marine waters given in per cent of the total nitrogen deposition. Calculations for the year 1995. Figures for dry and wet deposition as well as for the whole period 1989 to 1995 are given in Figures A.1 to A.21 Appendix A.

Largest contribution close to the coast

The largest contributions to the nitrogen deposition from Danish sources are found for the fjord, creek and bay systems close to the Danish emission areas. In some cases this contribution is even more than 50% (see Figure 3.1). Since wind directions in Denmark are predominantly west and north-west, the contribution is considerably smaller for the Danish North Sea area than for the waters east of Jutland. From the coast of Jutland (10 to 15%) and out to the most western part of the Danish North Sea (about 1%), a significant gradient is observed in the atmospheric contribution from Danish sources. On the east coast of Jutland and across the Kattegat Strait the computed gradient is considerably smaller.

3.2 The impact of Danish ammonia emissions

Dry deposition of NH_3

The largest contribution from Danish sources comes from dry deposition especially of ammonia. Figures 3.2 and 3.3 show the relative influence on atmospheric ammonia concentration and dry deposition of ammonia, respectively. The calculations are for the year 1995.

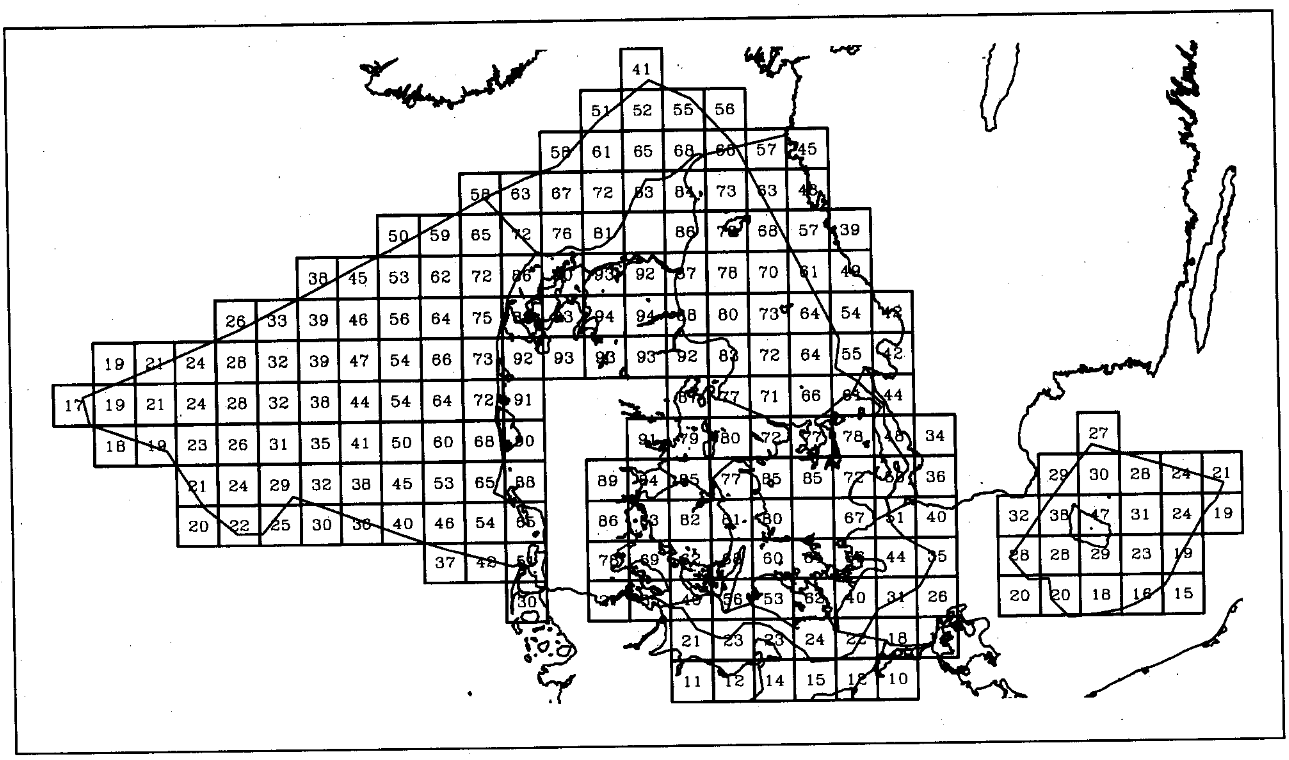


Figure 3.2 The relative impact of Danish emissions on the NH_3 concentrations over the Danish marine waters given in per cent. Calculations for the year 1995.

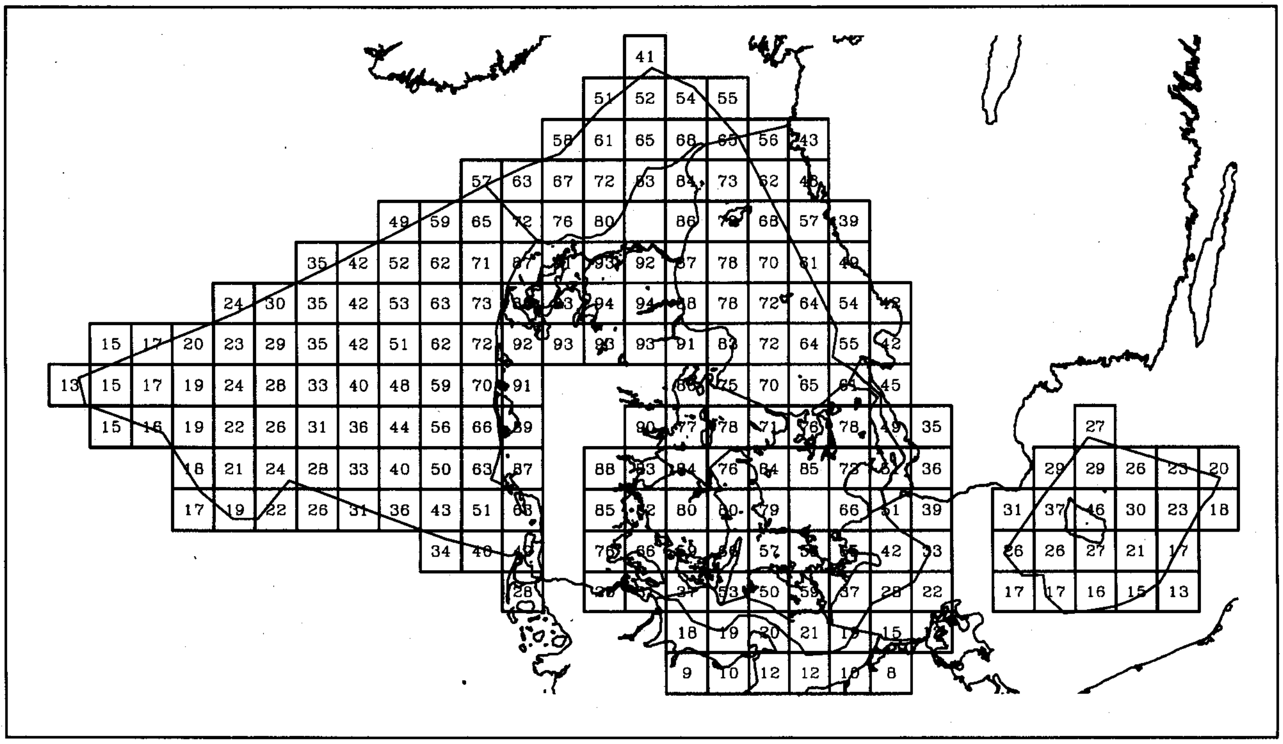


Figure 3.3 The relative impact of Danish emissions on the dry deposition of NH_3 to Danish marine waters given in per cent. Calculations for the year 1995.

HNO_3 increase

For the Danish marine waters, the air concentrations and depositions (mainly dry deposition) of nitric acid increases, when Danish emissions of all pollutants are set to zero. This is reflected in the negative values (increase when Danish emissions are set to zero) in figures 3.4 and 3.5 (the plotted values are also here obtained using Equation 4.1). The explanation for the increase in concentrations and depositions of nitric acid is the decrease in chemical removal. Nitric acid is quickly removed by reactions with ammonia released from Danish agricultural areas, when the air parcel passes over Denmark. The Danish NO_x emissions contribute only little to the nitric acid concentrations, since the reaction between nitrogen dioxide and OH radical only takes place with a conversion rate of about 5% per hour (see e.g. Hertel 1995). This indicates that the main part of the NO_x concentrations originating in Danish releases has left the Danish territory before being transformed to nitric acid.

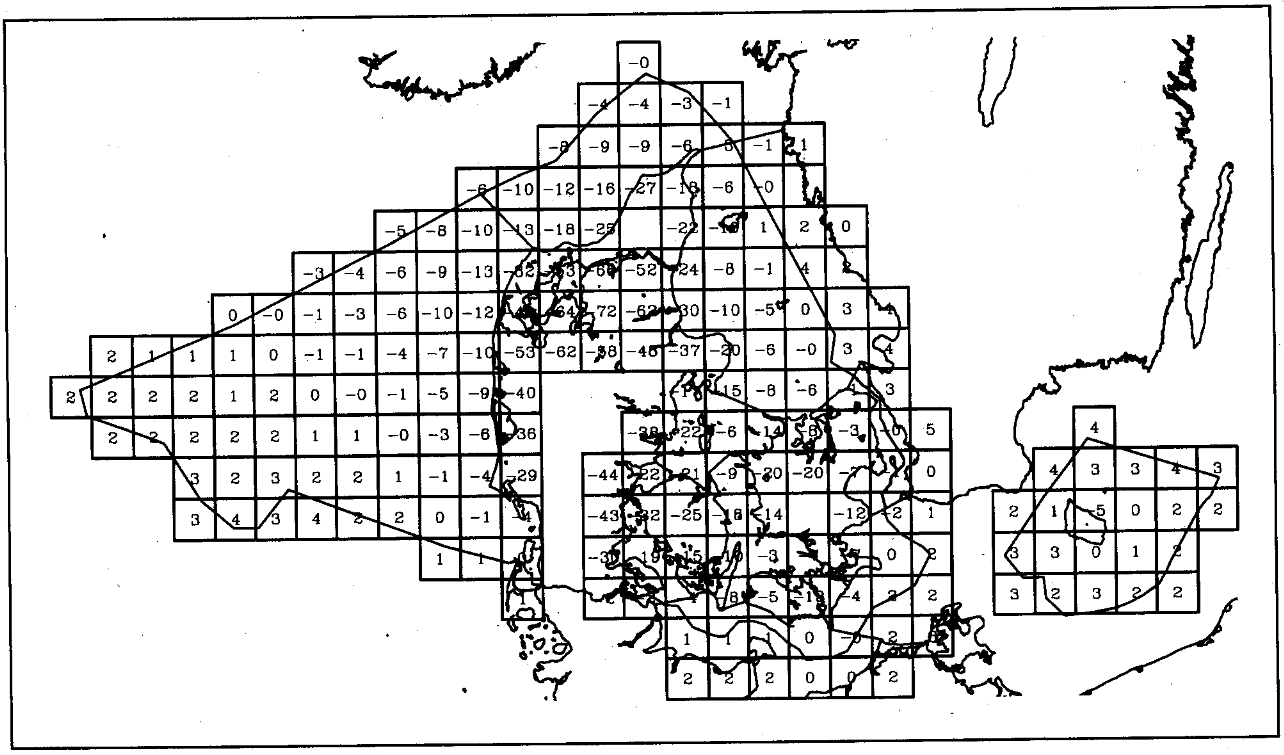


Figure 3.4 The relative impact of Danish emissions on the HNO_3 concentrations over the Danish marine waters given in per cent. Calculations for the year 1995.

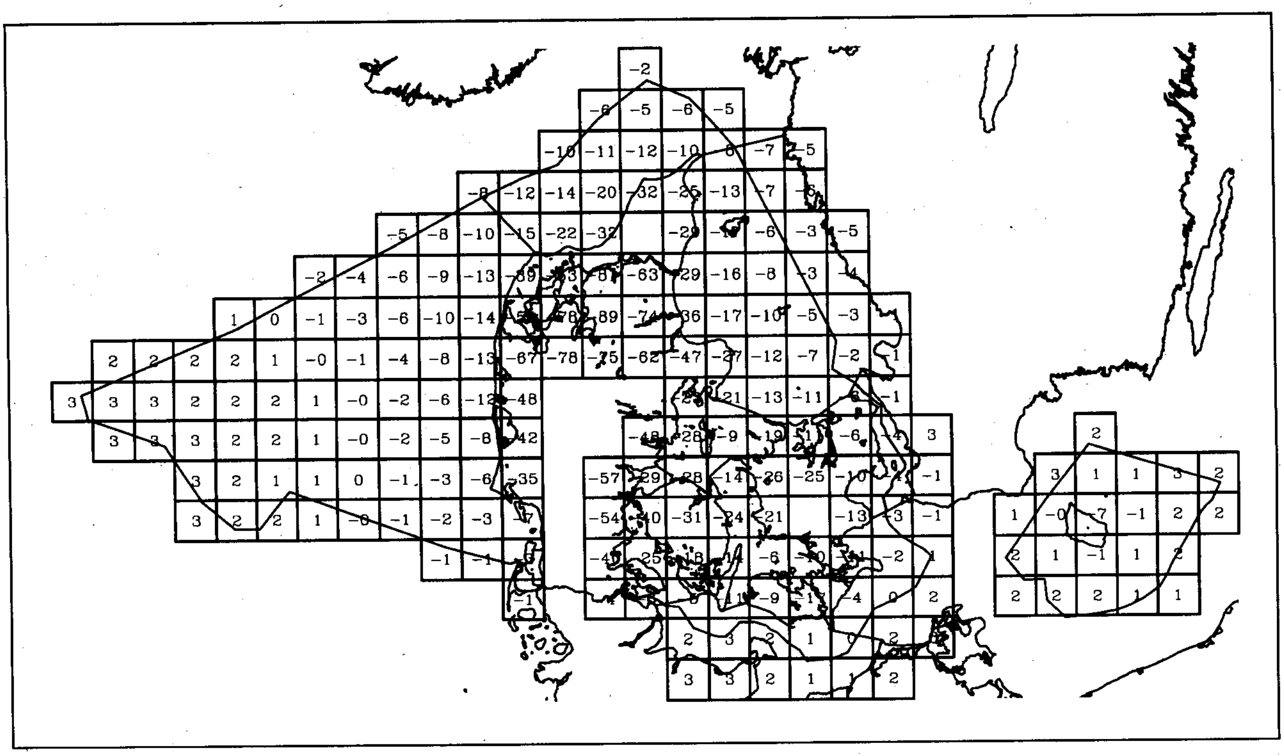


Figure 3.5 The relative impact of Danish emissions on the dry deposition of HNO_3 to Danish marine waters given in per cent. Calculations for the year 1991.

3.3 Contributions from dry and wet depositions

Relative contribution from dry deposition

Another way to illustrate the contribution from Danish sources is presented in Figures 3.6 and 3.7. These figures show the relative contribution from dry deposition to the total nitrogen load of marine water in each of the 212 receptor points.

$$R_{dry} = \frac{dry}{total} \cdot 100\%$$

where R_{dry} is the relative contribution from dry deposition, whereas dry and total are the calculated dry and total depositions, respectively.

The Figures 3.6 and 3.7 show the obtained results for 1995 with and without Danish emissions, respectively. The Danish sources contribute significantly to the deposition to the coastal waters, which is in accordance with expectations.

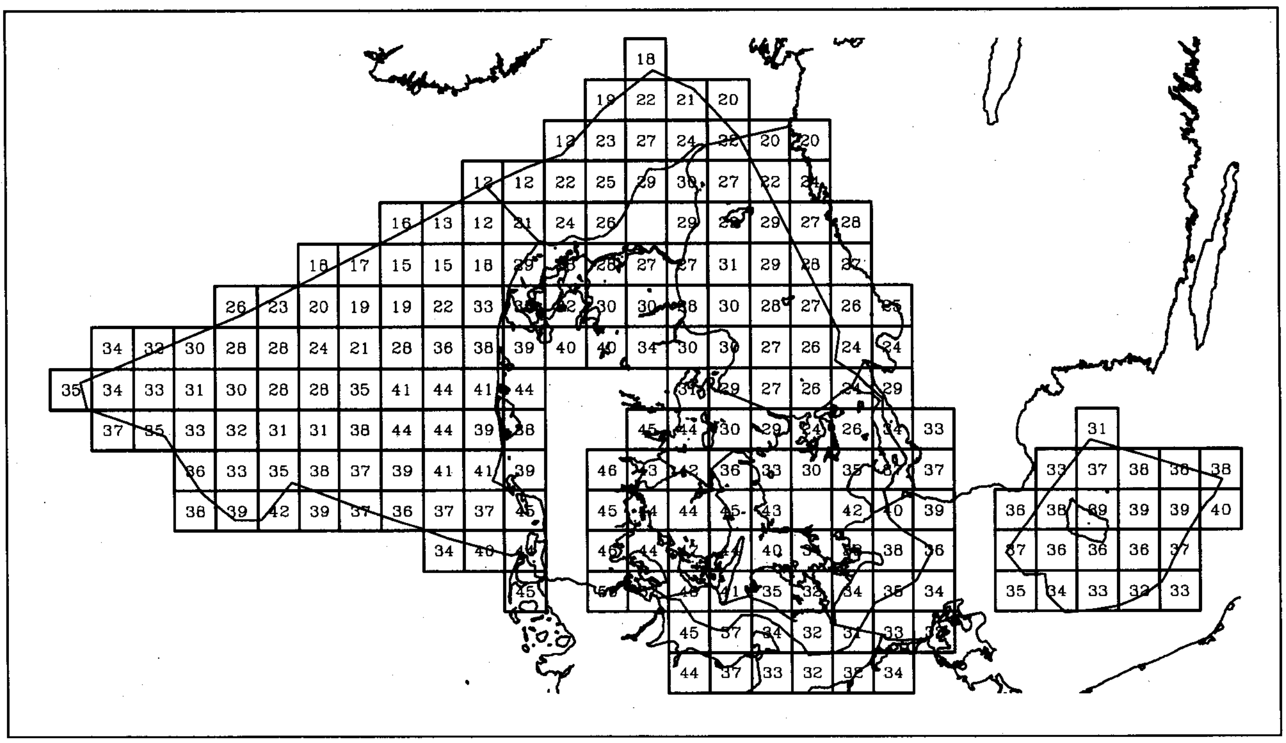


Figure 3.6 The nitrogen contribution from dry deposition relative to the total nitrogen load. Calculations for the year 1995, when Danish emissions are set to zero.

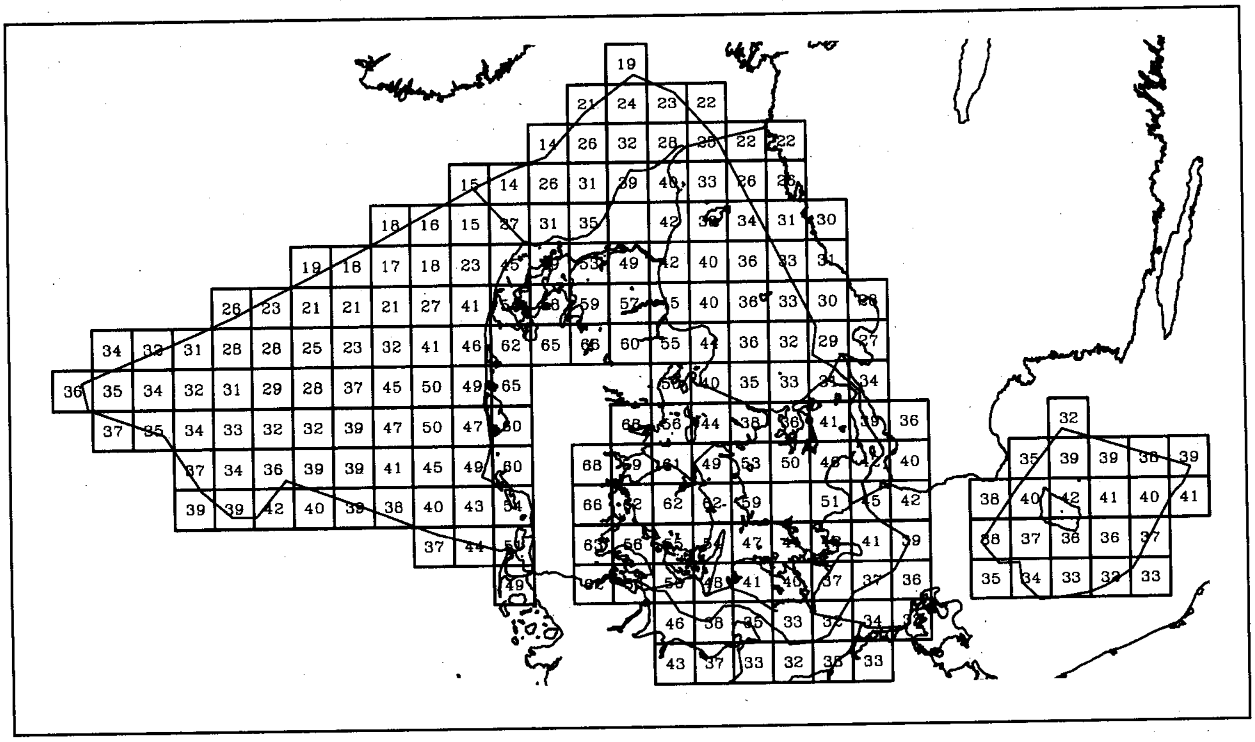


Figure 3.7 The nitrogen contribution from dry deposition relative to the total nitrogen load. Calculations for the year 1995.

3.4 Distribution on various Danish waters

Kattegat Strait

The contribution from Danish atmospheric sources to nitrogen deposition to the Kattegat Strait between Denmark and Sweden has within the Danish Marine Research Programme Sea90 been estimated to about 20% for 1990 (Asman et al. 1994; 1995). Compared to these results, the present calculations give a contribution in the range 19 to 33% and a somewhat higher contribution of about 30% for 1990, see Figure 3.8. In both cases the results are obtained from calculations with the ACDEP-model. The main differences between the two calculations are in the model description of the dry deposition of aerosol phase compounds (Skov et al. 1996; Ellermann et al. 1996). The results presented in the figure show only little development over the period 1989 to 1995 in the contribution from Danish sources as well as in the total deposition.

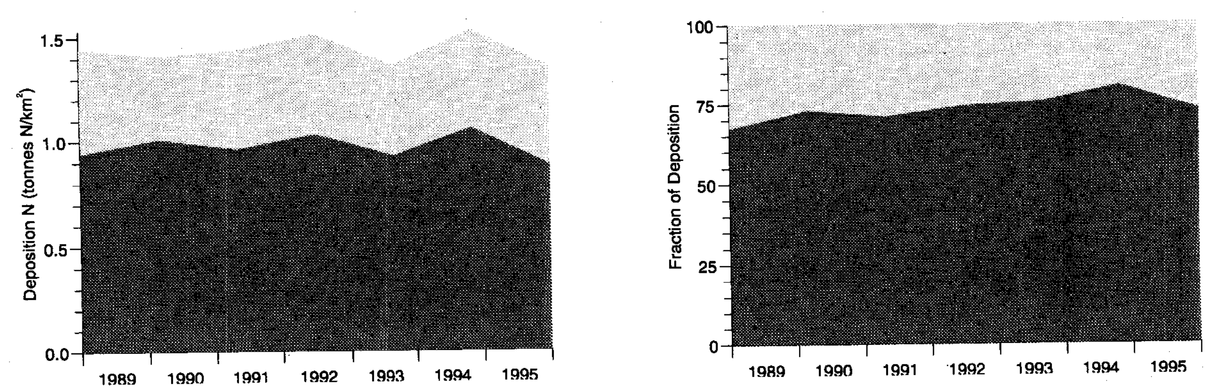


Figure 3.8 The evolution in nitrogen deposition to the Kattegat Strait between Denmark and Sweden during the period 1989 to 1995. The figure shows the Nitrogen deposition, the left figure in absolute numbers (kg/km²) and the right figure in relative numbers (%). The contribution from Danish sources is shown in light grey and contribution from all other sources in dark grey.

Calculations for 84 different waters

The contribution from Danish sources is to a large extend governed by dry deposition of ammonia. Since the agricultural activities are unevenly distributed over the country and the prevailing wind direction is from west and north-west, the contribution from Danish atmospheric sources varies considerably for the different waters. The Tables B.1 to B.7 in Appendix B show the calculated dry, wet and total nitrogen deposition during the years 1989 to 1995. The results are distributed on the 84 different Danish waters for which calculations have been performed. Included in the tables are also the estimated contributions from Danish atmospheric sources given in per cent. For some of the fjord systems the Danish sources contribute to more than half of the atmospheric nitrogen load, mainly due to dry deposition of ammonia.

Total load of Danish marine waters

Figure 3.9 shows the time evolution in total nitrogen deposition to all Danish marine waters. The total atmospheric nitrogen load is found to be in the order of 90 to 110 ktonnes N per year. According to the used geographic data from the Geological Survey of Denmark, the total surface area of the Danish marine waters is about 105,000 km^2. This means an average annual atmospheric load of 900 to 1000 kg N /km^2. The Danish contribution is determined to be in the range 150 to 170 kg N/km^2 or about 16% of the total atmospheric load. The model results show only little year to year variation over the period and no clear trend, especially taking into account the uncertainties estimated to be in the range of 40 to 60%.

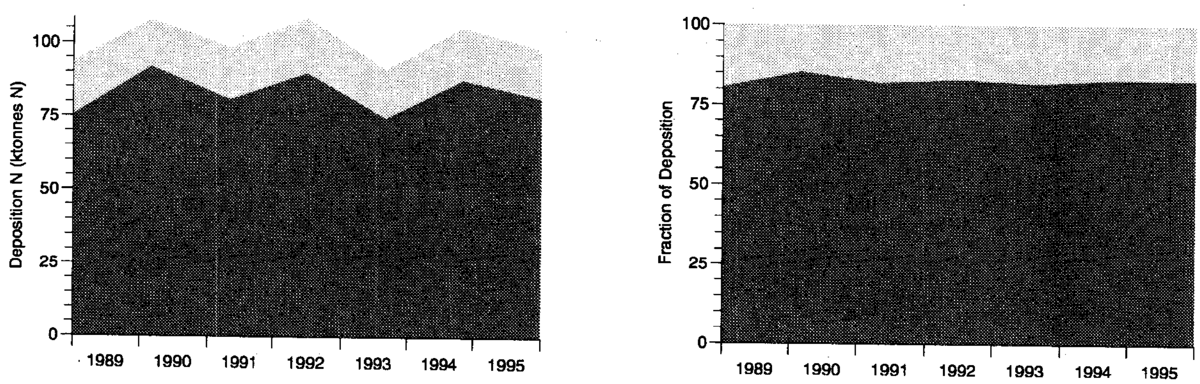


Figure 3.9 Average yearly nitrogen deposition to all Danish marine waters during the period 1989 to 1995. The left figure shows the deposition in absolute numbers and the right figure in relative numbers. The contribution from Danish sources is shown in light grey and contribution from all other sources in dark grey.

Contribution from ammonia

Deposition of ammonia plays a major role for the Danish contribution to the nitrogen deposition to Danish waters. This is illustrated in Figure 3.10, where the relative contribution from Danish sources (to the left) and from ammonia (to the right) is plotted as function of the total atmospheric nitrogen load per km^2. The two contributions are seen relative to the total nitrogen load. The calculations are performed for 1995 for each of the 84 waters. It is seen, that in general, the waters with the highest atmospheric load, are the ones where the largest contribution is comming from ammonia (up to more than 50%). These waters are fjords, creeks and bays, where the contribution from Danish sources is even more than 50%.

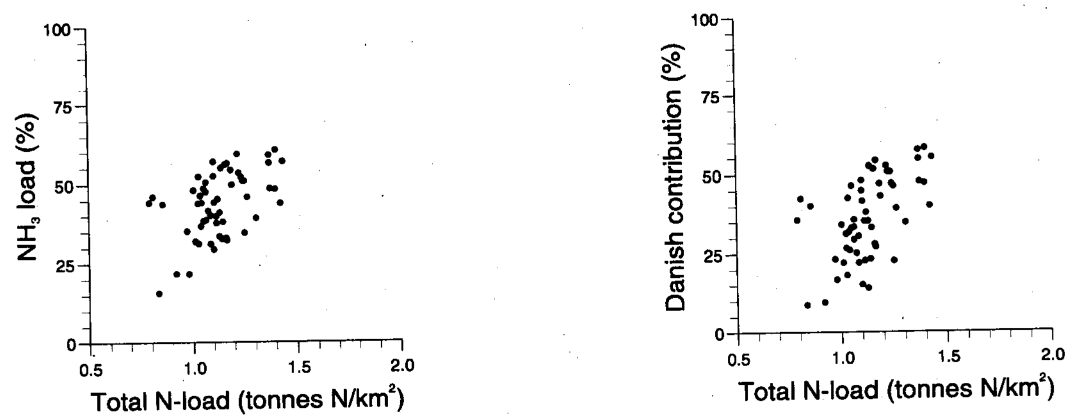
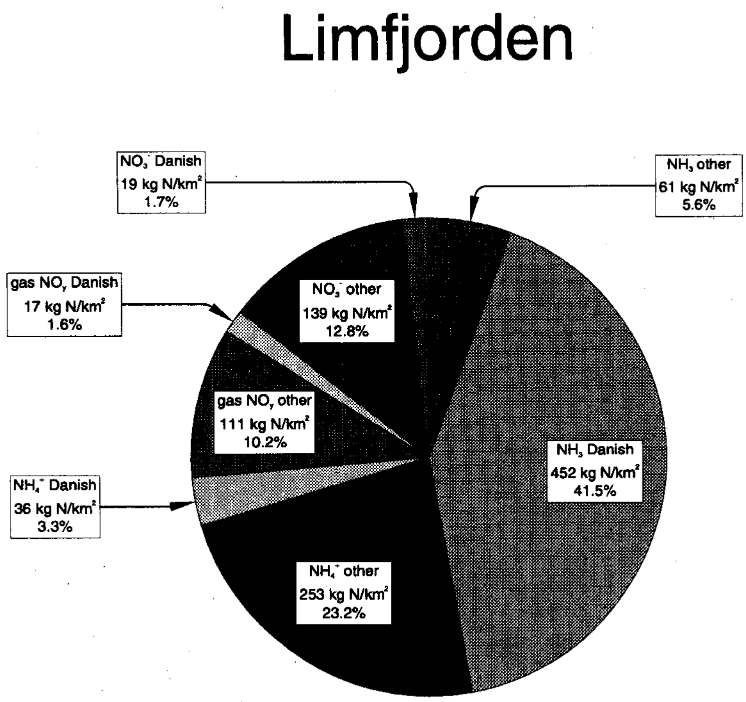


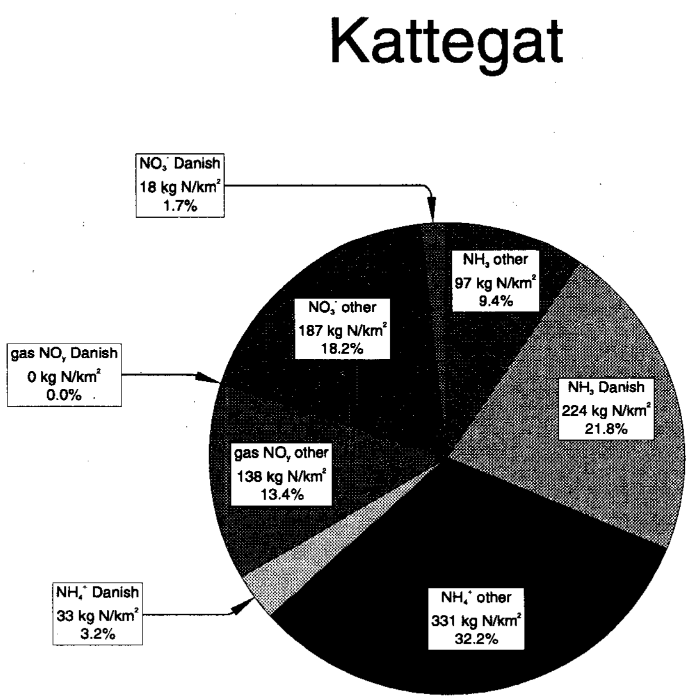
Figure 3.10 Atmospheric nitrogen contribution from respectively ammonia (to the left) and Danish sources (to the right) as a function of the total nitrogen load of the water. The two computed contributions are seen relative to the total nitrogen load. Calculations for each water performed for the year 1995.

Distribution of NH_x and NO_y compounds

A central part of the calculations have been to determine the contributions from agricultural ammonia emissions and nitrogen oxides from combustion processes for Danish and forreign sources. Figure 3.11 show the distribution of the nitrogen deposition on contributions from gas phase NH_3 and NO_y compounds and aerosol phase NH_4^+ and NO_3^-. The results show that for the fjord systems, here examplified with Limfjorden, the deposition of ammonia contributes by 47% of the deposition. Nearly 70% of the total dry deposition of nitrogen compounds to the Limfjorden, originate from dry deposition of ammonia (not shown here). The main part (41.5%) is from Danish agricultural activities. Deposition of aerosols containing ammonium contribute by 26.5% mainly from forreign sources. For the Kattegat Strait the contribution from ammonia per unit surface area is about half of the load of the Limfjorden. For the North Sea, the Danish contribution is as low as 8.8% due to little frequency of easterly winds. In average for Danish waters, emissions agricultural activities contribute by 63.7% of the atmopsheric load, of which the Danish contribution is 15.5%.

Figure 3.11 The distribution in 1995 of the total nitrogen deposition on contributions from the sum of dry and wet depositions of various compounds: gas phase NH_3 and NO_y compounds and NH_4^+ and NO_3^- compounds contained in aerosols. Results are given for the fjord system Limfjorden, the Kattegat Strait, the North Sea and the calculated average of all Danish marine waters. Gas NO_y is the sum of contributions from the gas phase compounds NO, NO_2, HNO_2, HNO_3, N_2O_5, NO_3 and PAN. Results are divided in contributions from Danish and foreign (marked as "other") sources.





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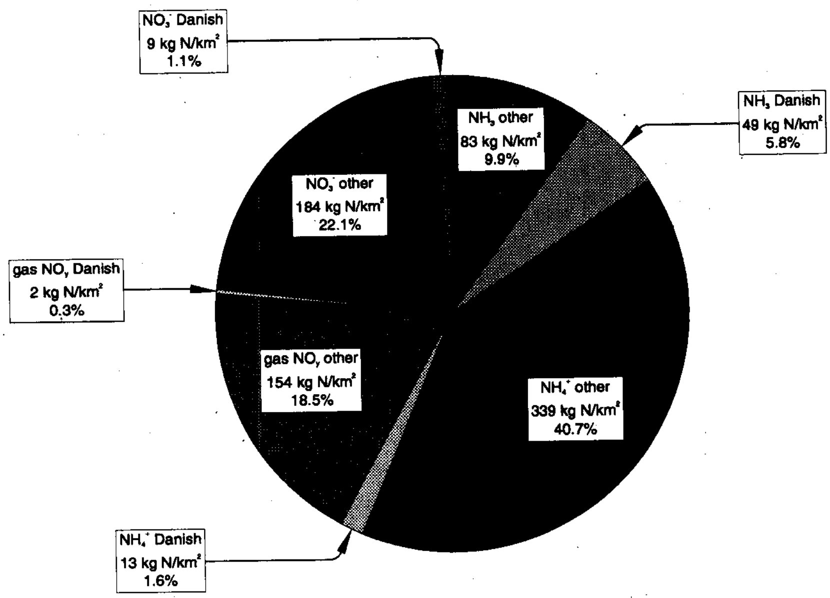
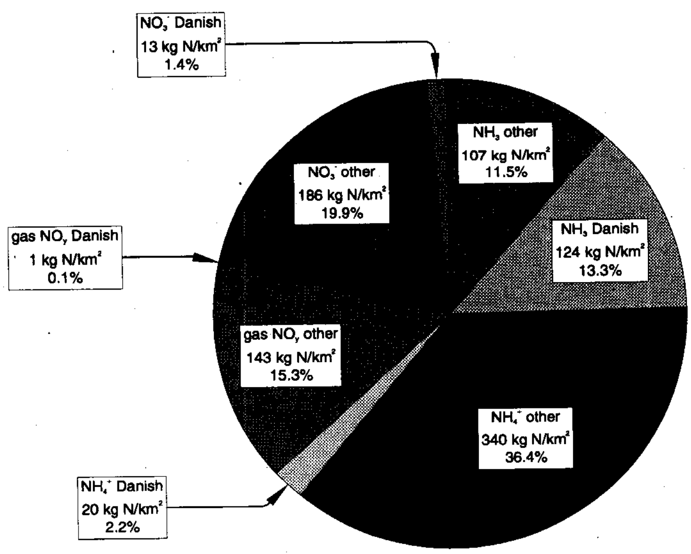


All Danish waters



3.5 Relative importance of the atmospheric load

In the Danish Marine Research Programme, the atmospheric nitrogen load was estimated to 30% of the total annual nitrogen load. Similar results were found in the Danish Background Monitoring Programme (Skov et al. 1996). In Table 3.1 the annual atmospheric contribution is compared with contributions from streams and point sources for all the open Danish waters. For the North Sea, Skagerrak, The Little Belt and The Southern Beltsea, the contribution from the atmospheric is more than 2/3 of the total nitrogen load. Half of the total the nitrogen deposition to Danish marine waters come from atmospheric nitrogen deposition. It should be noted that nitrogen compounds in the flows in and out of the water are disregarded in these estimates.

Table 3.1 The total nitrogen load of the open Danish waters from streams, direct point sources and the atmosphere, stated in ton N. It should be noted that the nitrogen contained in the flows in and out of the water is disregarded. Data for streams are computed by NERI, and point source emissions by the Danish EPA. These data are reported in Kaas et al. (1996).

Water	Streams[a]	Point sources	Atmosphere	Atm. %
The North Sea	21,000	560	40,000	65
Skagerrak	2,250	360	9,900	79
Kattegat	31,700	1,410	15,200	31
The Northern Beltsea	6,100	480	3,800	37
The Little Belt	7,900	540	2,180	21
The Great Belt	10,600	700	4,000	26
The Sound	1,850	4,130	1,400	19
The Southern Beltsea	750	20	2,700	78
The Eastern Baltic	1,073	222	10,600	89
The Western Baltic	1,179	29	3,600	75
Dk total[b]	84,400	8,450	98,000	51

[a] Including point sources received by the streams
[b] Including all Danish waters, fjords, bays and creeks

Table 3.2 shows similar figures as Table 3.1, but this time for the fjords, creeks and bays. As expected the contribution is significantly smaller than for the open waters. It should be noted that the uncertainties in these estimates are considerably higher than for the open waters (see the discussions in section 3.3).

Table 3.2 The total nitrogen load of the Danish fjords, creeks and bays from streams, direct point sources and the atmosphere, stated in ton N. It should be noted that the nitrogen contained in the flows in and out of the water is disregarded. Data for streams are computed by NERI, and point source emissions by the Danish EPA. These data are reported in Kaas et al. (1996).

Water	Streams	Point sources	Atmosphere	Atm. %
Aabenraa Fjord	205	46	34	12
Augustenborg Fjord	298	3	14	4
Dybsoe Fjord	73	0	19	21
Ebeltoft vig	115	4	94	44
Flensborg Fjord	448	40	135	22
Gamborg Fjord	117	0	12	9
Genner Bugt	94	0	5	5
Guldborg Bredning	286	0	38	12
Guldborg Sund	767	58	102	11
Haderslev Fjord	368	19	5	1
Halkaer Bredning	691	0	8	1
Helnaes Bugt	327	1	66	17
Holbaek Fjord	367	16	20	5
Holckenhavn Fj.	471	0	1	0
Holsteinborg Nor	40	2	9	18
Horsens Fjord	1,400	192	64	4
Isefjord inner	684	38	55	7
Isefjord outer	1,006	45	248	19
Kalundborg Fjord	154	47	84	29
Karrebaek Fjord.	2,131	60	16	1
Kolding Fjord	940	8	17	2
Korsoer Nor	68	2	10	13
Limfjorden	17,279	622	880	5
Lovns Bredning	698	1	97	12
Mariager Fjord	1,528	100	66	4
Nakskov Fjord	543	4	48	8
Nissum Fjord	2,930	1	64	2
Norsminde Fjord	168	3	2	1
Odense Fjord	2,312	105	75	3
Praestoe Fjord	258	3	25	9
Randers Fjord	5,215	93	30	1
Ringkoebing Fjord	6,351	62	305	5
Risgaarde Bredning	150	0	66	31
Roskilde Fjord	1,530	124	142	8
Skive Fjord	1271	1	40	3
Stavns Fjord	12	0	16	57
Stege Bugt	124	13	48	26
Vejle Fjord	1,833	11	68	4

3.6 Uncertainties in the calculations

Main uncertainties in calculations

The ACDEP-model is in the process of being further developed, and several of the uncertainties are subject to modifications in the future. The major uncertainties in the calculations can be summarised as:

- Uncertainties in the emissions inventories for Denmark as well as the rest of Europe. The uncertainties are generally estimated to be in the order of 30 to 40% on the annual country-wise emissions. For some countries, the reported emissions remain unchanged for several years. In these cases it seems likely that the uncertainties in the annual emissions are even higher than 40%. For the presented calculations some simple functions have been applied in order to describe the seasonal and diurnal variations (see Asman et al. 1994; 1995; Hertel et al. 1995; Ellermann et al. 1996). The uncertainties in the emissions at a given point to a give time of day and year can therefore be significant.
- Uncertainties in the applied meteorological data. The used data are on the coarse EMEP grid (150 km x 150 km) and especially for the precipitation amounts this is critical for the results. In order to avoid un-physical gradients over the marine waters, a simple smoothing has been applied in the calculation procedure (Skov et al. 1996; Ellermann et al. 1996). Precipitation events are highly local phenomena. Despite some adjustment of the precipitation amounts have been performed using observations, the uncertainties in these data are therefore still very high.
- The procedure for estimation of boundary layer height is based on the EMEP meteorological data. These data do not take into account the special conditions over water. Often the boundary layer heights over sea are considerably different from the conditions over land. This affects the air masses significantly when the air passes the transition between land and sea, especially within 5 to 10 km from the transition.
- The description of nitrogen compounds in aerosol phase is highly simplified. These compounds are treated in the same way as the gas phase compounds, except for the description of dry deposition where all compounds are assumed to be associated with aerosols with a diameter of 1 μm. In the marine boundary layer very large variations in actual aerosol size distributions occur , but in average this is probably a reasonable assumption (e.g. Hillamo et al. 1992; Pakkanen et al. 1996; Kerminen et al. 1997). The dry deposition velocity of aerosols vary with the diameter by several orders of magnitude, so a major uncertainty is introduced by this simplified procedure (e.g. Vignati, Hertel 1996).

Estimated uncertainty

In (Skov et al. 1996) the uncertainties in the total nitrogen deposition to Danish marine waters was estimated to about 40% for the open waters and 60% for the fjord systems, creeks and bays. The estimation of the contribution from Danish atmospheric sources is probably connected with similar uncertainties.

Slight change in presented results

It should be noted, that the computed depositions presented in this report are slightly higher than reported in Skov et al. (1996). The explanation for this is a minor error in the calculation of nitrogen deposition (N_2O_5 contains two N molecules, which was not accounted for in the results given in (Skov et al. 1996)).

4 Discussion and conclusions

Aim of the work

The primary aim of the present report was to estimate the contribution from Danish atmospheric sources to the nitrogen deposition to Danish marine waters. These estimates were obtained from model calculations performed with the ACDEP-model to a 30 km x 30 km grid covering all Danish marine waters, and including totally 212 receptor points. The calculations were performed with and without Danish atmospheric emissions, and the contribution from Danish sources was estimated from the differences in the two sets of model results.

Contribution from ammonia

Emissions of ammonia from agricultural activities give the largest contribution to nitrogen deposition from Danish sources. Ammonia has two main path ways in the atmosphere, dry deposition and removal due to chemical reactions. The further away from the agricultural sources, the more ammonia will be transformed into ammonium contained in aerosols. The nitrogen contribution per surface area from dry deposition of ammonia is therefore largest closer to the sources. Compared to the open waters, ammonia contributes therefore considerable more to the deposition to fjords, creeks and bays.

Contribution from nitrogen oxides

The analyses shows that the contributions of nitrogen oxides emitted from Danish sources are small. The primary pollutants NO and NO_2 are not deposited to sea. These have therefore to be chemically transformed into other nitrogen oxide compounds before giving a contribution to the nitrogen load. In most cases the air masses have left Danish territory before the nitrogen oxides have been transformed to nitric acid and nitrogen containing aerosols that are deposited to the sea.

Model results

The annual atmospheric nitrogen load to Danish marine waters has been estimated to be in the order of 100 ktonnes N. The total surface area of the Danish marine waters is about 105.000 km^2. This means an average annual atmospheric load of about 1000 kg N /km^2 of which the Danish contribution is about 160 kg N/km^2 (the results showed values between 14 and 19% for the various years). The model results show only little year to year variation over the period and no trend.

Emissions 1989 to 1995

The emission inventories for Denmark (Table 3.1) indicate a general decrease in the NH_3 emissions of about 15% over the period 1989 to 1995. For the same period the NO_x emissions are more or less unchanged. However, the 15% decrease in NH_3 emissions does not seem to have an effect on the calculated nitrogen deposition. Since the Danish contribution in most cases is limited. The non-linear impact from atmospheric reactions and year to year variations in meteorological conditions furthermore means that a decrease in emissions not necessarily leads to a similar decrease in the depositions. When acids such as sulphuric acid (H_2SO_4) and nitric acid (HNO_3) are present in the atmosphere, NH_3 will quickly react with these in gas phase or on the surface of aerosols and form ammonium containing aerosols. Also HCl will under certain conditions have a similar impact on the ammonia concentrations as the other acids, but this compound is not at yet included in the ACDEP-model. The ammonia reactions with atmospheric acids are sufficiently fast to remove a large part of the ammonia before it is dry deposited to the surface.

Wet deposition to open waters

The nitrogen depositions to the open marine waters are mainly governed by wet deposition of nitrogen containing aerosols. Most of these aerosols depositing over Danish waters are long range transported from source regions outside Denmark. If no precipitation events occur within an air parcel, the aerosols contained in the air parcel, may have life times of 7 to 10 days and can therefore be transported over thousands of kilometres. This is the main reason why the atmospheric nitrogen load of the open Danish waters is dominated by contributions from abroad, and not from domestic sources.

Main results

The analyses shows that the contributions from Danish sources to the open Danish waters are small. The geographic placement of fjords, creeks and bay closer to the agricultural ammonia sources over land, leads to a larger Danish contribution for these waters (up to half of the atmospheric load). However the uncertainties in the presented model calculations are large.

Significance of the atmospheric load

The presented calculations show that the atmospheric contribution is about half of the total nitrogen load of Danish waters (disregarding the nutrients transported within the flows from surrounding marine waters). For some of the open waters the contribution is about 2/3 of the total load. These calculations show the significance of the atmospheric load for Danish marine waters.

The Danish nitrogen budget

According to the emission inventories from EMEP, Danish atmospheric sources emit on annual basis about 105,000 tonnes of NH_3-N and 84,000 tonnes NO_x-N. The presented calculations gives a total load of the Danish marine waters of about 100,000 tonnes N in 1995. In average for Danish land areas, ACDEP calculations show that the nitrogen deposition is about 1.5 tonnes N/km^2 (these calculations are not shown here). Since the Danish land area is about 40,000 km^2, this means a total deposition of about 60,000 tonnes N to Danish land area. The total nitrogen budget for Denmark's shows therefore a minor net export of nitrogen, with about 160,000 tonnes N deposited to Danish land and sea and about 190,000 tonnes N emitted from Danish atmospheric sources. This net export, however, is within the uncertainty of the given figures.

References

Asman, W.A.H., Runge, E.H., Kilde, N.A., 1993: Emission of NH_3, NO_x, SO_2 and NMVOC to the atmosphere in Denmark (In Danish: Emission af NH_3, NO_x, SO_2 og NMVOC til atmosfæren i Danmark). Copenhagen, Danish Environmental Protection Agency. 108 pp. Under the series "Marine Research from the Danish Environmental Protection Agency", - Report no 19.

Asman, W.A.H., Berkowicz, R., Christensen, J., Hertel, O., Runge, E., 1994: Deposition of nitrogen compounds to Kattegat (In Danish: Afsætning af kvælstofforbindelser til Kattegat). Copenhagen, Danish Environmental Protection Agency. 115 pp. Under the series "Marine Research from the Danish Environmental Protection Agency", - Report no 37.

Asman, W.A.H., Hertel, O., Berkowicz, R., Christensen, J., Runge, E.H., Sørensen, L.L., Granby, K., Nielsen, H., Jensen, B., Gryning, S.E., Sempreviva, A.M., Larsen, S., Hummelshøj, P., Jensen, N.O., Allerup, P., Jørgensen, J., Madsen, H., Overgaard, S., Vejen, F., 1995: Atmospheric Nitrogen input to the Kattegat Strait. Ophelia, 42: 5-28.

Ellermann, T., Hertel, O., Skov, H., Manscher, O., 1996: The Nationwide Danish Monitoring Programme, Atmospheric Deposition of Nitrogen. Measuring methods and model calculations (In Danish: Vandmiljøplanens Overvågningsprogram 1995, Atmosfærisk deposition af kvælstof. Målemetoder og modelberegninger). Roskilde, National Environmental Research Institute. 57 pp. - Technical Report from NERI, no 174.

Hertel, O., Christensen, J., Runge, E.H., Asman, W.A.H., Berkowicz, R., Hovmand, M.F., Hov, Ø. 1995: Development and Testing of a new Variable Scale Air Pollution Model - ACDEP. Atmospheric Environment, 29 (11): 1267-1290.

Hertel, O., Skov, H., Ellermann, T., 1997: Long term modelling of the Nitrogen Deposition to Danish Sea Waters 1989-95 (pp 53-63). Proceedings of the REMAPE - workshop (Eds. G. Geernaert, A.W. Hansen and Z. Zlatev), Copenhagen University, Sep. 26-27, 1996. 280 pp. Roskilde, National Environmental Research Institute and University of Copenhagen.

Hillamo, R.M., Pacyna, J.M., Semb, A., and Hanssen, J.E., 1992: Size distributionbs of inorganic ions in atmospheric aerosol in Norway. In I. Allegrini (Ed.): Development of Analytical Techniques for Atmospheric Pollutants. Air Pollut. Res. Rep. 41, pp 239-261, Reidel, Norwell, Mass.

Iversen, T., Halvorson, N.E., Saltbones, J., Sandnes, H., 1990: Calculated budgets for airborne sulphur and nitrogen in Europe. Olso : Meteorological Synthesizing Centre-West, Norwegian Meteorological Institute. xx pp. - EMEP/MSC-W Report 2/90.

Kaas, H., Mølenberg, F., Josefson, A., Rasmussen, B., Krause-Jensen, D., Jensen, H.S., Svendsen, L.M., Windolf, J., Middelboe, A.L., Sand-Jensen, K., and Foldager Pedersen, M., 1996: Marine areas. Danish fjrods - status for the environment, baggrund and development (In Danish: Marine områder. Danske Fjorde - status over miljøtilstand, årsagssammenhænge og udvikling. Vandmiljøplanens Overvågningsprogram 1995). National Environmental Research Institute, 205 pp. - Technical Report from NERI, no 179.

Kerminen, V.M., Pakkanen, T.A., and Hillamo, R., 1997: Interactions between inorganic trace gases and supermicrometer particles at a coastal site. Atmospheric Environment, 31 (17): 2753-2765.

Mylona, S., 1996: Emissions; the collation and nature of the emission data. In.: Barret, K., Berge, E. (eds.): Transboundary Air Pollution in Europe. Part 1: Estimated dispersion of acidifying agents and of near surface ozone. Oslo : Meteorological Synthesizing Centre-West, Norwegian Meteorological Institute. 182 pp. - EMEP/MSC-W Report 1/96.

Pakkanen, T.A, Kerminen, V.-M., Hillamo, R.E., Mäkinen, M., Mäkelä, T., and Virkkula, A., 1996: Distribution of nitrate over sea-salt and soil derived particles - implications from a field study. Journal of Atmospheric Chemistry, 24: 189-205.

Skov, H., Hertel, O., Manscher, O., Hovmand, M.F., Grundahl, L., Kemp, K., Heidam, N.Z., 1995: The Nation-wide Danish Monitoring Programme 1994, Atmospheric Deposition of Nitrogen (In Danish: Vandmiljøplanens Overvågningsprogram 1994, Atmosfærisk deposition af kvælstof). Roskilde: National Environmental Research Institute. 83 pp.- Technical Report from NERI, no 144.

Skov, H., Ellermann,T., Hertel, O., Manscher, O., Frohn, L.M., 1996: The Nation-wide Danish Monitoring Programme 1995, Atmospheric Deposition of Nitrogen (In Danish: Vandmiljøplanens Overvågningsprogram 1995, Atmosfærisk deposition af kvælstof). Roskilde: National Environmental Research Institute. 85 pp (and separate enclosure report 283 pp.). - Technical Report from NERI, no 173.

Vignati, E., Hertel, O., 1996: Modelling Atmospheric Nitrogen Deposition to Sea. A newly initiated study of the influence of aerosols and heterogeneous chemistry (pp 140-142). In Hummelshøj, P. (Ed.): Proceedings of NOSA/NORSAC Symposium , Helsingør, Denmark, Nov. 15-17 1996. Roskilde, Risø National Laboratory. 151 pp. - Risø-R-934 (EN).

Appendix A. Dry, Wet and Total Nitrogen Deposition

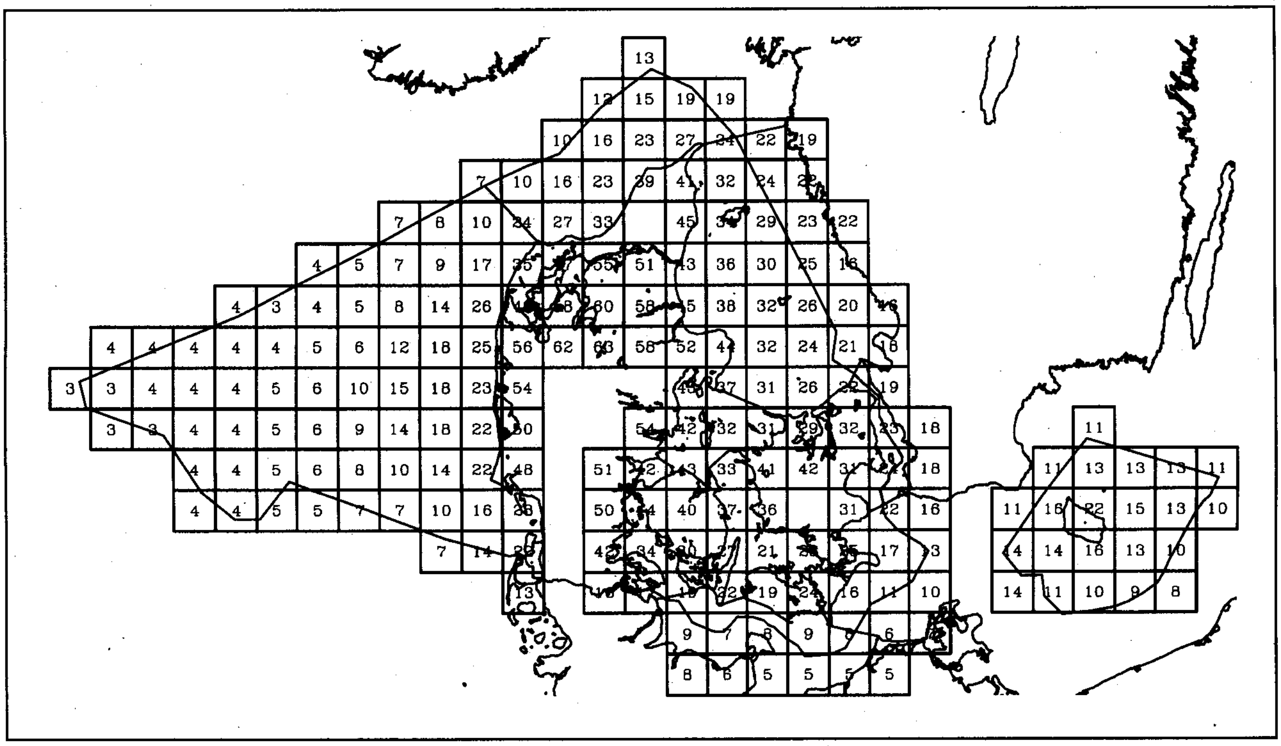


Figure A.1 The relative impact of Danish atmospheric emissions on the total deposition of nitrogen compounds to Danish marine waters given in per cent of the total nitrogen deposition. Calculations for the year 1989.

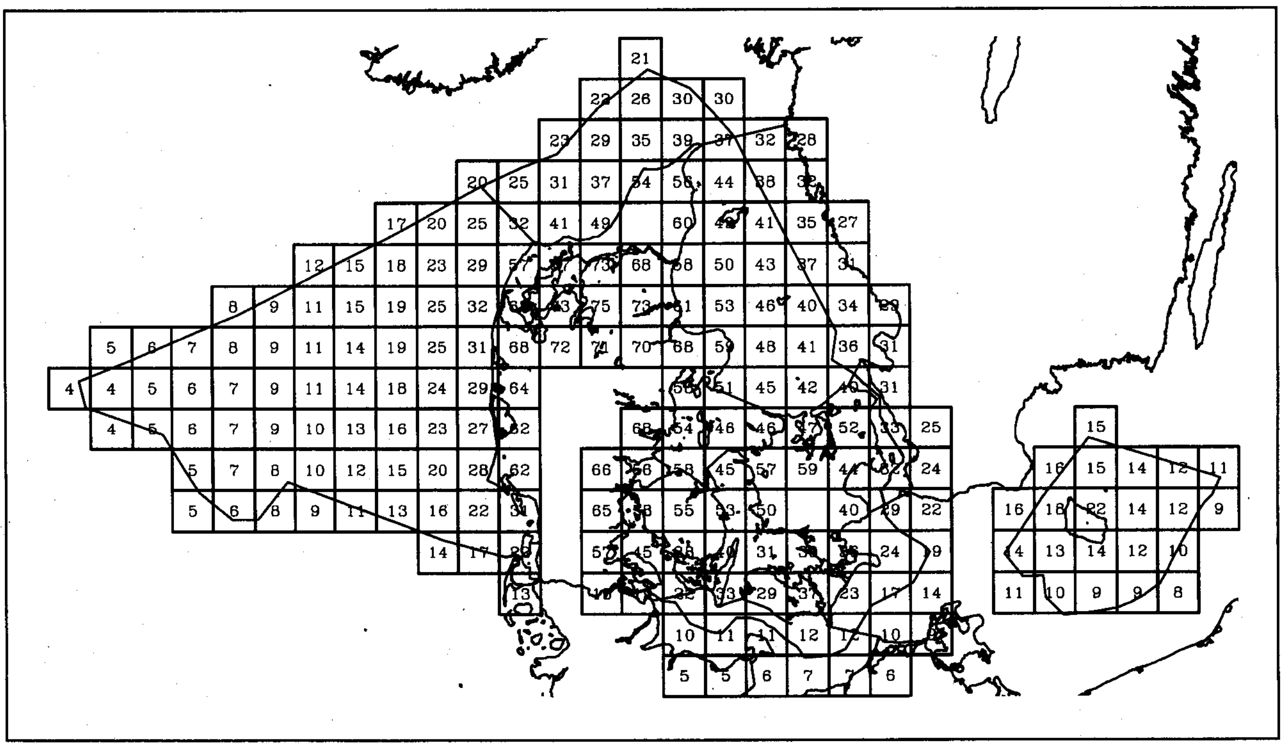


Figure A.2 The relative impact of Danish emissions on the dry deposition of nitrogen compounds to Danish marine waters given in per cent of the total dry deposition of nitrogen compounds. Calculations for the year 1989.

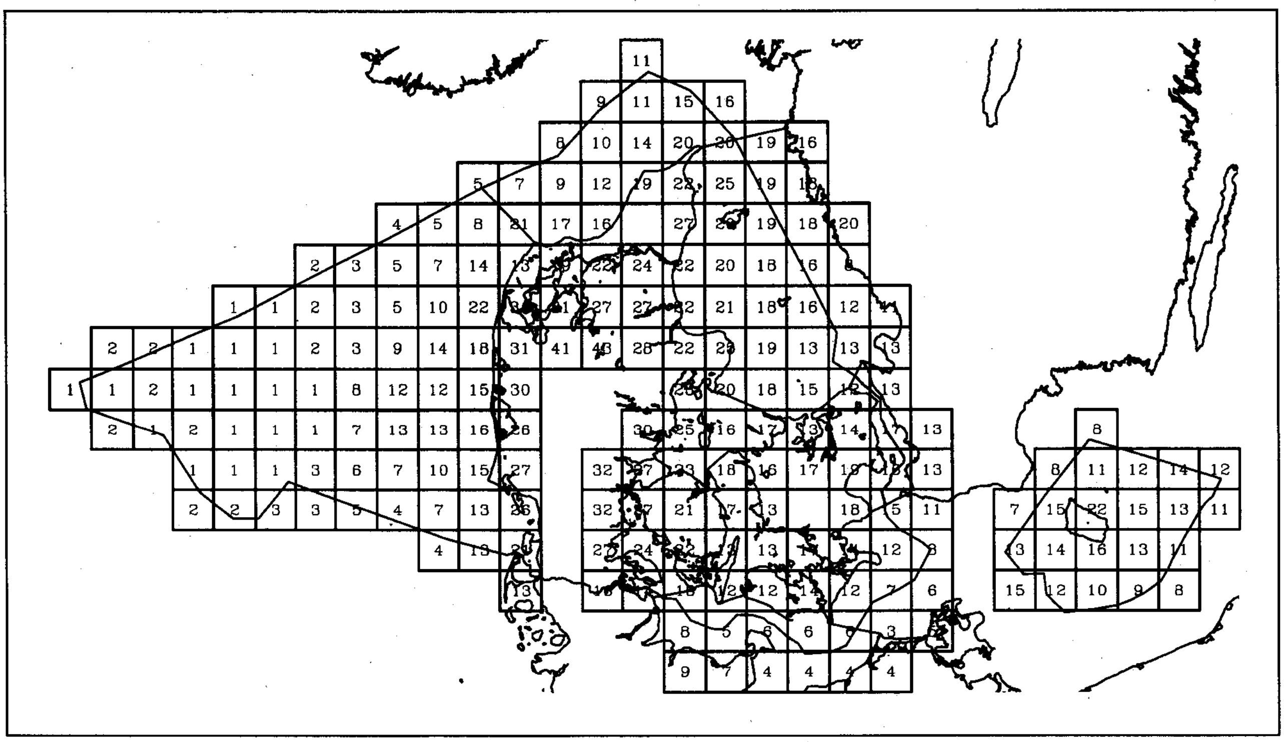


Figure A.3 The relative impact of Danish atmospheric emissions on the wet deposition of nitrogen to Danish marine waters given in per cent of the total wet deposition of nitrogen. Calculations for the year 1989.

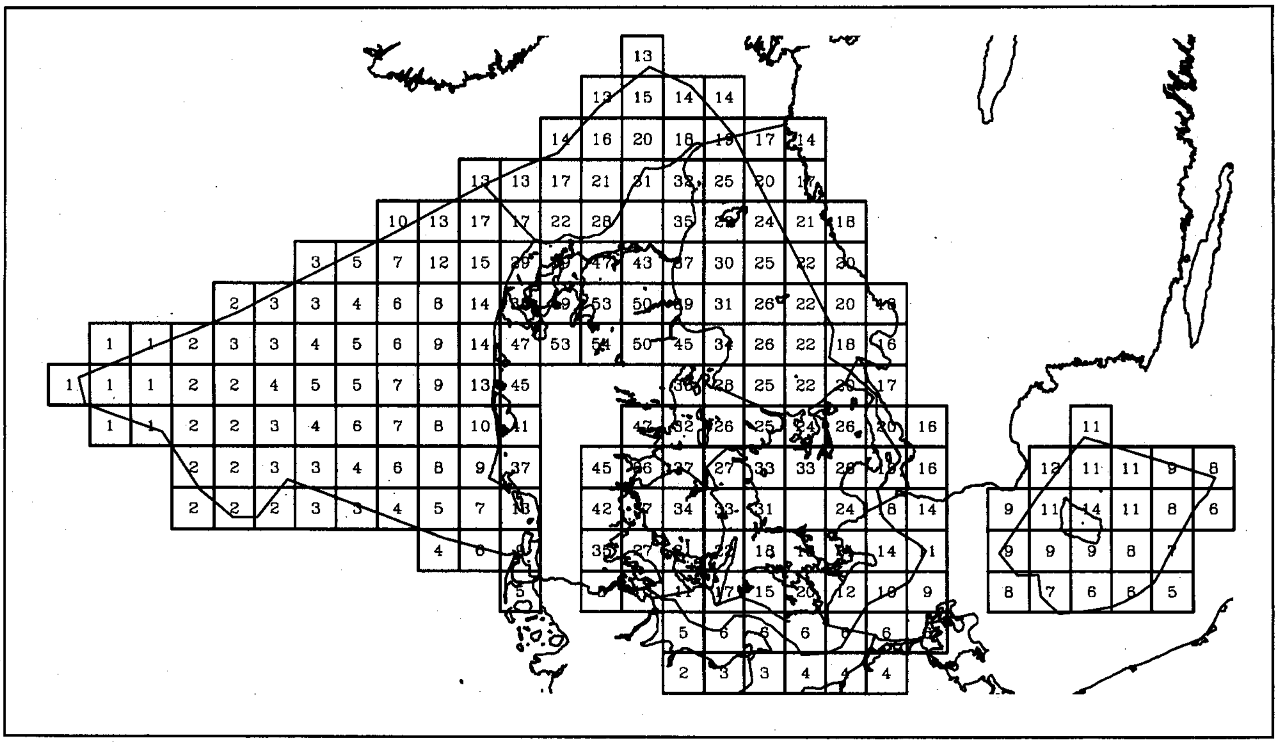


Figure A4. The relative impact of Danish atmospheric emissions on the total nitrogen deposition to Danish marine waters given in per cent of the total nitrogen deposition. Calculations for the year 1990.

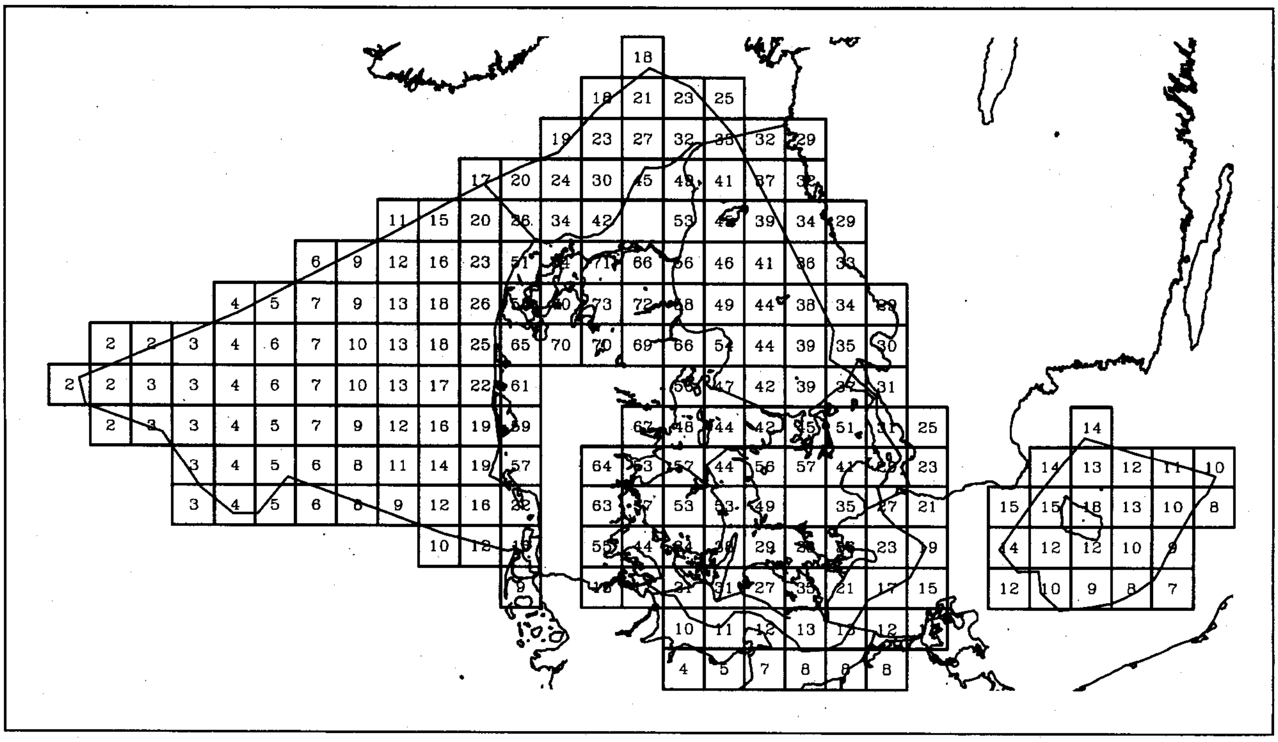


Figure A.5 The relative impact of Danish atmospheric emissions on the dry deposition of nitrogen compounds to Danish marine waters given in per cent of the total dry deposition of nitrogen. Calculations for the year 1990.

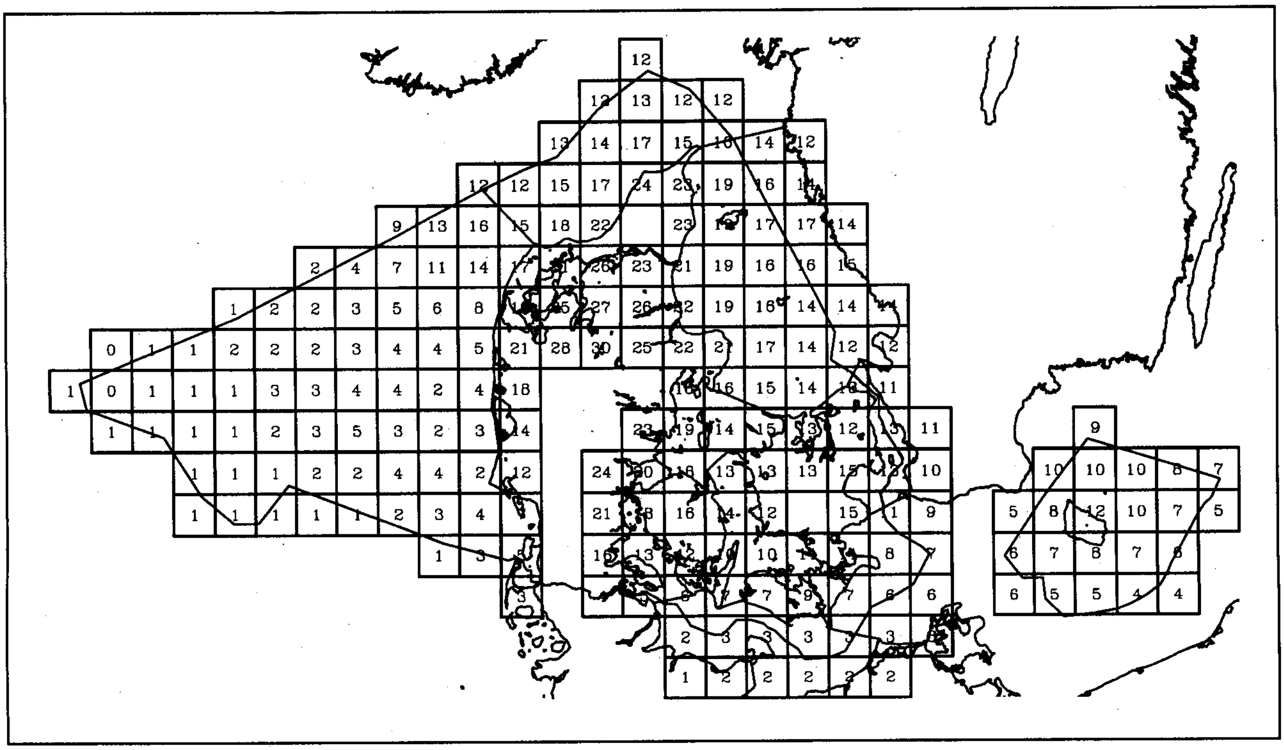


Figure A.6 The relative impact of Danish atmospheric emissions on the wet deposition of nitrogen to Danish marine waters given in per cent of the total wet deposition of nitrogen compounds. Calculations for the year 1990.

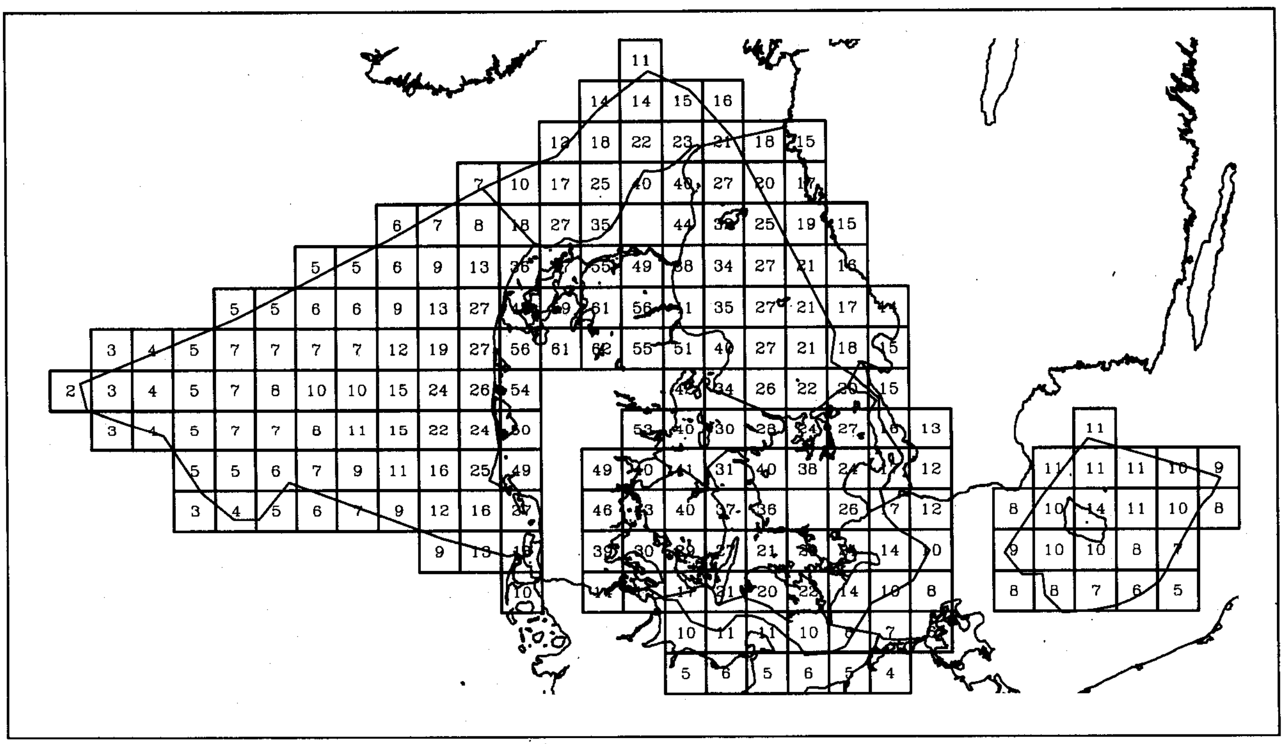


Figure A.7 The relative impact of Danish atmospheric emissions on the total nitrogen deposition to Danish marine waters given in per cent of the total nitrogen deposition. Calculations for the year 1991.

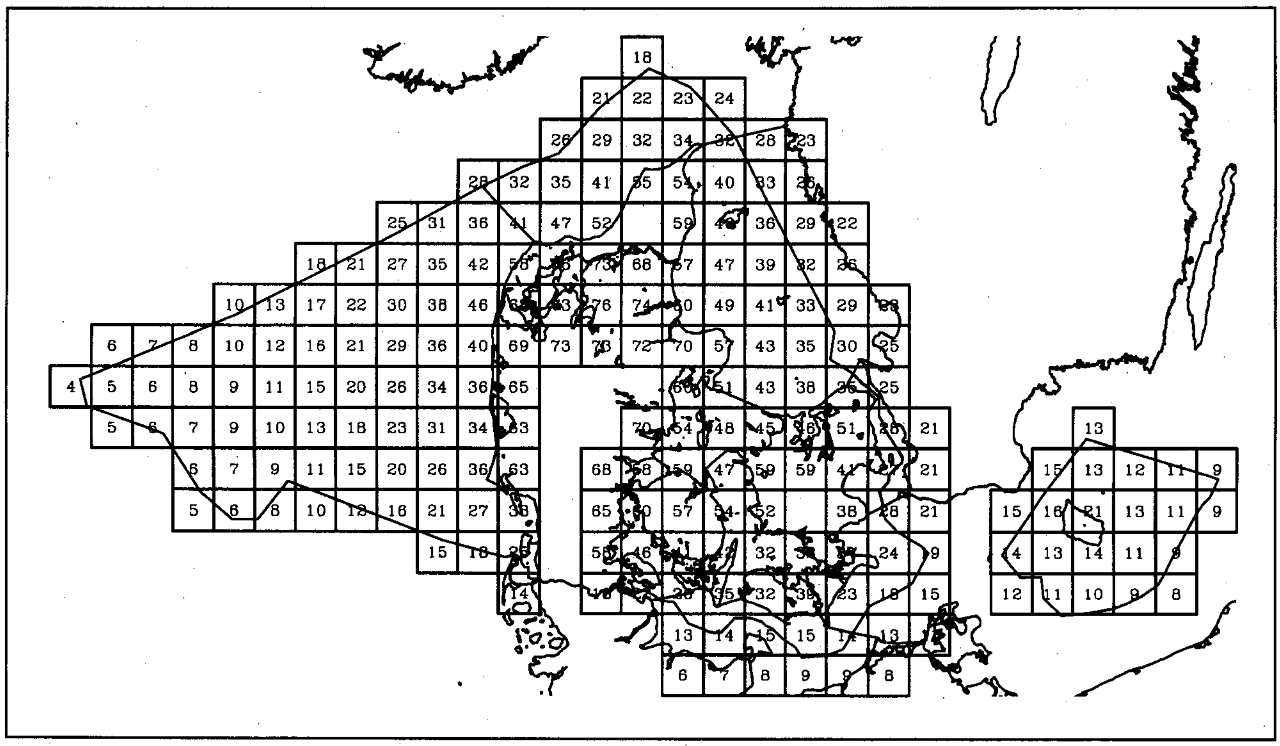


Figure A.8 The relative impact of Danish atmospheric emissions on the dry deposition of nitrogen compounds to Danish marine waters given in per cent of the total dry deposition of nitrogen compounds. Calculations for the year 1991.

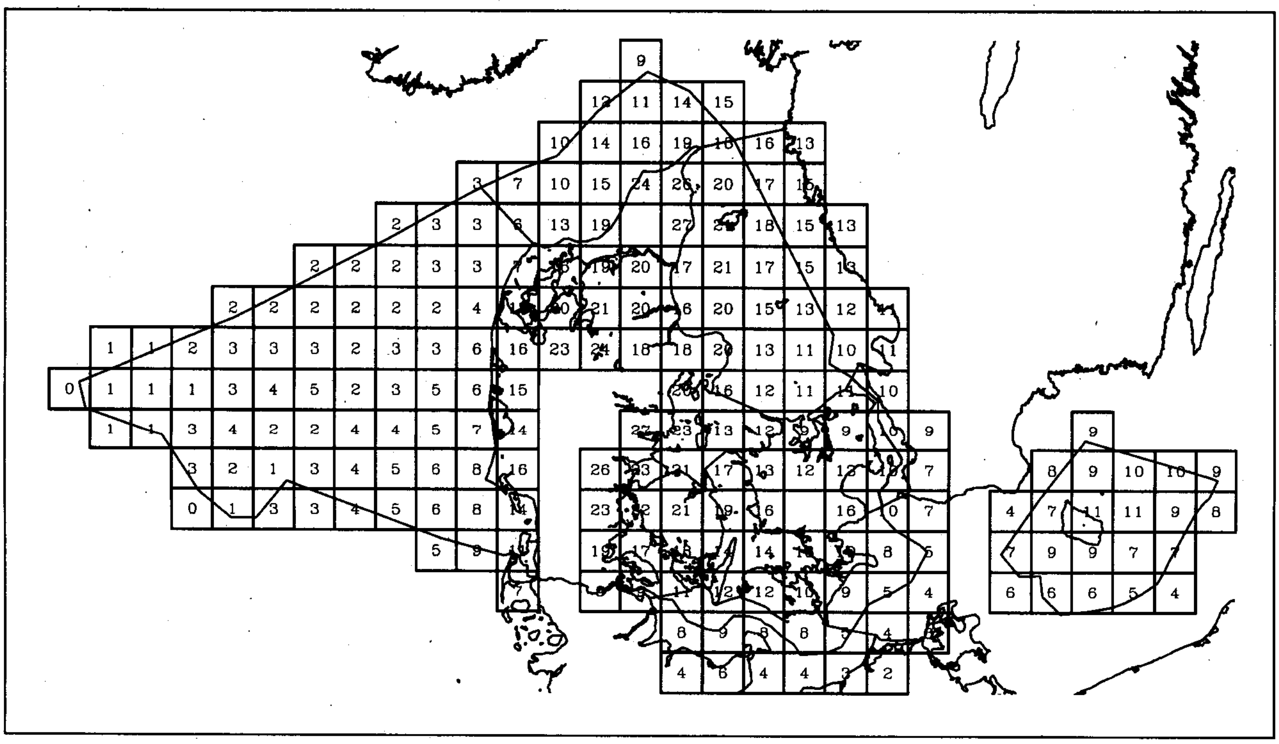


Figure A.9 The relative impact of Danish atmospheric emissions on the wet deposition of nitrogen compounds to Danish marine waters given in per cent of the total deposition. Calculations for the year 1991.

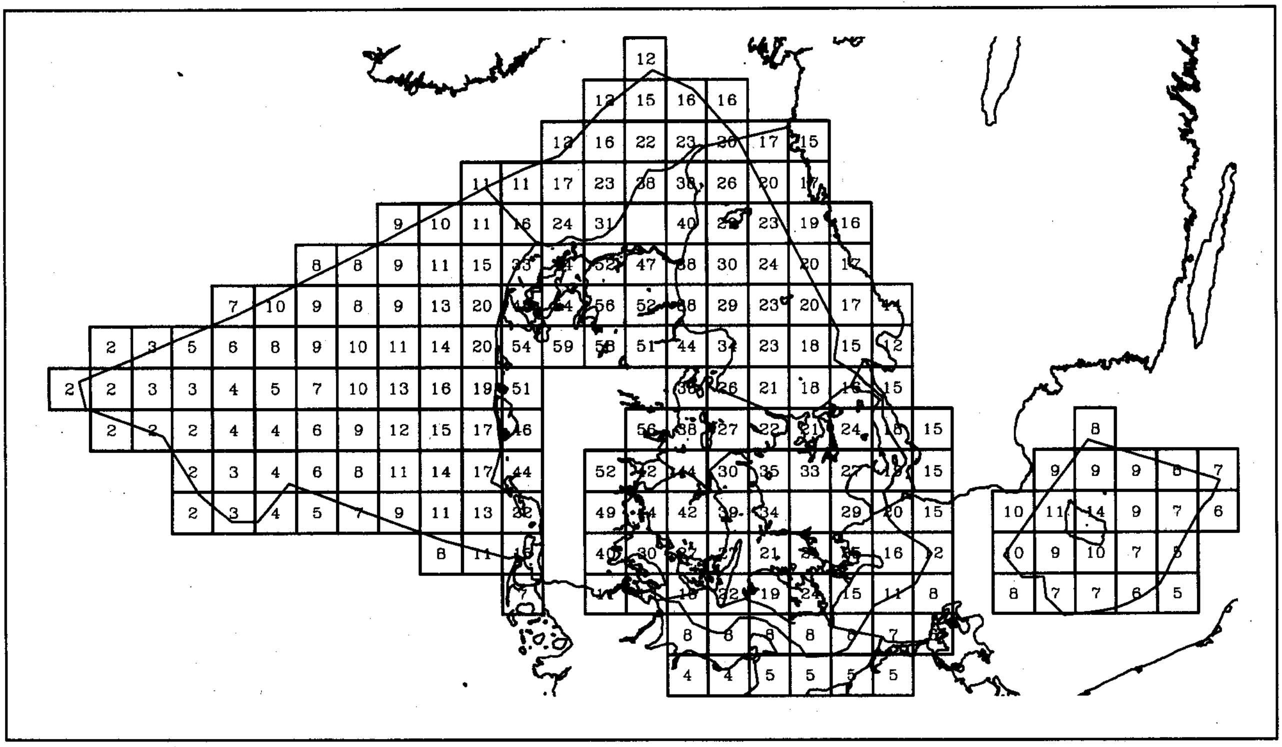


Figure A.10 The relative impact of Danish atmospheric emissions on the total nitrogen deposition to Danish marine waters given in per cent of the total atmospheric deposition. Calculations for the year 1992.

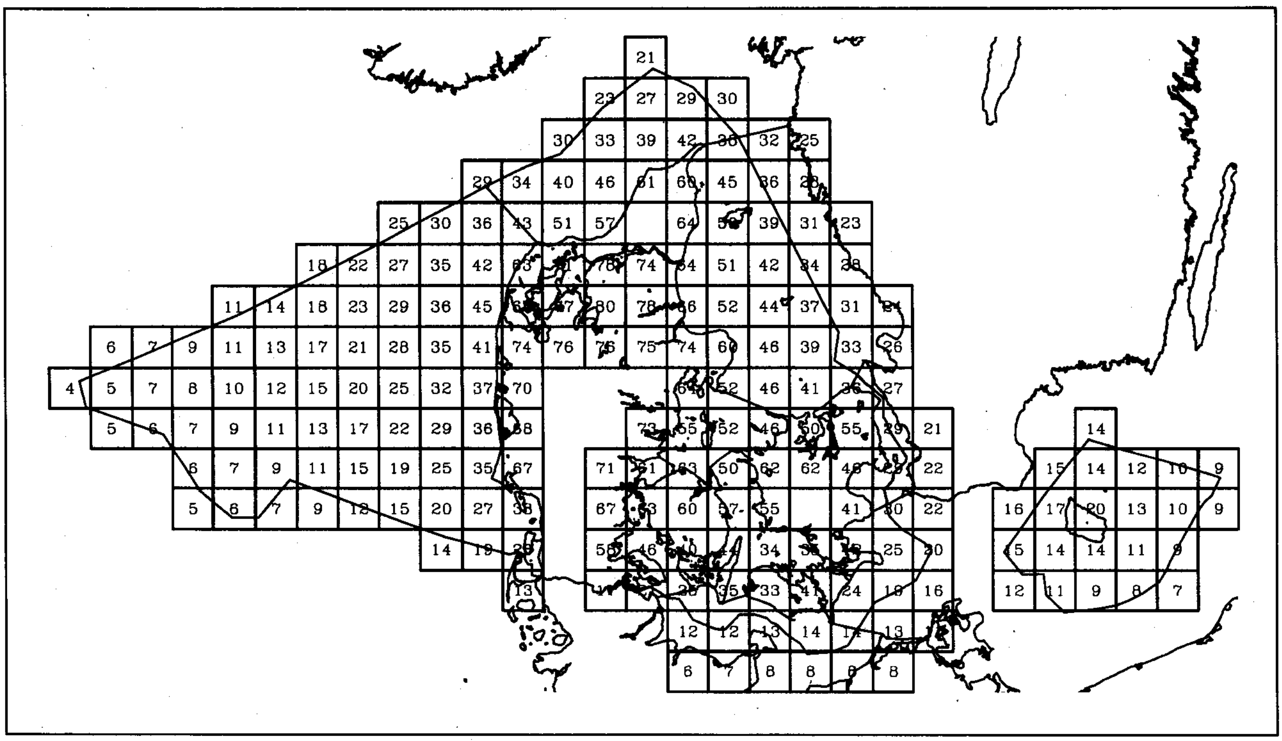


Figure A.11 The relative impact of Danish atmospheric emissions on the dry deposition of nitrogen compounds to Danish marine waters given in per cent of the total dry deposition of nitrogen compounds. Calculations for the year 1992.

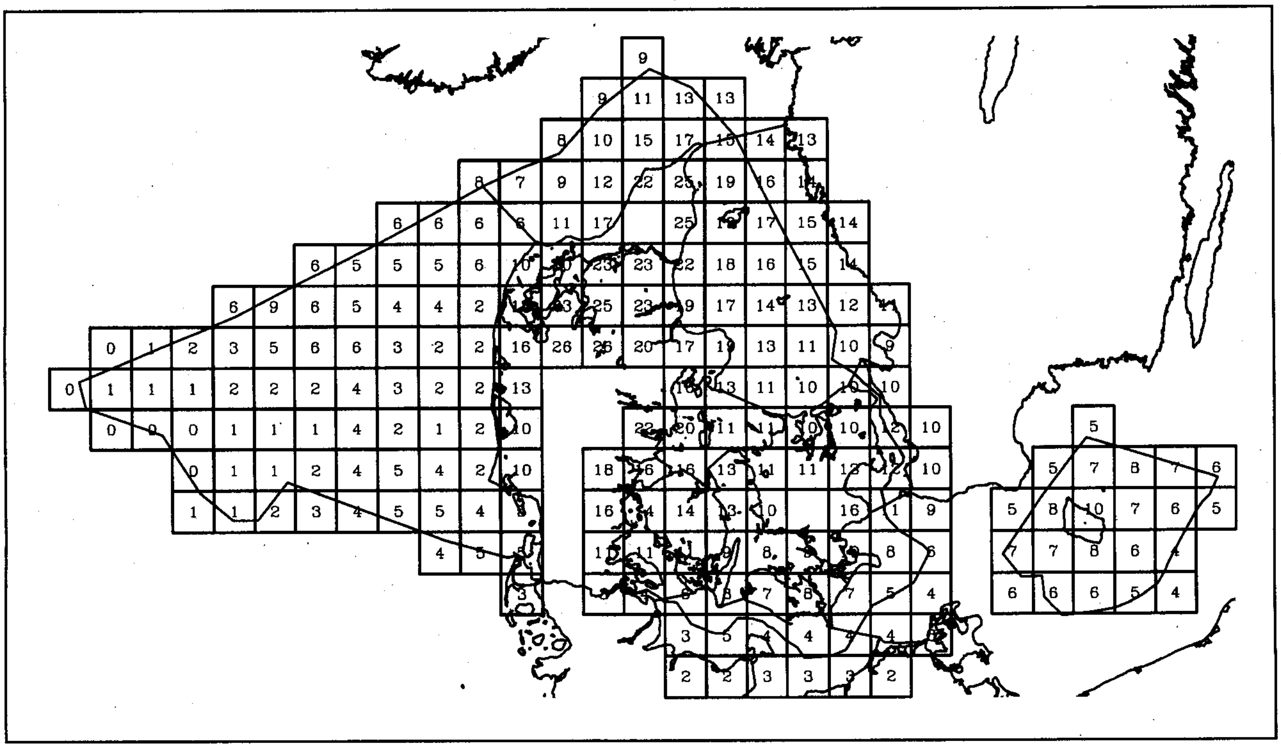


Figure A.12 The relative impact of Danish atmospheric emissions on the wet deposition of nitrogen compounds to Danish marine waters given in per cent of the total wet deposition of nitrogen compounds. Calculations for the year 1992.

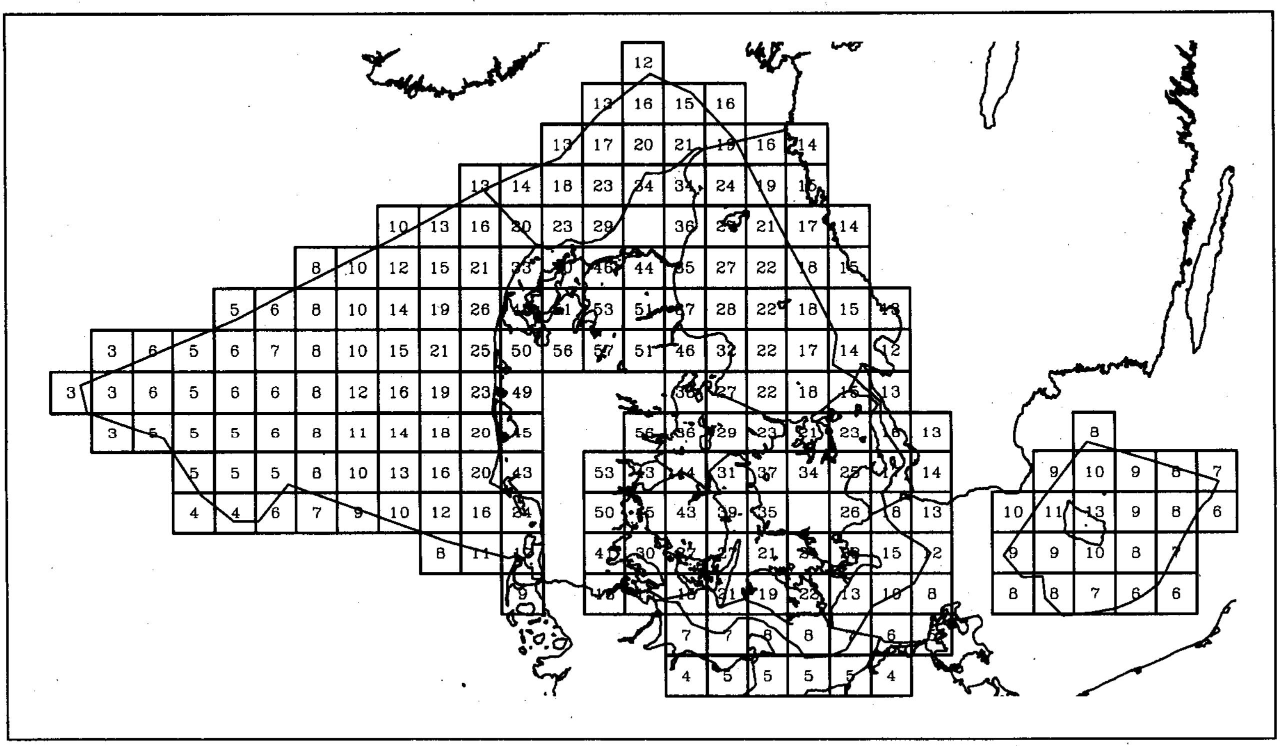


Figure A.13 The relative impact of Danish atmospheric emissions on the total nitrogen deposition to Danish marine waters given in per cent of the total nitrogen deposition. Calculations for the year 1993.

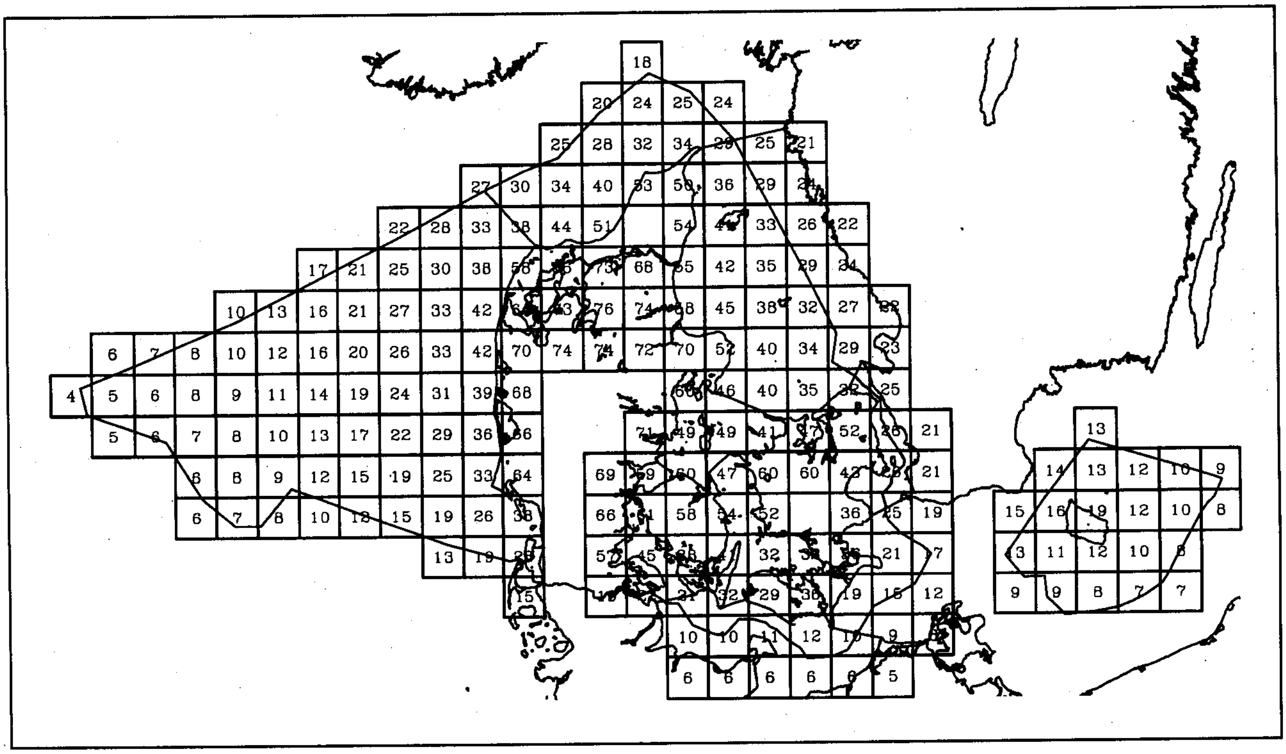


Figure A.14 The relative impact of Danish atmospheric emissions on the dry deposition of nitrogen compounds to Danish marine waters given in per cent of the total dry deposition of nitrogen compounds. Calculations for the year 1993.

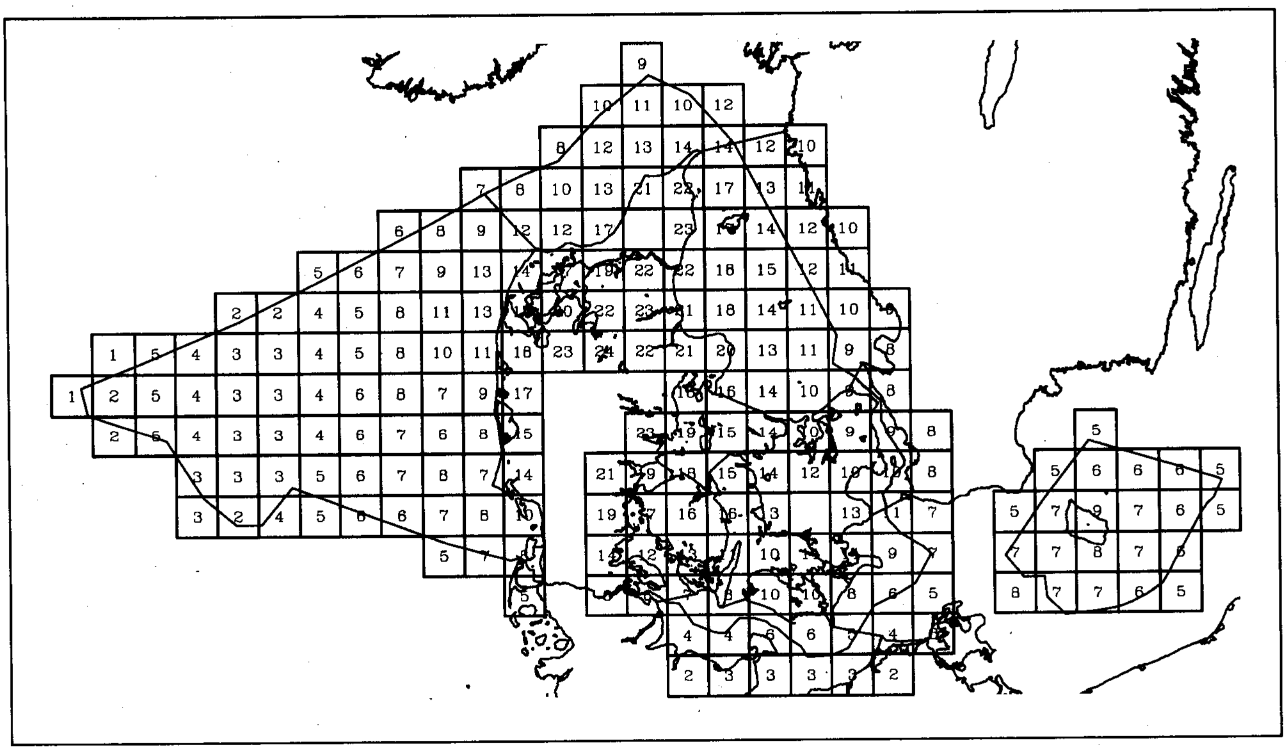


Figure A.15 The relative impact of Danish atmospheric emissions on the wet deposition of nitrogen compounds to Danish marine waters given in per cent of the total wet deposition of nitrogen compounds. Calculations for the year 1993.

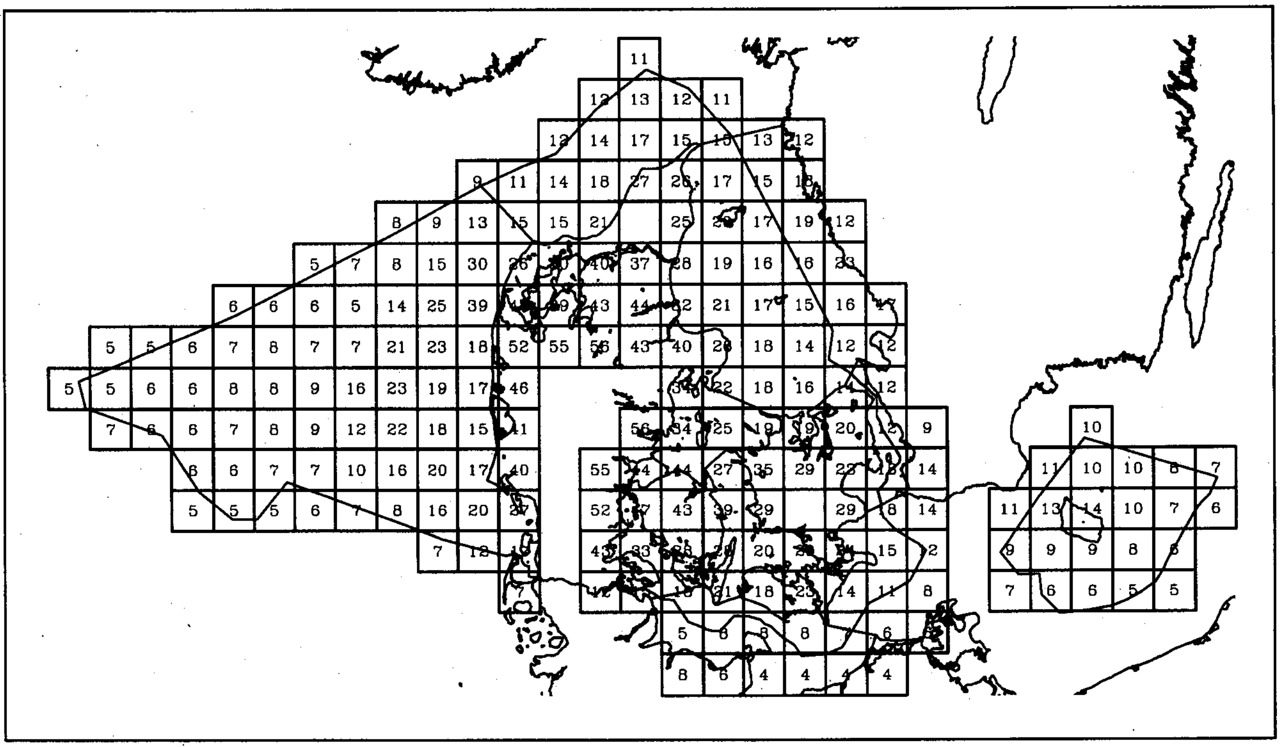


Figure A.16 The relative impact of Danish atmospheric emissions on the total nitrogen deposition to Danish marine waters given in per cent of the total nitrogen deposition. Calculations for the year 1994.

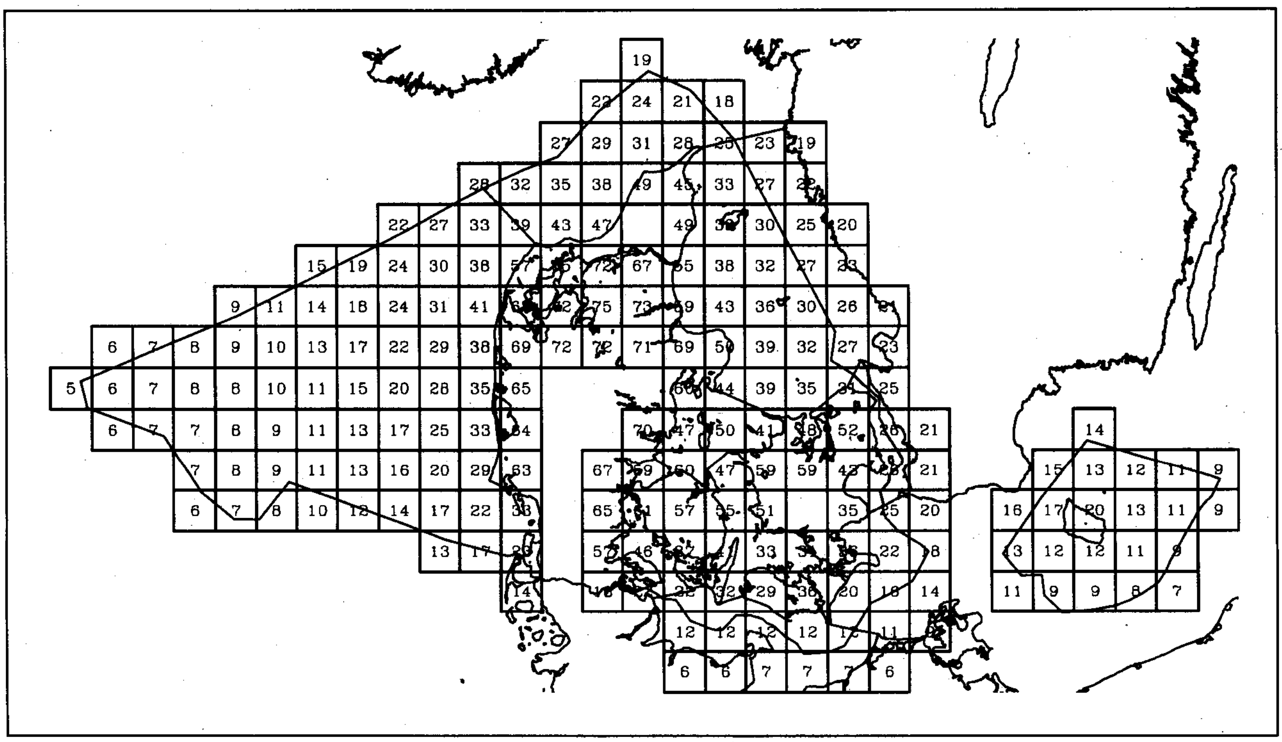


Figure A.17 The relative impact of Danish atmospheric emissions on the dry deposition of nitrogen to Danish marine waters given in per cent of the total nitrogen deposition. Calculations for the year 1994.

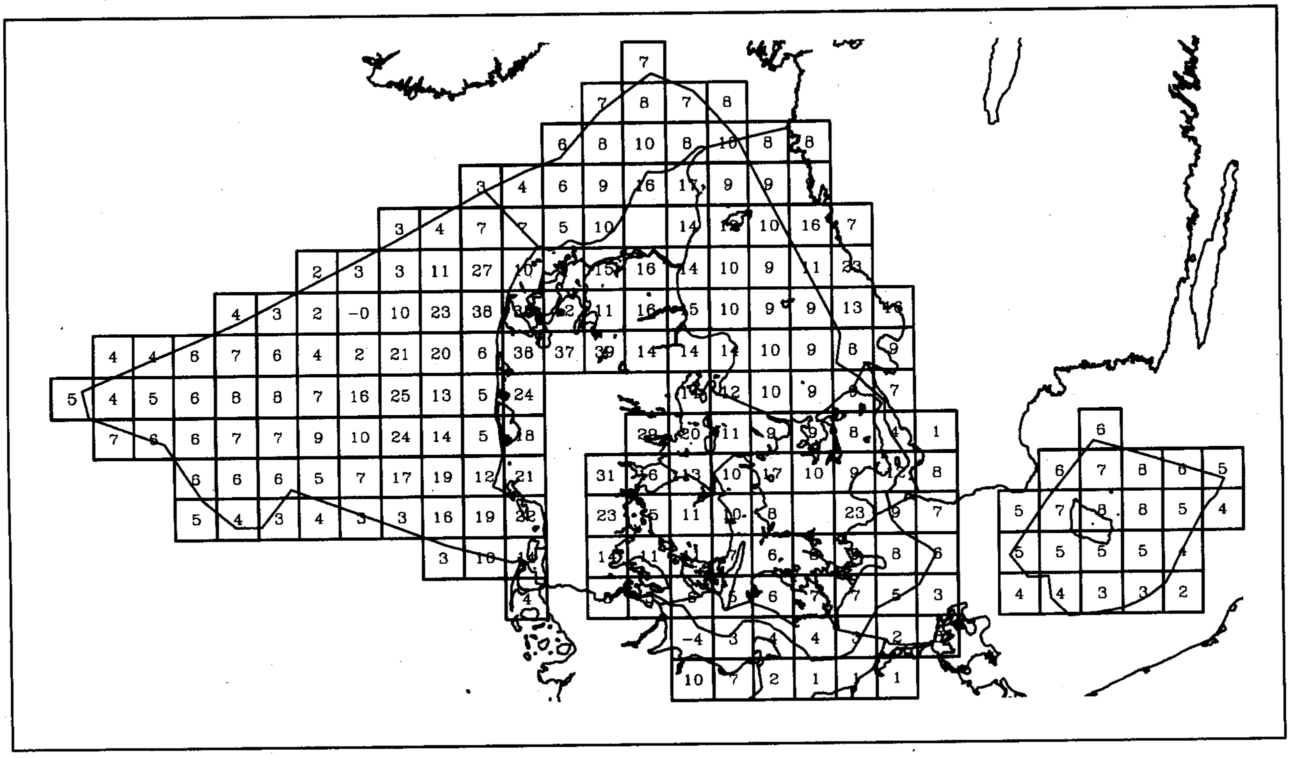


Figure A.18 The relative impact of Danish atmospheric emissions on the wet deposition of nitrogen compounds to Danish marine waters given in per cent of the total wet deposition of nitrogen compounds. Calculations for the year 1994.

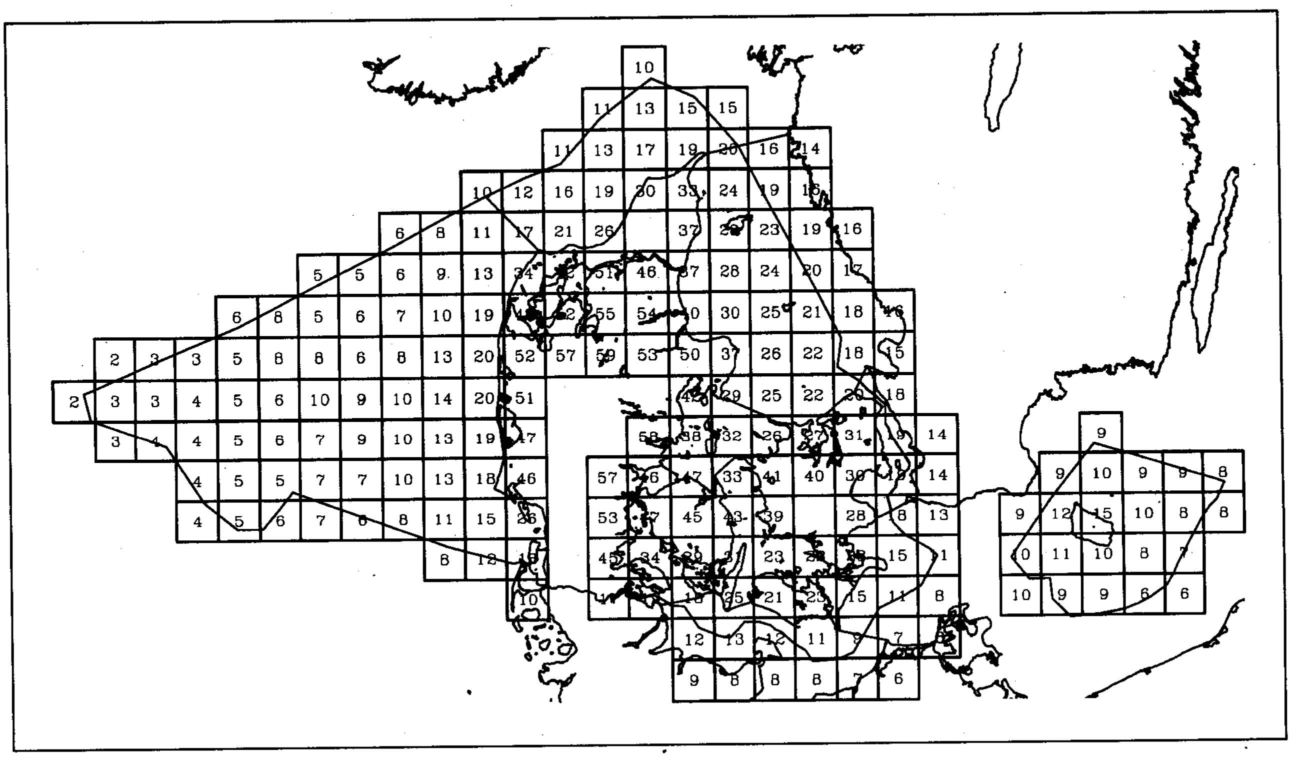


Figure A.19 The relative impact of Danish atmospheric emissions on the total nitrogen deposition to Danish marine waters given in per cent of the total nitrogen deposition. Calculations for the year 1995.

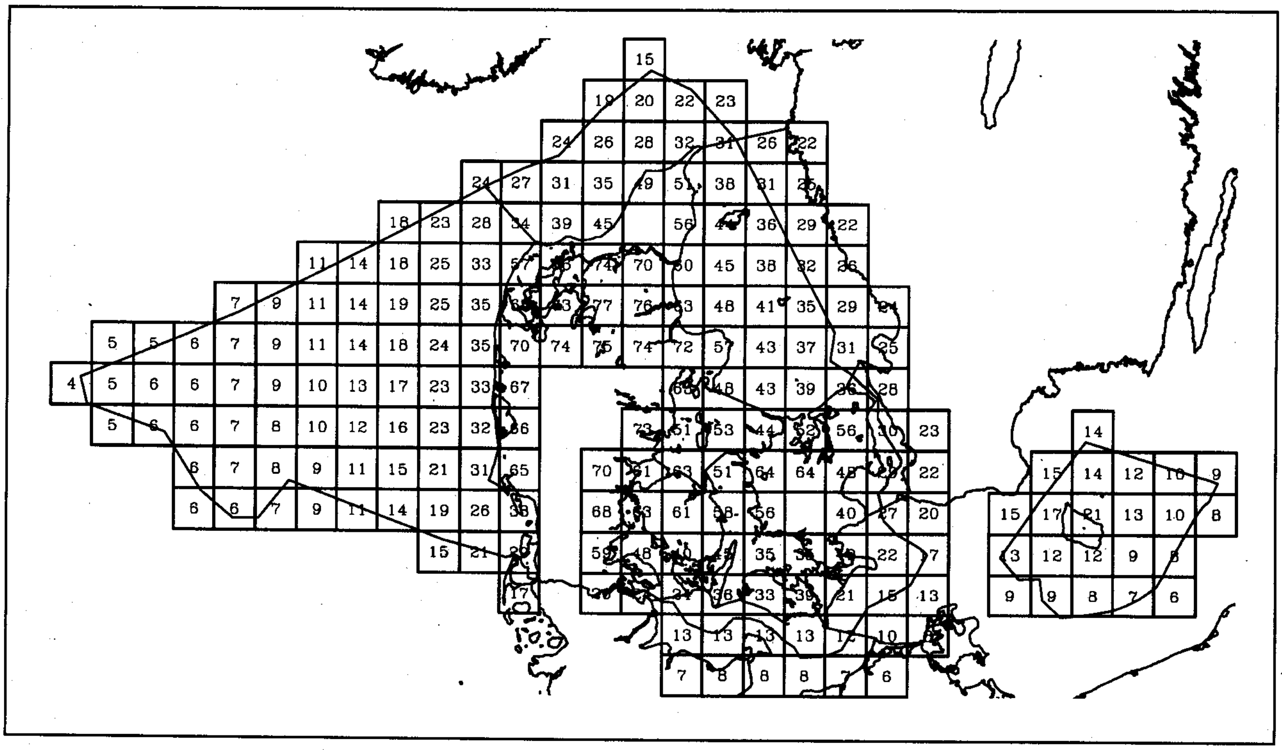


Figure A.20 The relative impact of Danish atmospheric emissions on the dry deposition of nitrogen compounds to Danish marine waters given in per cent of the total dry deposition of nitrogen compounds. Calculations for the year 1995.

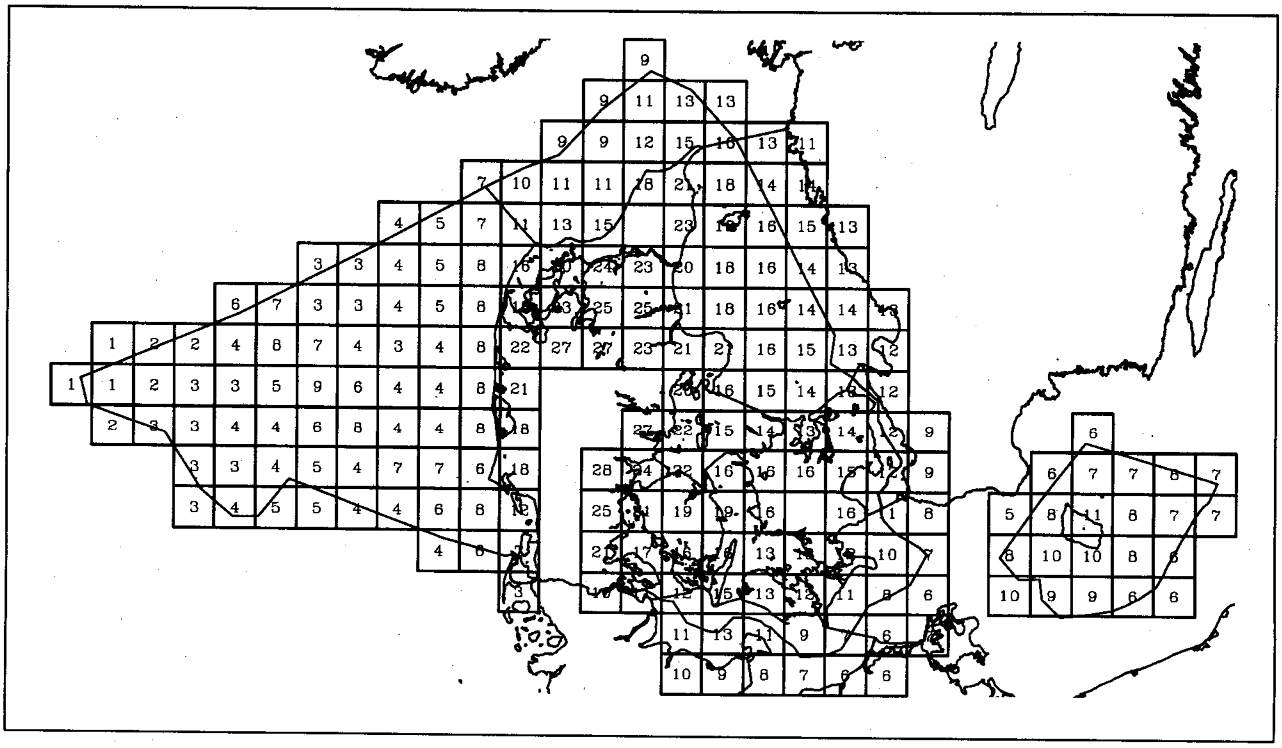


Figure A.21 The relative impact of Danish atmospheric emissions on the wet deposition of nitrogen compounds to Danish marine waters given in per cent of the total wet deposition of nitrogen compounds. Calculations for the year 1995.

Appendix B. Contribution from Danish sources to nitrogen deposition to Danish waters

Table B.1 Dry, wet and total nitrogen deposition for the different marine waters calculated for 1989. Included is also the estimated contribution from Danish atmospheric sources in per cent.

	Area	Dry Deposition		Wet Deposition		Total Deposition	
			%		%		%
	km^2	kg N	DK	kg N	DK	kg N	DK
Augustenborg Fjord	13.7	8419	45	9401	24	17820	34
Avnø Fjord	41.1	21194	30	24838	17	46032	23
Basnæs Nor	9.0	4717	31	5192	13	9909	21
Dybsø Fjord	17.5	9024	30	10576	17	19600	23
Ebeltoft Vig	84.4	48148	55	38741	21	86890	40
Emtekær Nor	0.8	597	58	522	27	1119	44
Flensborg Fjord	131.5	85103	18	95151	15	180253	16
Fåborg Fjord	11.8	7437	38	7878	22	15314	30
Gamborg Fjord	10.4	7765	58	6782	27	14546	44
Gamborg Nor	0.2	149	58	130	27	280	44
Genner Bugt	4.5	3129	57	3074	27	6202	42
Grådyb	138.0	59863	47	65658	27	125520	36
Guldborg Bredning	30.3	15848	37	19921	14	35769	24
Guldborg Sund	81.7	42731	37	53714	14	96447	24
Haderslev Fjord	3.9	3057	64	2621	32	5678	49
Halkær Bredning	6.1	4157	73	2257	22	6414	55
Helnæs Bugt	65.6	40313	45	45014	24	85326	34
Hjarbæk Fjord	25.0	22319	72	9993	39	32312	62
Holbæk Fjord	14.0	10382	59	7318	17	17700	42
Holckenhavn Fjord	0.7	559	53	456	17	1015	37
Holsteinborg Nor	7.0	5712	50	3598	13	9309	36
Horsens Fjord	46.0	46212	68	26942	30	73149	54
Isefjord Inderbredning	42.0	25856	5	22451	5	48308	7
Isefjord Yderbredning	212.6	98412	7	116698	3	215109	9
Kalundborg Fjord	79.0	48373	46	42292	18	90663	33
Karrebæk Fjord	14.8	7632	30	8944	17	16576	23
Kattegat Dansk	14775.4	6431371	48	7300204	19	13731531	33
Kattegat Svensk	6858.5	2122858	34	4618761	16	6741626	21
Keldsnor	1.0	544	33	619	12	1163	22
Kertinge Fjord	8.3	5028	45	4445	18	9473	33
Kolding Fjord	14.7	11051	61	9333	29	20384	47
Korsør Nor	8.0	6528	50	4112	13	10639	36
Lammefjord	20.0	9258	47	10978	13	20236	29
Lillebælt	2050.8	1339432	45	1369308	23	2708722	34
Limfjorden	832.5	480753	69	296121	23	776876	52
Lindelse Nor	6.7	3644	33	4150	12	7793	22
Lovns Bredning	67.3	58221	75	26777	27	85000	60
Lunkebugten	11.1	6800	40	6885	13	13685	27
Mariager Fjord	47.7	37407	68	20654	25	58060	52
Nakkebølle Fjord	7.3	4601	38	4874	22	9474	30
Nakskov Fjord	42.7	21678	31	26758	12	48437	20
Nissum Bredning	387.9	182843	63	128422	31	311262	50
Nissum Fjord	75.0	38825	56	23906	25	62732	44

	Area	Dry Deposition		Wet Deposition		Total Deposition	
			%		%		%
	km^2	kg N	DK	kg N	DK	kg N	DK
Nordlige Bælthav	3349.8	2069968	52	1726291	20	3796267	37
Nordsøen	48376.4	13416619	16	22993862	7	36410512	10
Norsminde Fjord	1.9	1336	54	950	25	2286	42
Nyborg Fjord	8.4	6707	53	5469	17	12177	37
Nykøbing Bugt	12.4	5740	47	6806	13	12546	29
Nysted Nor	0.9	471	37	592	14	1062	24
Nærå Strand	4.8	3936	58	3100	23	7036	43
Odense Fjord	60.3	48744	57	38948	22	87689	42
Præstø Fjord	21.8	11972	36	12034	14	24004	25
Randers Fjord	21.6	17584	66	9653	23	27236	51
Ringkøbing Fjord	294.0	186677	57	97376	24	284052	46
Risgårde Bredning	48.4	40130	74	18838	28	58969	60
Roskilde Fjord Nord	72.0	33304	48	39268	13	72571	29
Roskilde Fjord Syd	51.0	27894	50	26069	17	53964	34
Sakskøbing Fjord	21.1	11036	37	13872	14	24908	24
Skagerrak	10122.4	2867667	35	6201320	13	9068953	20
Skive Fjord	35.2	24953	72	12653	32	37608	59
Skælskør Fjord	1.8	1469	50	925	13	2394	36
Skælskør Nor	2.3	1877	50	1182	13	3059	36
Stadil Fjord	2.6	2194	64	895	30	3088	54
Stavns Fjord	15.6	8156	46	7466	16	15622	32
Stege Bugt	42.0	23064	36	23184	14	46246	25
Stege Nor	5.2	2856	36	2870	14	5726	25
Storebælt	3654.9	2244610	41	2161054	15	4405625	28
Sydfynske Øhav	389.2	227143	34	249040	16	476176	24
Sydlige Bælthav	2455.4	1129264	17	1634696	8	2763970	12
Søndernor	8.9	4840	33	5512	12	10352	22
Sønder Åby Bredning	0.3	209	58	183	27	392	44
Tempelkrog	4.0	2966	59	2091	17	5057	42
Thurø Sund	1.3	796	40	806	13	1603	27
Tryggelev Nor	0.4	218	33	248	12	465	22
Tybrind Vig	10.0	7467	58	6521	27	13987	44
Vejle Fjord	62.0	43678	58	38913	28	82592	44
Venø Bugt	97.6	75633	70	35192	36	110828	59
Vålse Vig	7.1	3661	30	4291	17	7952	23
Øresund Dansk	1333.6	616061	36	683929	16	1300005	25
Øresund Svensk	993.3	414816	32	521959	15	936779	22
Østersøen Øst	11514.1	4387844	14	7277458	13	11665390	13
Østersøen Vest	3232.4	1561306	25	1858291	11	3419632	17
Åbenrå Fjord	31.2	21692	57	21310	27	43003	42
Århus Bugt	315.0	198097	58	147609	23	345712	43

Table B.2 Dry, wet and total nitrogen deposition for the different marine waters calculated for 1990. Included is also the estimated contribution from Danish atmospheric sources in per cent.

	Area	Dry Deposition		Wet Deposition		Total Deposition	
	km^2	kg N	% DK	kg N	% DK	kg N	% DK
Augustenborg Fjord	13.7	7149	44	8984	13	16133	27
Avnø Fjord	41.1	18192	28	24931	11	43122	18
Basnæs Nor	9.0	4139	29	5689	10	9828	18
Dybsø Fjord	17.5	7746	28	10616	11	18361	18
Ebeltoft Vig	84.4	41904	52	55507	17	97410	32
Emtekær Nor	0.8	490	57	523	18	1014	37
Flensborg Fjord	131.5	72228	16	90052	5	162280	10
Fåborg Fjord	11.8	5843	34	8808	12	14651	21
Gamborg Fjord	10.4	6377	57	6802	18	13179	37
Gamborg Nor	0.2	123	57	131	18	253	37
Genner Bugt	4.5	2491	55	2710	16	5202	35
Grådyb	138.0	47033	40	55073	9	102106	23
Guldborg Bredning	30.3	13361	35	19370	9	32730	20
Guldborg Sund	81.7	36026	35	52228	9	88252	20
Haderslev Fjord	3.9	2398	62	2370	21	4768	42
Halkær Bredning	6.1	3447	71	3695	26	7142	47
Helnæs Bugt	65.6	34231	44	43020	13	77251	27
Hjarbæk Fjord	25.0	17692	71	12256	29	29949	54
Holbæk Fjord	14.0	8271	57	9901	13	18172	33
Holckenhavn Fjord	0.7	474	53	510	14	984	33
Holsteinborg Nor	7.0	4647	49	4514	12	9160	31
Horsens Fjord	46.0	36776	67	29267	23	66042	47
Isefjord Inderbredning	42.0	21356	53	30412	13	51768	30
Isefjord Yderbredning	212.6	86870	45	158302	13	245170	24
Kalundborg Fjord	79.0	43034	45	52460	13	95490	27
Karrebæk Fjord	14.8	6551	28	8978	11	15528	18
Kattegat Dansk	14775.4	5540202	45	10230622	17	15770751	27
Kattegat Svensk	6858.5	1897118	34	6117834	14	8014985	19
Keldsnor	1.0	474	31	648	7	1122	17
Kertinge Fjord	8.3	4496	44	5495	13	9990	27
Kolding Fjord	14.7	8888	59	8990	22	17878	40
Korsør Nor	8.0	5310	49	5159	12	10469	31
Lammefjord	20.0	8172	45	14892	13	23064	24
Lillebælt	2050.8	1109810	43	1361766	13	2471568	27
Limfjorden	832.5	406694	67	476773	23	883485	43
Lindelse Nor	6.7	3174	31	4343	7	7517	17
Lovns Bredning	67.3	47309	73	39264	27	86575	53
Lunkebugten	11.1	5912	38	7735	10	13646	22
Mariager Fjord	47.7	31278	66	30321	24	61598	45
Nakkebølle Fjord	7.3	3615	34	5449	12	9064	21
Nakskov Fjord	42.7	18710	29	26983	7	45692	16
Nissum Bredning	387.9	158049	58	154029	19	312078	39
Nissum Fjord	75.0	32804	51	28515	13	61319	34
Nordlige Bælthav	3349.8	1735674	48	2279190	16	4014818	30
Nordsøen	48376.4	12655199	11	33011094	5	45666340	7
Norsminde Fjord	1.9	1052	48	1265	19	2317	32
Nyborg Fjord	8.4	5683	53	6125	14	11808	33
Nykøbing Bugt	12.4	5067	45	9233	13	14300	24
Nysted Nor	0.9	397	35	575	9	972	20
Nærå Strand	4.8	3215	57	3362	18	6578	37

	Area	Dry Deposition		Wet Deposition		Total Deposition	
			%		%		%
	km^2	kg N	DK	kg N	DK	kg N	DK
Odense Fjord	60.3	39117	56	42031	17	81149	36
Præstø Fjord	21.8	10294	36	14450	11	24743	21
Randers Fjord	21.6	14416	64	14005	22	28421	44
Ringkøbing Fjord	294.0	149747	53	110873	12	260620	35
Risgårde Bredning	48.4	32726	73	27456	27	60182	52
Roskilde Fjord Nord	72.0	29177	47	52916	13	82094	25
Roskilde Fjord Syd	51.0	23425	48	32450	14	55877	28
Sakskøbing Fjord	21.1	9304	35	13488	9	22792	20
Skagerrak	10122.4	2514896	28	9302639	15	11817554	18
Skive Fjord	35.2	20596	70	17628	26	38223	50
Skælskør Fjord	1.8	1195	49	1161	12	2356	31
Skælskør Nor	2.3	1527	49	1483	12	3010	31
Stadil Fjord	2.6	1734	61	1009	18	2743	45
Stavns Fjord	15.6	7298	44	10378	14	17675	26
Stege Bugt	42.0	19833	36	27839	11	47670	21
Stege Nor	5.2	2456	35	3447	11	5902	21
Storebælt	3654.9	1925633	39	2417697	11	4343263	24
Sydfynske Øhav	389.2	189331	31	274129	9	463459	18
Sydlige Bælthav	2455.4	947216	17	1643856	4	2591086	9
Søndernor	8.9	4216	31	5770	7	9986	17
Sønder Åby Bredning	0.3	172	57	183	18	355	37
Tempelkrog	4.0	2363	57	2829	13	5192	33
Thurø Sund	1.3	692	38	906	10	1598	22
Tryggelev Nor	0.4	190	31	259	7	449	17
Tybrind Vig	10.0	6132	57	6541	18	12672	37
Vejle Fjord	62.0	36069	55	38439	21	74505	38
Venø Bugt	97.6	60966	67	40112	24	101076	50
Vålse Vig	7.1	3143	28	4307	11	7449	18
Øresund Dansk	1333.6	526765	33	781329	13	1308106	21
Øresund Svensk	993.3	357155	30	580022	12	937180	19
Østersøen Øst	11514.1	3887106	12	7694755	8	11581890	9
Østersøen Vest	3232.4	1328576	24	2183011	8	3511586	14
Åbenrå Fjord	31.2	17274	55	18790	16	36064	35
Århus Bugt	315.0	176570	56	200781	18	377338	36

Table B.3 Dry, wet and total nitrogen deposition for the different marine waters calculated for 1991. Included is also the estimated contribution from Danish atmospheric sources in per cent.

	Area	Dry Deposition		Wet Deposition		Total Deposition	
			%		%		%
	km^2	kg N	DK	kg N	DK	kg N	DK
Augustenborg Fjord	13.7	7846	46	9323	17	17169	30
Avnø Fjord	41.1	19977	32	29878	13	49854	20
Basnæs Nor	9.0	4469	32	6742	14	11211	21
Dybsø Fjord	17.5	8506	32	12722	13	21228	20
Ebeltoft Vig	84.4	45392	56	40659	18	86051	38
Emtekær Nor	0.8	605	61	536	22	1140	43
Flensborg Fjord	131.5	83084	21	90598	9	173685	15
Fåborg Fjord	11.8	7267	41	8629	18	15896	29
Gamborg Fjord	10.4	7864	60	6961	22	14825	43
Gamborg Nor	0.2	151	61	134	22	285	43
Genner Bugt	4.5	3133	58	2958	19	6091	39
Grådyb	138.0	67169	51	44739	15	111908	36
Guldborg Bredning	30.3	15618	39	20730	10	36348	22
Guldborg Sund	81.7	42113	39	55895	10	98007	22
Haderslev Fjord	3.9	3105	65	2612	23	5718	46
Halkær Bredning	6.1	4376	73	2230	19	6606	55
Helnæs Bugt	65.6	37569	46	44643	17	82210	30
Hjarbæk Fjord	25.0	23703	74	7767	23	31469	61
Holbæk Fjord	14.0	10029	59	8407	12	18435	38
Holckenhavn Fjord	0.7	533	54	518	19	1050	37
Holsteinborg Nor	7.0	5592	52	4387	16	9979	36
Horsens Fjord	46.0	44884	70	28777	27	73660	53
Isefjord Inderbredning	42.0	24521	55	25220	10	49740	32
Isefjord Yderbredning	212.6	89951	46	127658	9	217617	24
Kalundborg Fjord	79.0	45163	47	48180	17	93339	31
Karrebæk Fjord	14.8	7194	32	10759	13	17952	20
Kattegat Dansk	14775.4	5954514	45	7693770	17	13648290	29
Kattegat Svensk	6858.5	1976202	29	5495693	14	7471934	18
Keldsnor	1.0	525	35	754	12	1279	21
Kertinge Fjord	8.3	4680	47	5067	17	9747	31
Kolding Fjord	14.7	11129	63	9607	24	20736	45
Korsør Nor	8.0	6391	52	5014	16	11405	36
Lammefjorden	20.0	8462	46	12009	9	20472	24
Lillebælt	2050.8	1304900	47	1402226	17	2707125	32
Limfjorden	832.5	504798	70	267199	18	772007	52
Lindelse Nor	6.7	3517	35	5053	12	8569	21
Lovns Bredning	67.3	62160	76	24140	21	86299	61
Lunkebugten	11.1	6533	42	8073	14	14606	27
Mariager Fjord	47.7	36908	68	21576	18	58485	50
Nakkebølle Fjord	7.3	4496	41	5338	18	9834	29
Nakskov Fjord	42.7	21254	33	30601	12	51853	21
Nissum Bredning	387.9	200244	64	93716	13	293960	47
Nissum Fjord	75.0	43921	59	18635	11	62557	45
Nordlige Bælthav	3349.8	1963561	52	1870604	18	3834145	35
Nordsøen	48376.4	15552032	21	22259994	3	37812024	11
Norsminde Fjord	1.9	1281	54	1034	23	2315	40
Nyborg Fjord	8.4	6391	54	6211	19	12602	37
Nykøbing Bugt	12.4	5246	46	7446	9	12693	24
Nysted Nor	0.9	464	39	616	10	1080	22
Nærå Strand	4.8	3754	59	3410	21	7164	41

	Area	Dry Deposition		Wet Deposition		Total Deposition	
			%		%		%
	km²	kg N	DK	kg N	DK	kg N	DK
Odense Fjord	60.3	47351	58	42535	21	89886	41
Præstø Fjord	21.8	11273	37	15534	10	26808	21
Randers Fjord	21.6	17218	67	10199	17	27416	49
Ringkøbing Fjord	294.0	208037	59	79263	12	287308	46
Risgårde Bredning	48.4	42837	76	16522	21	59358	60
Roskilde Fjord Nord	72.0	30817	47	43449	9	74269	25
Roskilde Fjord Syd	51.0	26566	49	34405	12	60972	28
Sakskøbing Fjord	21.1	10876	39	14436	10	25312	22
Skagerrak	10122.4	2871701	36	7300242	13	10171889	19
Skive Fjord	35.2	26619	73	9719	21	36339	59
Skælskør Fjord	1.8	1438	52	1128	16	2566	36
Skælskør Nor	2.3	1837	52	1442	16	3279	36
Stadil Fjord	2.6	2434	65	691	15	3125	54
Stavns Fjord	15.6	7632	48	8598	13	16230	30
Stege Bugt	42.0	21718	37	29927	10	51647	21
Stege Nor	5.2	2689	37	3705	10	6394	21
Storebælt	3654.9	2142414	43	2580941	15	4723344	27
Sydfynske Øhav	389.2	220668	36	287061	14	507731	24
Sydlige Bælthav	2455.4	1084138	20	1765305	9	2849468	13
Søndernor	8.9	4672	35	6712	12	11383	21
Sønder Åby Bredning	0.3	212	61	187	22	399	43
Tempelkrog	4.0	2865	59	2402	12	5267	38
Thurø Sund	1.3	765	42	946	14	1711	27
Tryggelev Nor	0.4	210	35	302	12	512	21
Tybrind Vig	10.0	7561	60	6693	22	14255	43
Vejle Fjord	62.0	43205	60	40392	23	83597	42
Venø Bugt	97.6	82156	71	25422	20	107580	59
Vålse Vig	7.1	3451	32	5161	13	8612	20
Øresund Dansk	1333.6	586882	32	949482	11	1536376	19
Øresund Svensk	993.3	398826	28	693184	10	1092007	16
Østersøen Øst	11514.1	4037406	13	8794321	8	12831772	10
Østersøen Vest	3232.4	1467177	25	2332961	8	3800201	14
Åbenrå Fjord	31.2	21724	58	20506	19	42229	39
Århus Bugt	315.0	185217	60	161693	20	346910	42

Table B.4 Dry, wet and total nitrogen deposition for the different marine waters calculated for 1992. Included is also the estimated contribution from Danish atmospheric sources in per cent.

	Area	Dry Deposition		Wet Deposition		Total Deposition	
			%		%		%
	km^2	kg N	DK	kg N	DK	kg N	DK
Augustenborg Fjord	13.7	8053	46	6947	11	15000	30
Avnø Fjord	41.1	19465	35	22301	9	41766	21
Basnæs Nor	9.0	4320	34	4734	8	9055	21
Dybsø Fjord	17.5	8288	35	9496	9	17784	21
Ebeltoft Vig	84.4	45464	59	73893	15	119354	31
Emtekær Nor	0.8	621	63	386	14	1007	44
Flensborg Fjord	131.5	87516	20	67569	4	155082	13
Fåborg Fjord	11.8	7704	40	5870	11	13575	28
Gamborg Fjord	10.4	8077	63	5016	14	13093	44
Gamborg Nor	0.2	155	63	96	14	252	44
Genner Bugt	4.5	3356	58	2191	11	5548	40
Grådyb	138.0	65928	52	54911	7	120842	32
Guldborg Bredning	30.3	16480	41	17750	8	34230	24
Guldborg Sund	81.7	44436	41	47861	8	92296	24
Haderslev Fjord	3.9	3311	67	1876	16	5187	49
Halkær Bredning	6.1	4472	78	4179	23	8651	52
Helnæs Bugt	65.6	38562	46	33266	11	71825	30
Hjarbæk Fjord	25.0	23142	77	14578	26	37721	57
Holbæk Fjord	14.0	10326	62	14018	11	24345	33
Holckenhavn Fjord	0.7	536	57	374	13	909	39
Holsteinborg Nor	7.0	5452	55	4579	10	10031	34
Horsens Fjord	46.0	45551	73	23564	22	69115	56
Isefjord Inderbredning	42.0	25044	58	44101	10	69145	28
Isefjord Yderbredning	212.6	90330	50	235795	10	326128	21
Kalundborg Fjord	79.0	44199	50	51188	12	95388	30
Karrebæk Fjord	14.8	7009	35	8030	9	15040	21
Kattegat Dansk	14775.4	5921434	48	13463316	15	19384964	25
Kattegat Svensk	6858.5	1933053	31	7030592	13	8963623	17
Keldsnor	1.0	545	35	489	8	1034	22
Kertinge Fjord	8.3	4577	50	5308	13	9885	30
Kolding Fjord	14.7	11295	67	7191	17	18486	47
Korsør Nor	8.0	6231	55	5233	10	11464	34
Lammefjord	20.0	8498	50	22182	10	30680	21
Lillebælt	2050.8	1346989	48	1021061	11	2368036	32
Limfjorden	832.5	497102	74	489543	21	986634	48
Lindelse Nor	6.7	3652	35	3276	8	6927	22
Lovns Bredning	67.3	60709	80	45866	25	106576	56
Lunkebugten	11.1	6416	44	5771	9	12188	27
Mariager Fjord	47.7	36043	73	40128	21	76172	46
Nakkebølle Fjord	7.3	4766	40	3632	11	8398	28
Nakskov Fjord	42.7	22310	34	22432	7	44743	20
Nissum Bredning	387.9	179179	68	139559	14	318737	44
Nissum Fjord	75.0	38420	64	28718	10	67136	41
Nordlige Bælthav	3349.8	1982754	55	2560282	14	4543094	32
Nordsøen	48376.4	13905784	21	28342320	3	42248124	9
Norsminde Fjord	1.9	1302	55	1138	20	2440	38
Nyborg Fjord	8.4	6427	57	4482	13	10909	39
Nykøbing Bugt	12.4	5268	50	13753	10	19022	21
Nysted Nor	0.9	490	41	527	8	1017	24

	Area	Dry Deposition		Wet Deposition		Total Deposition	
	km²	kg N	% DK	kg N	% DK	kg N	% DK
Nærå Strand	4.8	3777	63	2460	16	6237	44
Odense Fjord	60.3	48553	62	30996	15	79550	44
Præstø Fjord	21.8	11161	42	11733	10	22894	25
Randers Fjord	21.6	16968	72	19577	18	36545	43
Ringkøbing Fjord	294.0	189974	64	133210	9	323178	41
Risgårde Bredning	48.4	41706	80	31416	25	73123	56
Roskilde Fjord Nord	72.0	31289	51	78406	10	109696	22
Roskilde Fjord Syd	51.0	27237	53	41644	11	68881	28
Sakskøbing Fjord	21.1	11476	41	12361	8	23837	24
Skagerrak	10122.4	2801875	41	8140875	12	10942760	19
Skive Fjord	35.2	25539	77	18398	23	43937	55
Skælskør Fjord	1.8	1402	55	1177	10	2579	34
Skælskør Nor	2.3	1791	55	1504	10	3296	34
Stadil Fjord	2.6	2202	70	1113	13	3316	51
Stavns Fjord	15.6	7521	52	12184	11	19706	27
Stege Bugt	42.0	21503	42	22604	10	44108	25
Stege Nor	5.2	2662	42	2799	10	5461	25
Storebælt	3654.9	2121508	45	2047855	10	4169417	28
Sydfynske Øhav	389.2	228149	36	194369	8	422525	23
Sydlige Bælthav	2455.4	1143241	20	1332574	5	2475812	12
Søndernor	8.9	4850	35	4351	8	9202	22
Sønder Åby Bredning	0.3	218	63	135	14	352	44
Tempelkrog	4.0	2950	62	4005	11	6956	33
Thurø Sund	1.3	752	44	676	9	1427	27
Tryggelev Nor	0.4	218	35	196	8	414	22
Tybrind Vig	10.0	7766	63	4823	14	12589	44
Vejle Fjord	62.0	43049	63	30631	16	73681	44
Venø Bugt	97.6	77661	75	41614	21	119273	56
Vålse Vig	7.1	3363	35	3852	9	7215	21
Øresund Dansk	1333.6	596149	35	875052	12	1471200	21
Øresund Svensk	993.3	404972	29	677651	11	1082627	18
Østersøen Øst	11514.1	4042404	13	8279466	7	12321882	9
Østersøen Vest	3232.4	1470206	26	1816659	8	3286851	16
Åbenrå Fjord	31.2	23270	58	15193	11	38463	40
Århus Bugt	315.0	181862	64	231938	16	413784	38

Table B.5 Dry, wet and total nitrogen deposition for the different marine waters calculated for 1993. Included is also the estimated contribution from Danish atmospheric sources in per cent.

	Area	Dry Deposition		Wet Deposition		Total Deposition	
	km²	kg N	% DK	kg N	% DK	kg N	% DK
Augustenborg Fjord	13.7	7423	45	5923	12	13346	30
Avnø Fjord	41.1	18655	32	20994	11	39650	21
Basnæs Nor	9.0	4150	32	4304	10	8454	21
Dybsø Fjord	17.5	7943	32	8939	11	16882	21
Ebeltoft Vig	84.4	42409	53	59025	17	101436	32
Emtekær Nor	0.8	581	61	338	17	918	45
Flensborg Fjord	131.5	77144	21	62902	6	140050	14
Fåborg Fjord	11.8	7226	38	5246	13	12473	27
Gamborg Fjord	10.4	7551	61	4389	17	11939	45
Gamborg Nor	0.2	145	61	84	17	230	45
Genner Bugt	4.5	3080	57	1948	14	5028	41
Grådyb	138.0	67829	51	56094	12	123919	33
Guldborg Bredning	30.3	15293	36	16776	10	32070	22
Guldborg Sund	81.7	41235	36	45233	10	86471	22
Haderslev Fjord	3.9	3107	66	1627	19	4734	50
Halkær Bredning	6.1	4102	73	3975	19	8076	46
Helnæs Bugt	65.6	35544	45	28363	12	63907	30
Hjarbæk Fjord	25.0	22135	75	12948	24	35082	56
Holbæk Fjord	14.0	9717	60	11369	12	21085	34
Holckenhavn Fjord	0.7	496	54	328	16	823	39
Holsteinborg Nor	7.0	5221	52	4036	13	9258	35
Horsens Fjord	46.0	42694	71	20089	23	62781	56
Isefjord Inderbredning	42.0	23736	56	36556	11	60291	29
Isefjord Yderbredning	212.6	86904	47	200091	10	286989	21
Kalundborg Fjord	79.0	41582	47	42992	15	84577	31
Karrebæk Fjord	14.8	6718	32	7560	11	14278	21
Kattegat Dansk	14775.4	5774019	41	10750660	15	16524704	24
Kattegat Svensk	6858.5	2017339	27	4269200	11	6286568	16
Keldsnor	1.0	510	32	463	8	973	21
Kertinge Fjord	8.3	4305	47	4464	15	8769	31
Kolding Fjord	14.7	10743	64	6092	20	16835	48
Korsør Nor	8.0	5967	52	4613	13	10580	35
Lammefjord	20.0	8175	47	18823	10	26998	21
Lillebælt	2050.8	1243810	46	897735	13	2141520	32
Limfjorden	832.5	468662	69	474613	19	943262	44
Lindelse Nor	6.7	3418	32	3100	8	6517	21
Lovns Bredning	67.3	57433	76	42771	22	100203	53
Lunkebugten	11.1	6042	41	5121	11	11163	27
Mariager Fjord	47.7	33372	68	34783	22	68155	45
Nakkebølle Fjord	7.3	4470	38	3246	13	7716	27
Nakskov Fjord	42.7	20872	30	20881	9	41753	20
Nissum Bredning	387.9	184288	64	151032	17	335319	43
Nissum Fjord	75.0	39946	61	33758	15	73702	40
Nordlige Bælthav	3349.8	1865303	51	2091031	16	3956342	32
Nordsøen	48376.4	14348064	21	20990708	6	35338760	12
Norsminde Fjord	1.9	1217	49	963	19	2179	36
Nyborg Fjord	8.4	5947	54	3931	16	9878	39
Nykøbing Bugt	12.4	5069	47	11670	10	16739	21
Nysted Nor	0.9	454	36	498	10	953	22
Nærå Strand	4.8	3520	60	2144	18	5664	44

	Area	Dry Deposition		Wet Deposition		Total Deposition	
	km²	kg N	% DK	kg N	% DK	kg N	% DK
Odense Fjord	60.3	44941	59	26820	17	71763	44
Præstø Fjord	21.8	10481	36	10530	11	21011	23
Randers Fjord	21.6	15618	67	16179	21	31797	44
Ringkøbing Fjord	294.0	193826	61	143770	14	337590	41
Risgårde Bredning	48.4	39530	76	29473	22	69002	53
Roskilde Fjord Nord	72.0	30102	48	67169	10	97270	22
Roskilde Fjord Syd	51.0	25981	50	35698	11	61679	27
Sakskøbing Fjord	21.1	10649	36	11682	10	22332	22
Skagerrak	10122.4	2895794	35	5603890	12	8499662	20
Skive Fjord	35.2	24468	74	17795	20	42263	51
Skælskør Fjord	1.8	1342	52	1038	13	2380	35
Skælskør Nor	2.3	1715	52	1326	13	3042	35
Stadil Fjord	2.6	2221	68	1276	17	3497	49
Stavns Fjord	15.6	7166	49	9856	15	17023	29
Stege Bugt	42.0	20193	36	20287	11	40480	23
Stege Nor	5.2	2500	36	2512	11	5012	23
Storebælt	3654.9	2004730	42	1827930	12	3832715	28
Sydfynske Øhav	389.2	212760	33	177684	10	390444	23
Sydlige Bælthav	2455.4	1110219	16	1184914	6	2295129	11
Søndernor	8.9	4540	32	4117	8	8657	21
Sønder Åby Bredning	0.3	203	61	118	17	321	45
Tempelkrog	4.0	2776	60	3248	12	6024	34
Thurø Sund	1.3	708	41	600	11	1307	27
Tryggelev Nor	0.4	204	32	185	8	389	21
Tybrind Vig	10.0	7260	61	4220	17	11480	45
Vejle Fjord	62.0	40805	61	25960	19	66762	45
Venø Bugt	97.6	76041	72	45098	20	121136	53
Vålse Vig	7.1	3223	32	3627	11	6849	21
Øresund Dansk	1333.6	576686	31	753953	10	1330642	19
Øresund Svensk	993.3	394639	26	580287	10	974926	16
Østersøen Øst	11514.1	4214524	11	5264416	7	9478929	9
Østersøen Vest	3232.4	1458019	22	1558487	8	3016508	15
Åbenrå Fjord	31.2	21358	57	13502	14	34860	41
Århus Bugt	315.0	167445	60	189309	18	356769	38

Table B.6 Dry, wet and total nitrogen deposition for the different marine waters calculated for 1994. Included is also the estimated contribution from Danish atmospheric sources in per cent.

	Area	Dry Deposition		Wet Deposition		Total Deposition	
			%		%		%
	km^2	kg N	DK	kg N	DK	kg N	DK
Augustenborg Fjord	13.7	8091	46	4527	11	12618	33
Avnø Fjord	41.1	20330	31	19073	8	39403	20
Basnæs Nor	9.0	4614	33	4019	6	8632	20
Dybsø Fjord	17.5	8656	31	8121	8	16777	20
Ebeltoft Vig	84.4	45018	53	74772	13	119789	28
Emtekær Nor	0.8	621	61	273	15	895	47
Flensborg Fjord	131.5	82244	21	57202	5	139446	14
Fåborg Fjord	11.8	7194	37	4050	11	11243	28
Gamborg Fjord	10.4	8077	61	3554	15	11631	47
Gamborg Nor	0.2	155	61	68	15	224	47
Genner Bugt	4.5	3260	57	1543	14	4803	43
Grådyb	138.0	69092	48	91744	22	160837	33
Guldborg Bredning	30.3	16348	36	13359	7	29706	23
Guldborg Sund	81.7	44079	36	36020	7	80099	23
Haderslev Fjord	3.9	3223	65	1432	23	4655	52
Halkær Bredning	6.1	4246	72	5407	15	9653	40
Helnæs Bugt	65.6	38742	46	21678	11	60420	33
Hjarbæk Fjord	25.0	22753	73	22912	31	45664	52
Holbæk Fjord	14.0	10123	59	15607	10	25729	29
Holckenhavn Fjord	0.7	542	55	302	10	843	39
Holsteinborg Nor	7.0	5618	51	5670	8	11288	29
Horsens Fjord	46.0	45074	70	23059	29	68131	56
Isefjord Inderbredning	42.0	24933	56	48099	9	73031	25
Isefjord Yderbredning	212.6	92838	48	251314	9	344157	19
Kalundborg Fjord	79.0	45762	48	53068	10	98828	28
Karrebæk Fjord	14.8	7321	31	6868	8	14189	20
Kattegat Dansk	14775.4	5789100	39	13040191	10	18829396	19
Kattegat Svensk	6858.5	2034480	25	5071304	12	7105864	16
Keldsnor	1.0	553	32	381	5	934	21
Kertinge Fjord	8.3	4747	47	5458	10	10205	27
Kolding Fjord	14.7	11369	64	5894	24	17263	50
Korsør Nor	8.0	6421	51	6480	8	12901	29
Lammefjord	20.0	8734	48	23642	9	32376	19
Lillebælt	2050.8	1326772	47	723039	11	2049796	34
Limfjorden	832.5	492809	68	715207	11	1208017	35
Lindelse Nor	6.7	3705	32	2555	5	6261	21
Lovns Bredning	67.3	59706	75	60484	11	120191	43
Lunkebugten	11.1	6709	41	4364	7	11073	28
Mariager Fjord	47.7	35147	67	43480	15	78626	39
Nakkebølle Fjord	7.3	4450	37	2505	11	6956	28
Nakskov Fjord	42.7	22511	30	17300	6	39811	20
Nissum Bredning	387.9	194690	62	310242	38	504948	47
Nissum Fjord	75.0	41924	58	53364	24	95290	39
Nordlige Bælthav	3349.8	1957585	50	2575310	12	4532886	29
Nordsøen	48376.4	14757074	19	29940132	10	44696932	13
Norsminde Fjord	1.9	1200	47	1162	20	2363	34
Nyborg Fjord	8.4	6499	55	3620	10	10119	39
Nykøbing Bugt	12.4	5415	48	14658	9	20073	19
Nysted Nor	0.9	486	36	397	7	882	23
Nærå Strand	4.8	3782	60	1865	13	5647	44

	Area	Dry Deposition		Wet Deposition		Total Deposition	
	km^2	kg N	% DK	kg N	% DK	kg N	% DK
Odense Fjord	60.3	48095	59	22849	12	70946	44
Præstø Fjord	21.8	11527	36	9208	9	20736	24
Randers Fjord	21.6	16538	67	19906	14	36444	38
Ringkøbing Fjord	294.0	206729	59	231070	16	437801	36
Risgårde Bredning	48.4	41130	74	43078	11	84208	42
Roskilde Fjord Nord	72.0	31953	49	85327	9	117282	20
Roskilde Fjord Syd	51.0	27275	50	45338	9	72613	24
Sakskøbing Fjord	21.1	11384	36	9303	7	20686	23
Skagerrak	10122.4	3041494	34	7153264	8	10194697	16
Skive Fjord	35.2	25538	72	30166	15	55702	41
Skælskør Fjord	1.8	1445	51	1458	8	2903	29
Skælskør Nor	2.3	1846	51	1863	8	3709	29
Stadil Fjord	2.6	2337	65	2031	24	4368	46
Stavns Fjord	15.6	7918	50	13408	11	21327	25
Stege Bugt	42.0	22209	36	17740	9	39949	24
Stege Nor	5.2	2750	36	2196	9	4946	24
Storebælt	3654.9	2188044	42	1839308	8	4027354	27
Sydfynske Øhav	389.2	223446	33	140901	7	364348	23
Sydlige Bælthav	2455.4	1140757	18	938560	4	2079330	11
Søndernor	8.9	4922	32	3394	5	8316	21
Sønder Åby Bredning	0.3	218	61	96	15	313	47
Tempelkrog	4.0	2892	59	4459	10	7351	29
Thurø Sund	1.3	786	41	511	7	1297	28
Tryggelev Nor	0.4	221	32	152	5	374	21
Tybrind Vig	10.0	7767	61	3418	15	11184	47
Vejle Fjord	62.0	44016	61	23652	19	67669	46
Venø Bugt	97.6	79324	70	81439	38	160768	54
Vålse Vig	7.1	3512	31	3295	8	6807	20
Øresund Dansk	1333.6	593316	31	823952	10	1417273	18
Øresund Svensk	993.3	402745	26	624058	8	1026801	15
Østersøen Øst	11514.1	4462667	12	4671092	6	9133773	9
Østersøen Vest	3232.4	1535930	23	1357819	8	2893749	16
Åbenrå Fjord	31.2	22601	57	10699	14	33300	43
Århus Bugt	315.0	185573	60	248598	14	434164	34

Table B.7 Dry, wet and total nitrogen deposition for the different marine waters calculated for 1995. Included is also the estimated contribution from Danish atmospheric sources in per cent.

	Area	Dry Deposition		Wet Deposition		Total Deposition	
			%		%		%
	km^2	kg N	DK	kg N	DK	kg N	DK
Augustenborg Fjord	13.7	7681	48	6104	17	13785	34
Avnø Fjord	41.1	18208	35	26431	13	44639	22
Basnæs Nor	9.0	4112	35	4638	13	8750	23
Dybsø Fjord	17.5	7753	35	11254	13	19007	22
Ebeltoft Vig	84.4	42296	57	51740	18	94034	35
Emtekær Nor	0.8	590	63	359	21	949	47
Flensborg Fjord	131.5	77754	23	57555	11	135309	18
Fåborg Fjord	11.8	6944	40	5609	16	12553	29
Gamborg Fjord	10.4	7672	63	4662	21	12333	47
Gamborg Nor	0.2	148	63	90	21	237	47
Genner Bugt	4.5	3104	59	1857	21	4961	45
Grådyb	138.0	62334	51	46859	15	109192	36
Guldborg Bredning	30.3	15297	39	22573	12	37869	23
Guldborg Sund	81.7	41247	39	60864	12	102109	23
Haderslev Fjord	3.9	3102	67	1648	25	4750	53
Halkær Bredning	6.1	4015	74	3527	24	7542	51
Helnæs Bugt	65.6	36779	48	29226	17	66007	34
Hjarbæk Fjord	25.0	21830	75	12391	26	34221	58
Holbæk Fjord	14.0	9995	64	9923	16	19918	40
Holckenhavn Fjord	0.7	515	58	318	19	833	43
Holsteinborg Nor	7.0	5202	56	3640	16	8842	39
Horsens Fjord	46.0	44055	73	20407	27	64460	58
Isefjord Inderbredning	42.0	24421	60	30458	14	54877	35
Isefjord Yderbredning	212.6	89454	52	158406	13	247849	27
Kalundborg Fjord	79.0	41520	52	42567	16	84084	33
Karrebæk Fjord	14.8	6557	35	9518	13	16074	22
Kattegat Dansk	14775.4	5534004	44	9665639	17	15199715	27
Kattegat Svensk	6858.5	1845133	28	4653950	14	6499051	18
Keldsnor	1.0	512	36	564	15	1076	25
Kertinge Fjord	8.3	4296	51	4439	16	8735	33
Kolding Fjord	14.7	10844	66	6178	26	17022	52
Korsør Nor	8.0	5945	56	4160	16	10106	39
Lammefjord	20.0	8415	52	14902	13	23316	27
Lillebælt	2050.8	1260514	49	923453	18	2183990	36
Limfjorden	832.5	452811	70	424478	21	877297	46
Lindelse Nor	6.7	3428	36	3780	15	7208	25
Lovns Bredning	67.3	56683	77	39912	25	96596	55
Lunkebugten	11.1	6147	45	5238	16	11385	31
Mariager Fjord	47.7	33891	71	31631	23	65524	48
Nakkebølle Fjord	7.3	4296	40	3470	16	7766	29
Nakskov Fjord	42.7	20864	34	26748	14	47612	23
Nissum Bredning	387.9	170456	63	143352	18	313808	42
Nissum Fjord	75.0	36172	59	28118	16	64290	40
Nordlige Bælthav	3349.8	1850470	54	1934081	17	3784507	35
Nordsøen	48376.4	13016955	17	27337236	5	40354236	91
Norsminde Fjord	1.9	1189	51	942	22	2130	38
Nyborg Fjord	8.4	6178	58	3812	19	9991	43
Nykøbing Bugt	12.4	5217	52	9239	13	14456	27
Nysted Nor	0.9	454	39	670	12	1125	23
Nærå Strand	4.8	3647	63	2316	22	5963	47

	Area	Dry Deposition		Wet Deposition		Total Deposition	
	km²	kg N	% DK	kg N	% DK	kg N	% DK
Odense Fjord	60.3	46355	62	29035	21	75389	46
Præstø Fjord	21.8	10418	40	14470	12	24887	23
Randers Fjord	21.6	15972	70	14240	22	30212	47
Ringkøbing Fjord	294.0	178774	61	126265	16	305032	43
Risgårde Bredning	48.4	38829	76	27462	24	66292	55
Roskilde Fjord Nord	72.0	30997	53	52698	13	83692	28
Roskilde Fjord Syd	51.0	26899	55	31580	15	58480	33
Sakskøbing Fjord	21.1	10652	39	15719	12	26371	23
Skagerrak	10122.4	2578572	31	7349920	12	9928485	17
Skive Fjord	35.2	23522	73	16539	23	40062	53
Skælskør Fjord	1.8	1338	56	936	16	2274	39
Skælskør Nor	2.3	1709	56	1196	16	2905	39
Stadil Fjord	2.6	2084	67	1106	21	3189	51
Stavns Fjord	15.6	7126	53	9105	15	16232	32
Stege Bugt	42.0	20071	40	27878	12	47947	23
Stege Nor	5.2	2485	40	3452	12	5936	23
Storebælt	3654.9	2009943	46	1959550	15	3969460	30
Sydfynske Øhav	389.2	210205	37	196086	15	406286	26
Sydlige Bælthav	2455.4	1060666	19	1710571	11	2771280	14
Søndernor	8.9	4554	36	5022	15	9576	25
Sønder Åby Bredning	0.3	206	63	126	21	332	47
Tempelkrog	4.0	2856	64	2835	16	5691	40
Thurø Sund	1.3	720	45	614	16	1333	31
Tryggelev Nor	0.4	205	36	226	15	430	25
Tybrind Vig	10.0	7376	63	4482	21	11859	47
Vejle Fjord	62.0	41646	63	26727	25	68372	48
Venø Bugt	97.6	72406	72	41709	24	114116	54
Vålse vig	7.1	3145	35	4566	13	7711	22
Øresund Dansk	1333.6	573050	35	777496	13	1350555	22
Øresund Svensk	993.3	385695	29	590532	12	976231	19
Østersøen Øst	11514.1	3960739	12	6621495	8	10582237	10
Østersøen Vest	3232.4	1405984	24	2153325	10	3559336	15
Åbenrå Fjord	31.2	21524	59	12874	21	34398	45
Århus Bugt	315.0	173883	63	174041	20	347918	42

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Publications:
NERI publishes professional reports, technical instructions, and the annual report. A R&D projects' catalogue is available in an electronic version on the World Wide Web.
Included in the annual report is a list of the publications from the current year.