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Effects of policy measures implemented in Denmark on nitrogen pollution of the aquatic environment

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ABSTRACT

Since 1985, seven national Action Plans (AP) have been implemented in Denmark to reduce nitrogen discharges from point sources and nitrogen losses from agriculture. The instruments applied include regulations on point source discharges from waste water treatment plants, area-related measures, e.g. reestablishment of wetlands and afforestation and nutrient-related measures, e.g. mandatory fertilizer plans and improved utilization of nitrogen in manure. A national monitoring programme was launched in 1988 to monitor trends in nitrogen losses from point sources and diffuse agricultural sources. Four national indicators were defined: nitrogen discharges from point sources, nitrogen surplus in agriculture, nitrogen leaching from agricultural land and nitrogen concentrations and loads in surface waters. Since the introduction of mitigation programmes, discharges of nitrogen from point sources have been reduced by 74% (1989–2003), nitrogen surplus by 31% (1990–2003), and model calculated nitrogen leaching from the root zone on agricultural land by 33% (1989–2002). Trend analysis of total nitrogen concentrations and loads in 86 streams draining smaller agricultural catchments shows an average respective reduction of 29 and 32% (1989–2004). The change in model calculated nitrogen leaching varies between 28 and 44% as calculated for catchments within eight geo-regions covering most of Denmark. The average trend calculated for nitrogen concentrations measured in the same streams and geo-regions shows a reduction in total nitrogen concentration between 8 and 45%. The instruments and measures adopted in Denmark to regulate nitrogen losses from different pressures have therefore proven successful. The impact of the regulations are, however, not equally high in all geo-regions which is possibly related to delays in travel time in groundwater. Until now, the regulation has been performed on a national scale. A more regional or local approach is believed to be necessary in future to meet the demands of the EU Water Framework Directive.

1. Introduction

Intensive farming and livestock production characterises large parts of Western Europe including Denmark (European Environment Agency, 1999). This has lead to significant N-losses from agriculture with detrimental environmental effects caused by eutrophication of surface water bodies (Kronvang et al., 2005; European Environment Agency, 1995).

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Consequently, the European Union has imposed two major directives to mitigate the effects of N emissions to the environment. First, The Nitrates Directive (1991/696/EC) was imposed in 1991, aiming to reduce nitrate water pollution in the Nitrate Vulnerable Zones (NVZs) of Europe. Secondly, The Water Framework Directive (2000/60/EC) was imposed in 2000. The aim is to protect groundwater resources, and all surface waters in a state close to that without anthropogenic interferences.

One of the first countries, to discover the nitrogen problems, was Denmark. In the 1970's and the early 1980's, there was increasing concern about the effect of nutrient losses from agriculture. Elevated nitrogen concentrations were observed in groundwater extracted for household consumption, and surveys and monitoring of oxygen concentrations in the Danish marine waters indicated an increasing frequency of situations with serious oxygen depletion. However, the event that finally kick-started the regulation of nutrient management in agriculture was a television report which showed dead lobsters in the Kattegat sea lying between Denmark and Sweden. The reason for the finding of dead lobsters was attributed to hypoxia resulting from an algal blooms stimulated by agricultural nutrient runoff.

A national water monitoring programme (NOVA) was established in the late 1980s after the Danish Parliament had adopted the first two Action Plans to reduce nutrient pollution in the Aquatic Environment (Kronvang et al., 1993). The monitoring programme was intended to create data and information that enabled authorities to quantify the different sources of nitrogen loadings to surface waters and assist in establishing the longer term trends in nitrogen concentrations and loads at catchment, regional and national scales. The monitoring programme was established 3 years before the EC adopted the Nitrates Directive (91/676/EC) and therefore well ahead of the integrated water resource management scheme in Europe set by the WFD. The experience gathered from NOVA can today be used as a demonstration of a surveillance monitoring network as demanded by the WFD to be established in all EU member countries before 2007.

From 1985 until today, a series of national Action Plans have been imposed in Denmark with remarkable effects on point source discharges of N, agricultural N-efficiency, restoration of wetlands and N-emissions to the aquatic environment. Consequently, Denmark has been one of the most successful among the EU countries, to reduce N-surpluses and N-losses (OECD, 2001). Moreover, these effects have been achieved while still increasing the animal production and the value of agricultural products produced. Therefore, elements from "The Danish Model" might be desirable for wider adoption in other countries throughout the World experiencing N pollution.

This paper describes and documents the experience and effects of the different instruments included in the Danish Action Plans adopted since the mid 1980s on nitrogen emissions to water bodies.

2. Land use and landscape in Denmark

Denmark is characterized by a general east-west gradient in soil types with loamy soils in the east and coarse-textured sandy soils in the west (Fig. 1). A similar gradient in precipitation pattern can be observed with western Denmark receiving a considerably higher amount of precipitation than the rest of the country. The agricultural production in Denmark is very intensive and the use of N fertilizer and manure is among the highest in Europe (European Environment Agency, 1995). In 2004 input of fertilizer and manure was, respectively, 78 and 102 kg N ha^{-1} year^{-1}. Moreover, agricultural land constitutes 60% of the total Danish land area. Almost 90% of the agricultural land is arable (Danmarks Statistik, 2005).

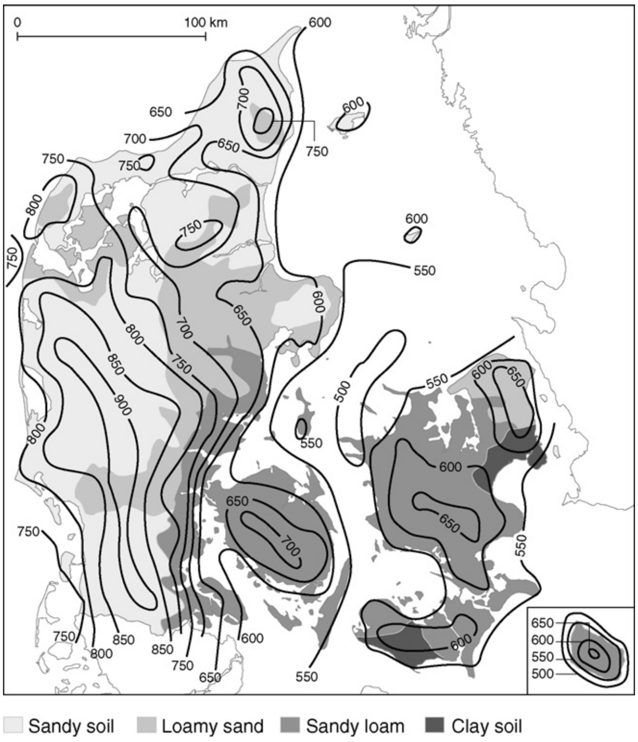

Fig. 1 – Annual precipitation pattern and major soil types in Denmark.

3. Danish policy measures for reduction of nitrogen pollution

From 1985 until today, several national Action Plans have been imposed in Denmark with the aim of reducing nitrogen pollution of the aquatic environment (Table 1). The three main instruments behind the N-regulation in Denmark are: (1) mandatory requirements for improving treatment measures on Waste Water Treatment Plants (WWTP's) including nitrogen removal on larger WWTP's; (2) mandatory fertilizer- and crop rotations plans, with limits on the plant-available N applied to different crops, and (3) statutory norms for the proportion of manure N assumed to be plant available. The first instrument for reduction of point source discharges of nitrogen was implemented in the AP adopted in 1987. The latter two instruments have been enforced in several rounds, for example with the 1991, 1998, 2000 and 2004 restrictions of

Table 1 – Summary of the Danish measurers imposed to reduce nitrogen losses from agriculture

Danish policy actions	Policy measures imposed
1985: NPo Action Plan to reduce N- and P-pollution	• Minimum 6 months slurry storage capacity • Ban on slurry spreading between harvest and 15 October on soil destined for spring cropping • Maximum stock density equivalent to 2 LU ha^{-1}. (1 livestock unit = 1 LU corresponds to one large dairy cow) • Various measures to reduce runoff from silage clamps and manure heaps • A floating barrier (natural crust or artificial cover) mandatory on slurry tanks
1987: The First Action Plan for the Aquatic Environment (AP-I), aiming to halve N-losses and reduce P-losses by 80%	• Minimum 9 months slurry storage capacity • Ban on slurry spreading from harvest to 1 November on soil destined for spring crops • Mandatory fertilizer and crop rotation plans • Minimum proportion of area to be planted with winter crops • Mandatory incorporation of manure within 12 h of spreading
1991: Action Plan for a Sustainable Agriculture, aiming to reduce N-losses from agricultural fields by 100×10^6 kg N	• Ban on slurry spreading from harvest until 1 February, except on grass and winter rape • Obligatory fertilizer budgets • Maximum limits on the plant-available N applied to different crops, equal to the economic optimum. The economic optimum is calculated annually, taking into account the mineral N in the soil (from a comprehensive soil sampling system) • Statutory norms for the proportion of manure N assumed to be plant-available (Pig slurry: 60%, cattle slurry: 55%, deep litter: 25%, other types: 50%)
1998: The Second Action Plan for the Aquatic Environment (AP-II)	• Subsidies to establish 16,000 ha wetlands, designed to reduce nitrate leaching through denitrification and reduced demand for fertilizer • Subsidies to enable reduced nutrient inputs to up to 88,000 ha of areas designated as being specially sensitive with regards the environment • An expectation that animal feeding practice would be improved to reduce N excretion • A reduction of the stock density maximum to 1.7 LU ha^{-1} • Subsidies to encourage the conversion of 170,000 ha to organic agriculture • The statutory norms for the proportion of manure N assumed to be plant-available were increased from 1999 (pig slurry: 65%, cattle slurry: 60%, deep litter: 35%, other types: 55%) • Maximum limits on the application of plant-available N to crops reduced to 10% below the economic optimum • Mandatory 6% of the area with cereals, legumes and oil crops to be planted with catch crops • Subsidies to encourage afforestation on up to 20,000 ha
2000: AP-II Midterm Evaluation and Enforcement	• Increased economic incentives to establish wetlands • The N assumed to be retained by catch crops must be included in the fertilizer plans • Further tightening of the statutory norms for the proportion of assumed plant-available N in manure. From 2001; pig slurry: 70%, cattle slurry: 65%, deep litter: 40%, other types: 60%; from 2002 pig slurry: 75%, cattle slurry: 70%, deep litter: 45%, other types: 65% • Reduced fertilization norms to grassland and restrictions on additional N-application to bread wheat
2001: Ammonia Action Plan	• Subsidies to encourage good manure handling in animal housing and improved housing design • Mandatory covering of all dung heaps • Ban on slurry application by broadcast spreader • Slurry spread on bare soil must be incorporated within 6 h • Ban on the treatment of straw with ammonia to improve its quality as an animal feed • Options for planning authorities to restrict agricultural expansion near sensitive ecosystems
2004: The Third Action Plan for the Aquatic Environment (AP-III). AP-III is very closely related to the EU-Water Framework Directive and the EU Habitat Directive. N-leaching must be reduced by further 13% by 2015	• Further tightening of the request for catch crops

Table 1 (*Continued*)

Danish policy actions	Policy measures imposed
The agricultural P-balance of 32.7×10^6 kg year^{-1} must be halved by 2015. (First AP that regulate P handling in agriculture)	• Further increase in the statutory norms for the proportion of manure N assumed to be plant-available based on research
General reduction objectives will be laid down. In addition, regional objectives will be set for individual water bodies and natural habitats	• Establishment of further wetland areas (ca. 4,000 ha) • Afforestation is assumed on 20,000–25,000 ha • Establishment of 50,000 ha of buffer zones along streams and around lakes before 2015 to reduce discharge of P • Improved utilization of N and P in feed is assumed to reduce losses of N and agricultural surplus of P • A tax of DKK. 4 kg^{-1} mineral P in feed • Protection zones of 300 m around ammonia sensitive habitats such as raised bogs, lobelia lakes and heats larger than 10 ha • Strengthening of organic farming • Evaluations of the effect of AP-III will be carried out in 2008 and 2011 • Based on the evaluations further initiatives will be implemented if necessary

the norms for the proportion of manure N to be plant available (Table 1). Norms for the proportion of manure N to be plant available were controlled through annual farm fertilizer accounts as an increase in plant available N in manure should substitute chemical N fertilizer at farm level as specific N norms are given for each crop type. Throughout the period, N-regulations have been designed in close dialogue with researchers, farmers and farmer associations, and have been followed-up by extension and education. Also, extensive, strategic research programmes have been supported; for example on improved understanding of nitrogen processes in soils and water, optimization of manure utilization, and organic farming production systems (Hansen et al., 2001).

With the 3rd AP for the Aquatic Environment, Danish N-regulation is moving towards a more holistic approach, where the focus will no longer only be on the reduction of nitrate leaching from agricultural land. The aim is a more integrated approach, where protection of the aquatic environment is combined with regional development objectives and nature protection through restoration of formerly regulated rivers and restoration of rivers and wetlands (Hoffmann and Baattrup-Pedersen, 2007). The former represents the new direction of EC agricultural policies towards rural development, while the later reflects the national obligations according to the EC Habitat Directive and The International Convention on Biological Diversity, signed at the Rio Earth Summit in 1992.

4. The Danish Stream Monitoring Programme

A network of 180 Danish stream monitoring stations were established in Denmark in 1988 covering the existing gradients in climate, soil types, geology, land use and agricultural practices (Kronvang et al., 1993). The sampling stations were selected to obtain reliable results on the state and trends in nutrient loadings to water bodies, on changes in nutrient sources and trends in nutrient concentrations and composition of surface waters. The monitoring network is designed to obtain information on nutrient pollution at national, regional and catchment levels. Each monitoring station is instrumented with equipment for continuous recording of water stage, and discharge is measured fortnightly or monthly to enable calculation of daily discharge. Standardised protocols have been developed for water sampling, laboratory analysis and load estimation to obtain reliable and comparable monitoring results. Concentrations of total N are measured at weekly, fortnightly or monthly intervals, the interval between sampling dates being longest in baseflow dominated rivers (Kronvang and Bruhn, 1996). A more detailed description of the river monitoring programme and methods can be found in Kronvang et al. (1993). The information on total N concentration and loads analysed for trends is extracted from 86 smaller catchments draining dominantly arable land (Fig. 2 and Table 2). The catchments represent eight of the nine major geo-regions in Denmark (Fig. 2).

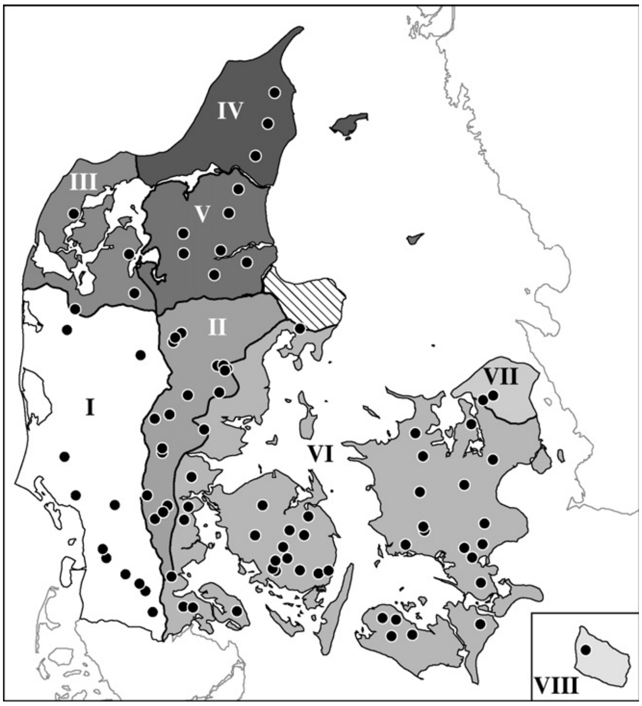

Fig. 2 – Eight major geo-regions of Denmark (I–VIII) and the 86 arable catchments studied for nitrogen leaching and trends in nitrogen concentrations and loads in streams.

Table 2 – Description of the Danish catchments analysed for trends of total nitrogen concentrations and loads in streams

Geo-regions	Number of catchments	Median catchment area (km^2)	Median proportion agricultural land (%)	Median proportion of sandy soils (%)	Median proportion of loamy soils (%)	Median proportion of organic soils (%)
I. Vestjylland	11	43.5	78	94	0	5
II. Midtjylland	18	10.6	79	57	32	1
III. Thy	4	14.2	82	42	57	1
IV. Nordjylland	3	15.6	77	88	5	6
V. Himmerland	7	28.1	76	90	1	7
VI. Østdanmark	40	26.1	74	18	79	2
VII. Nordsjælland	2	15.6	77	88	5	6
VIII. Bornholm	1	42.6	79	19	81	0

5. Methods applied when calculating nitrogen leaching and analysing trends

The root zone nitrate leaching is simulated for the years, 1985 and 2002. Nitrate leaching from agricultural land is calculated with the Danish DAISY model (Abrahamsen and Hansen, 2000). The Daisy approach is used in national simulations, using soil and farm practice data collected at the municipality level (N = 275). The basic simulations are upscaled to regional and national level via the GNL-framework (Børgesen and Heidmann, 2002; Børgesen et al., 2004). The GNL-framework to simulate and upscale N-leaching builds upon disaggregated results for each municipality in Denmark, represented with its own specific farm- and soil-type distribution, irrigation practice, livestock manure production, fertilization practice, etc. Consequently, the N-leaching results can be distributed geographically, thereby revealing municipalities with ‘‘hot-spots’’ for N-leaching. To exclude effects of extreme weather situations in single years, the procedure includes 10-years of climate normalization. For example, the leaching for year 1985 is calculated as the average of 10 simulations with the actual agricultural practice in 1985 combined with weather data from each of the years 1990–2001, except the year 1992 where extreme weather conditions could not be satisfactory simulated with the Daisy model. These simulations also give information on crop yields (Børgesen and Heidmann, 2002). The simulations of total N-harvest in the form of crop yields were calibrated against average regional results from the years 1990–2001 in the regional simulations. Root zone nitrate leaching from non-agricultural areas was estimated based on Danish monitoring and research projects (Blicher-Mathiesen et al., 2006). The following estimates were used: forest 5 kg N ha^{-1} year^{-1}; heath 2 kg N ha^{-1} year^{-1}; other nature 3 kg N ha^{-1} year^{-1}; build-up areas 4 kg N ha^{-1} year^{-1}; and wetlands and lakes 0 kg N ha^{-1} year^{-1}.

Trend analysis of time series of TN concentrations and loads was undertaken using the Mann-Kendall seasonal test with correction for serial correlation (Hirsch and Slack, 1984). This is a robust non-parametric site-specific statistical test for monotone trends. The number of seasons per year was set at 12, one for each month of the year. A test statistic was calculated for each season, the seasonal statistics being combined to one overall test statistic, thereby eliminating seasonal effects. The test statistic identifies whether the trend is upward (positive) or downward (negative). Normally, N concentrations depend heavily on the discharge at the time of measurement. To detect trends attributable mainly to anthropogenic interactions, it is necessary to compute discharge-adjusted concentrations, and discharge adjustment was hence performed by applying the robust curve fitting procedure Locally Weighted Scatterplot Smoothing (LOWESS; Cleveland, 1979). The magnitude of the trend was estimated by the robust and non-parametric Sen's slope estimator (Hirsch et al., 1982). The absolute change in yearly transport, given in kg N ha^{-1}, was calculated as follows. For each month the estimated slope was multiplied by the average daily runoff for that given month and also multiplied by the number of years in the time series minus 1. The average runoff is the average of all daily runoffs in the time series for that given month. This gives an absolute change in transport for the given month. Finally, the yearly change in transport was calculated by adding the monthly changes. The percentage changes in total N concentration were calculated by multiplying the estimated yearly slope with the number of years minus one in the time series and divide this value with the average concentration in the first year of the time series.

6. Changes in nitrogen field balance for Danish agriculture

Nationwide consumption of commercial fertilizer has decreased from 395,000 tonnes N in 1990 to 196,000 tonnes N in 2003 (Andersen et al., 2006). Over the same period, the amount of N applied as manure has decreased from 244,000 tonnes N to 237,000 tonnes N (Andersen et al., 2006). The amount of N removed in the crops has varied during the period depending on the year's crop (Fig. 3). The total surplus in the field balance has decreased from 375,000 tonnes N in 1990 to 247,000 tonnes N in 2003, a reduction of 34%. Part of the reduction is due to the fact that some arable land is no longer cultivated. If the surplus is calculated on a per hectare basis, the surplus has decreased by 31% over the period 1990–2003. In 2003, the surplus was 93 kg N ha^{-1}. The field surplus of N is generally greatest on cattle holdings and least on crop holdings.

7. Model calculated trends in nitrate leaching

The change in nitrate leaching was modelled for 86 smaller agricultural catchments believed to be fairly representative of

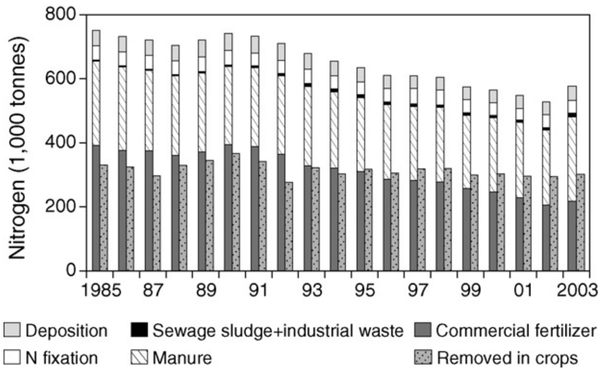

Fig. 3 – Nitrogen balances in Danish agriculture during the period 1985–2003 (Andersen et al., 2006).

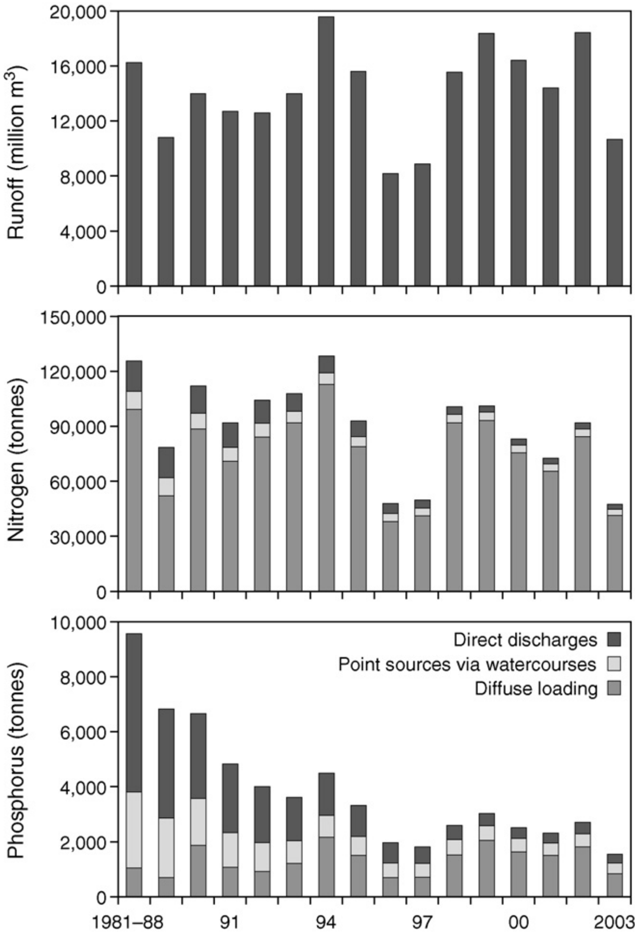

Fig. 4 – Annual runoff, nitrogen and phosphorus loadings of the Danish aquatic environment during the period 1981–1988 to 2003.

Denmark in relation to climate, soil types, geology and agricultural practices. The changes in nitrate leaching are shown in Table 3 as an average for eight major geo-regions during the period 1989–2002. The changes are fairly even in the different geo-regions lying between 28 and 45% with an overall average reduction in N-leaching at 33% for all 86 catchments.

8. Observed trends in total nitrogen in streams

The loading of nutrients to freshwater and coastal waters to the Danish North Sea and Baltic Sea regions has been represented by substantial inter-annual variations since the mid 1980s (Fig. 4). Discharge of nitrogen from point sources to freshwater and coastal waters has decreased due to improved treatment including nitrogen removal at WWTP's and, to a minor degree, reductions in nitrogen discharges from industrial plants, fish farms and scattered dwellings (Fig. 4). Consequently, the majority of the land-based nitrogen loading of Danish aquatic environment is today delivered from diffuse sources (Fig. 4). The reduction in nitrogen discharges from point sources to the aquatic environment has been from a total of 27,600 tonnes N in 1989 to 7200 tonnes N in 2003 equalling a reduction of 74% (Andersen et al., 2006).

Trends in total N concentrations and loads were analysed based on fortnightly observations during the period 1989–2004 for 86 streams draining catchments where land use is dominated by arable land (Table 4). The observed concentrations of total N in the 86 streams are shown in Fig. 5 for the period 1989–2004. In most of the streams the average annual concentration of total N was below the targeted nitrate-N concentration of 50 mg $NO_3^- L^{-1}$ as demanded in the EC Nitrates Directive. The highest average nitrate-N concentration was observed in 1992 caused by extreme dry conditions in

Table 3 – Root zone nitrate leaching for 1989 and change in rootzone leaching between 1989 and 2002 within eight major Danish geo-regions

Geo-region	Number of catchments	Rootzone leaching 1989 (kg N ha^{-1} year^{-1})	Change in rootzone leaching 1989–2002 (kg N ha^{-1} year^{-1})	Change in rootzone leaching 1989–2002 (%)
I. Vestjylland	11	91.5	−36.6	−40
II. Midtjylland	18	76.0	−23.9	−30
III. Thy	44	103.2	−36.2	−35
IV. Nordjylland	3	79.4	−21.9	−28
V. Himmerland	7	92.3	−30.6	−31
VI. Østdanmark	40	53.8	−17.5	−33
VII. Nordsjælland	2	75.7	−33.8	−45
VIII. Bornholm	1	73.4	−23.3	−32

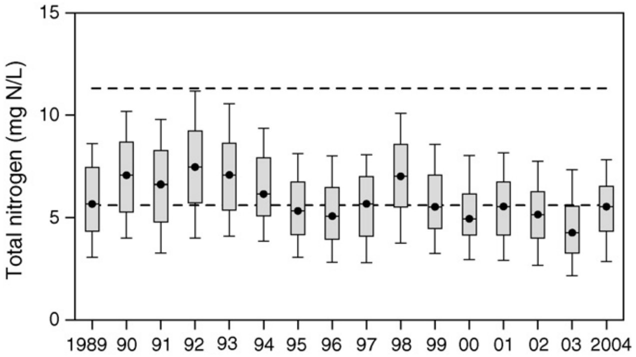

Fig. 5 – Descriptive statistics (Box-Cox plot) for the annual total nitrogen concentrations in the 86 arable catchments studied during the period 1989–2004. The 50 mg NO_3^- L^{-1} and 25 mg NO_3^- L^{-1} thresholds stipulated by the EC Nitrates Directive are depicted.

summer, a low crop yield and consequently higher nitrate-leaching from the root zone. The observed trends in total N concentrations and annual total N loads during the period 1989–2004 are shown in Table 4 for eight main geo-regions in Denmark. The average reduction of total N concentration and total N load was 29 and 32%, respectively, for all 86 streams during the period 1989–2004.

9. Discussion

Since 1987 the national monitoring programme and several research programmes have significantly increased our understanding in Denmark of how agriculture interacts with the environment. The target set in the Danish Action Plan from 1987 of reducing nitrogen losses to the aquatic environment with 50% within a 5-year period was unrealistic both in a scientific and management context. Firstly, the response time of natural hydrological systems nearly always delays the full impact of regulations adopted on agricultural land due to the travel time for nitrogen in groundwater (Grimvall et al., 2002; Wendland et al., 2002). Furthermore, the agricultural system is influenced by decisions taken by thousands of individual farmers. They have to change their farming practice according to the regulations imposed in the Action Plans and it takes time for the farming system to adopt new regulations.

Nitrogen mineral fertilizer consumption in Denmark has been halved from 1990 to 2003 from 395,000 tonnes N in 1990 to 196,000 tonnes N in 2003. On comparison, the nitrogen mineral fertilizer consumption in the EU-15 was only reduced with 12% from 1990 to 2001 (European Environment Agency, 2005a). The N surplus in Danish agriculture was reduced with 34% during the period 1990–2003 compared with a reduction of 16% in the EU-15 (European Environment Agency, 2005a).

The average reduction in modelled nitrate leaching within the 86 catchments of 33% is directly comparable with the average reduction found in total N concentration or total N load in the streams draining the 86 catchments (28 and 31%). However, moving down in scale to the major Danish geo-regions shows a somewhat more complex pattern. One of the analysed geo-regions, Himmerland, shows a reduction in N-leaching of 31% (Table 3) as compared to a downward trend in the total N-concentration in the streams draining the 7 catchments of 8% (Table 4). The apparent discrepancy between changes in N-leaching and trends in observed total N-concentrations for the catchments lying in this geo-region could be linked to different natural or anthropogenic factors.

A total of 72 Danish streams out of 86 analysed (84%) experienced a statistically significant downward trend in N concentrations. Trend data from rivers in other European countries reveals a somewhat opposite picture as many countries have a much lower percentage of rivers with downward trends (Table 5).

The results of the model calculated nitrate leaching from the root zone within the 86 smaller agricultural catchments is compared to the calculated trends in total nitrogen concentrations observed in the streams draining the same catchments in Fig. 6. The trend observed in the 86 catchments are not lying on the 1:1 line as it is to be expected if the relative reduction observed in nitrate leaching also should appear in the total N concentrations or loads in the streams. The reasons for this apparent discrepancy in N-response are likely to include:

- Uncertainty in input data and model calculations of nitrate leaching.
- Delays in the response between land management, nitrate leaching and nitrogen delivery to streams.

Table 4 – Calculated trends in total N concentration and total N loss in streams draining smaller agricultural dominated catchments within 8 Danish geo-regions

Geo-region	Number of catchments (N)	Mean trend in total N concentration (%) (±S.D.)	Mean trend in total N loss (kg N ha^{-1}) (±S.D.)	Number of streams experiencing statistically significant downward trends
I. Vestjylland	11	−26 (±13)	−4.2 (±2.9)	8 (73%)
II. Midtjylland	18	−35 (±11)	−7.1 (±3.4)	16 (89%)
III. Thy	4	−28 (±5)	−5.2 (±1.9)	4 (100%)
IV. Nordjylland	3	− 27 (±3)	−5.2 (±1.7)	3 (100%)
V. Himmerland	7	−8 (±8)	−1.7 (±1.5)	3 (43%)
VI. Østdanmark	40	−30 (±10)	−5.0 (±4.9)	35 (88%)
VII. Nordsjælland	2	−42 (±5)	−5.4 (±1.6)	2 (100%)
VIII. Bornholm	1	− 45 (–)	−10.5 (–)	1 (100%)

Table 5 – Percentage of rivers in different European countries showing downward trend, no trend or upward trends in nitrate-N concentrations during the period 1992–2002 (European Environment Agency, 2005b)

Country (number of rivers analysed)	Trend in nitrate-N concentrations in rivers		
	Downward trend (%)	No trend (%)	Upward trend (%)
Slovenia (10)	10	60	30
Finland (42)	14	69	17
Lithuania (42)	17	55	28
Spain (115)	21	58	21
France (225)	24	52	25
UK (173)	31	55	14
Poland (68)	31	35	34
Bulgaria (43)	40	44	16
Norway (153)	40	54	6
Hungary (60)	40	35	25
Sweden (55)	44	40	16
Austria (239)	44	51	5
Slovakia (26)	46	35	19
Latvia (29)	48	41	10
Germany (148)	73	26	1
Czech R. (65)	74	26	0

- Differences in the impact of the regulatory measures in certain regions due to differences in agricultural production systems.
- Differences in the nitrate removal through denitrification in groundwater and surface water systems in the catchments.

The environmental response to changes in agriculture is also complicated by the fact that year-to-year variations in climate are significantly influencing the final nitrogen state in the aquatic environment (Fig. 4). The period investigated, 1989–2004, experienced extreme years including both drought years and very wet years (Kronvang et al., 2005). The catchments experiencing the lowest reduction in observed total N concentrations in streams as compared to the reductions in modelled N-leaching (lying above the 1:1 line in Fig. 6) are in general also the catchments having the highest baseflow index (BFI). This suggests that the hydrology of the catchments plays the greatest role in the discrepancy between modelled N-leaching and trends in observed total N concentrations in streams. Information of this kind is important for managers of river basins and catchments under the EU W FD.

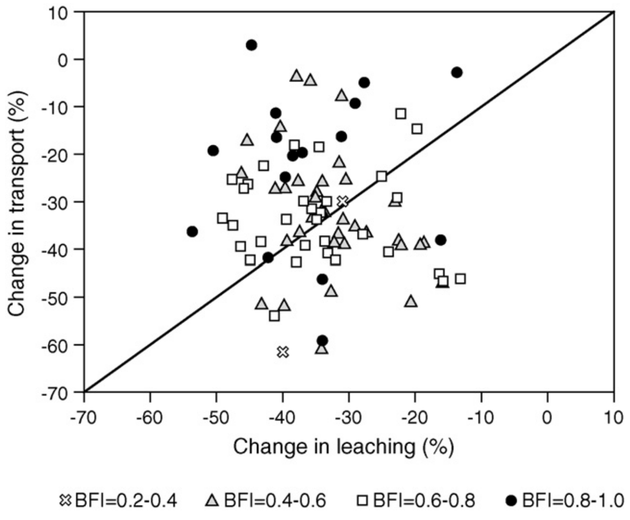

Fig. 6 – Modelled change in the N-leaching from the 86 catchments (1985–2002) as compared to the downstream trends observed in total N-concentrations (1989–2004). The 1:1 line and the baseflow index for each stream during the period 1989–2004 are depicted.

In the intensive Danish agriculture it has proven possible to reduce N-leaching by on average 33% and N-concentrations and loads in surface waters with on average 29–32% while maintaining at the same time crop yields and increasing livestock production significantly. This has been achieved by a strong focus on improving nitrogen efficiency facilitated by regulatory measures, intensive research efforts and an innovative farming community. Future agri-environmental initiatives in Denmark will be based on a more holistic approach, integrating protection of the aquatic environment and natural habitats, and linking national N-regulations to EC-directives and other international obligations. No doubt there will be a change from national approach towards a catchment or river system approach in order to meet the environmental objectives for individual water bodies and natural habitats.

10. Conclusion

The principal lessons for other countries in the EU provided by the Danish experience of regulating nitrogen losses to the aquatic environment, can be summarized as:

- The measures applied to point sources have shown great reductions in N-discharges to the aquatic environment.
- The measures applied in the agricultural production system need to focus on improved utilization of animal manure, fertilizer and crop rotation plans, improved utilization of feed-stuffs and limitations on total N application.
- The applied measures have shown remarkable effects on improved N-utilization, reduction of N-surplus and reduction of N-leaching.
- Policy makers and catchment managers must take account of delay in catchment response to N mitigation. This delay is both due to the necessary time for farmers to change their behaviour and to the natural hydrologic delay in catchments characterized by a high baseflow index (Fig. 6).

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