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The Aquatic Environment in Denmark 1996-1997

State of Danish freshwaters and inlets in 1996 and 1997

Miljøstyrelsen
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CONTENTS:

Foreword

Since 1990, the results of the monitoring programme of the Action Plan for the Aquatic Environment have been reported in the form of an annual review of the aquatic environment.

Nutrients

Inputs and concentrations of nutrients and their impact on the aquatic environment are included in the monitoring programme of the Action Plan for the Aquatic Environment. Consequently, these subjects are the core matters of this report.

Environmental contaminants and heavy metals

In order to produce a more complete picture of the state of the aquatic environment, information has also been obtained about environmental factors beyond the monitoring programme of the Plan. They, for instance, include heavy metals and contaminants.

Since 1994, the reports have been thematic. In this report, the theme is the environmental conditions of and developments in Danish freshwater systems and estuaries and fjords.

Unfavourable physical conditions and waste water from sparsely populated areas

Unfavourable conditions and the input of waste water from sparsely populated areas have great impact on the state of the environment. For this reason it is unlikely that reductions of the nutrient loading of the aquatic environment agreed as a part of the Action Plan for the Aquatic Environment will have any significant influence on the environmental conditions of streams.

Phosphorus loading from the countryside has strong influence on lakes

In lakes, current and previous discharges of phosphorus from the open country in particular have decisive influence on the state of the environment. In the long term, the reduction of the phosphorus targets of the Action Plan for the Aquatic Environment will have a favourable influence on the environment in lakes. However, large phosphorus accumulations in lake sediments which are constantly being released into the lake water, will delay the effect of the reduction of the phosphorus loading of the lakes.

In addition, the report summarises the state of the remainder of the aquatic environment and, furthermore, it includes a list of inputs of substances to the aquatic environment.

1. Introduction

Oxygen depletion and dead fjords, algae soup in the lakes and dried-out watercourses, as well as nitrate and insecticide loading of watercourses and drinking water. There are many examples of problems in the Danish aquatic environment. The Action Plan for the Aquatic Environment is part of the efforts made to secure clean water in the future.

1.1 Targets and tools of the Action Plan for the Aquatic Environment

The creation and objects of the Action Plan for the Aquatic Environment

In 1987, the Folketing passed the “Action Plan against Pollution with Nutrients of the Danish Aquatic Environment”, popularly known as the Action Plan for the Aquatic Environment. Its objective is to reduce the total loading of the aquatic environment by nitrogen and phosphorus from agriculture, municipal sewage treatment plants and individual industrial loads from a level of 290,000 tonnes of nitrogen and 15,000 tonnes of phosphorus when the plan was passed, to 145,000 tonnes and 3,000 tonnes, respectively. This is the equivalent of 50% and 80% reductions, respectively.

The means of the Action Plan for the Aquatic Environment

The means of achieving the agreed reduction objectives included mandatory purification of waste water, storage and spreading of domestic animal manure etc. In addition to these requirements, the Plan contains declarations on a general reduction of the loading by freshwater and salt-water fish farms, as well as the limitation of nitrogen emissions into the atmosphere. The Plan is based on an expansion of sewage treatment plants, and on efforts to ensure that the agricultural sector reduces the loss of nutrients to the aquatic environment, on a voluntary basis and by means of good farming practice. Despite the fact that the sewage treatment plants have since then been expanded as prescribed, and though the agricultural sector generally speaking lives up to the binding demands, it has not been possible to meet the reduction objectives of the Action Plan for the Aquatic Environment.

1.2 The elements of the monitoring programme

Purpose

The overriding purpose of the monitoring programme is to prove the effects of the regulations and investments which are the consequence of the measures specified in the report on the Action Plan for the Aquatic Environment. The nutrient loading from various sources of ground water, watercourses, lakes, and marine waters are established through systematic collection of data, and the water quality and its development are assessed in the various phases of the water cycle. The monitoring programme will of course also contribute to improving and proving the effects of additional measures to improve the aquatic environment, including the meeting of objectives in the counties' plans for the wetland areas. The monitoring programme was launched in 1989. The contents of the programme for 1989-1992 are described in the Environmental Project No. 115 (The Danish EPA, 1989). The contents of the current programme which covers the years from 1993 to 1997 are described in the Danish EPA’s Report No. 1, 1993. The monitoring programme supplements the counties' supervision, and data from this supervision will be collected and used in connection with the annual reports.

Ground water

The environmental conditions of the ground water were the theme of the monitoring programme report of 1995. The purpose of ground water monitoring is i) to monitor the development of the quality and utilisation of ground water resources, ii) to study the ground water contents of nutrients and other substances, natural as well as those originating from the pollution of various types of aquifers; iii) to monitor the development of the ground water quality from near-surface and deeper lying aquifers, partly over time and partly as a result of man-made intervention in the form of pollution and water extraction, and thus to contribute to securing ground water in quantities and of a quality suitable for the production on drinking water and at all times to meet all quality requirements.

Watercourses and springs

Monitoring of watercourses and springs primarily aims at following the development of nutrient transportation and ecological conditions in Danish watercourses, as well as following effects of changes in the nutrient load. It also aims at learning more about the water quality of watercourses, while at the same time establishing the quantities of nitrogen, phosphorus and organic matter which are passed into Danish waters via watercourses.

Lakes

The monitoring programme includes studies of a total of 37 lakes which are representative of the country as a whole with regard to environmental conditions and type of lake. The purpose of lake monitoring is to assess the nutrient loads and environmental conditions of the lakes, to monitor developments and to increase our knowledge of the reaction of the lakes to changes in the nutrient loads.

The marine environment

The environmental conditions in Danish lakes must be described as unsatisfactory, being in general heavily polluted with nutrients. However, there is a small improvement in about half of the monitored lakes thanks to a reduction of phosphorus discharge from waste water.

Loading of lakes

The open land is the largest source of nutrient loading of Danish lakes. Open land accounted for an average of 57% of the Tot-Nutrient input and 73% of the Tot-Nitrogen input in monitored lakes during 1992-1996.

Discharge of phosphorus via waste water in 1992-1996 accounted for only about 10% of the Tot-Phosphorus load. Previously, waste water loading from towns and industry was more significant.

Phosphorus

Generally speaking, phosphorous input to the monitored lakes remained unchanged during the period from 1989-1996. However, there was a drop in the phosphorus input to the most heavily loaded lakes from 8-10 tonnes a year until 1991, to 2-4 tonnes after that, but the total input is still high.

The trend in environmental conditions from 1989 to 1996

Secchi depth

In 1996, Secchi depths in the monitored lakes, expressed as a summer median, was 1.5 metre.

It was less than 1 metre in 52% of the lakes investigated under regional supervision. Low Secchi depths must be considered unsatisfactory.

Small improvement in Secchi depths in lakes

Nevertheless, there is a very small improvement in the Secchi depths of the lakes since 1989, concurrent with a drop in the chlorophyll-a content in the lake water.

There is no change in the occurrence and distribution of zooplankton and subsurface weeds.

Objectives for lakes

34% of target achievement

The targets were met for no more than 34% of the lakes for which objectives have been set.

Ground water

No effect on the ground water of the Action Plan

Generally speaking, no effect on the nitrate content of the ground water as a result of the Action Plan for the Aquatic Environment has been established. In certain areas and in Jutland in particular, nitrate in the ground water remains a significant threat to the future drinking water supply.

Pesticides found

During the period from 1990-1996, pesticides are found in 13% of the investigated filters under the ground water monitoring programme. Of these, 4% exceeded the drinking water threshold value.

In connection with the waterworks' borehole checks in 1992-1996, pesticides were found in approx. 12% of the investigated drillings, in approx. 5% exceeding the drinking water threshold value.

Extended pesticide investigations

A number of counties and waterworks have carried out analyses for a number of pesticides and decomposition products in addition to the 8 analysed so far. The results show that the number of pesticides found in the ground water increases with the number of substances analysed.

Monitoring of additional pesticides

With effect from 1998, the ground water monitoring programme will be extended to include a further considerable number of pesticides and decomposition products. The Environmental Agency's guidelines for the drilling control of waterworks recommend an extended analytic programme for organic micropollutants.

Other analysis parameters

Pollution of ground water by other micropollutants than pesticides is caused by leaching from refuse dumps in particular. As far as non-organic trace elements are concerned, it is aluminium, nickel, and zinc in particular which have been found in ground water in concentrations exceeding the maximum permitted.

Marine areas

In 1996, very low nitrogen loads were found in all Danish marine waters, and in the East Jutland fjords, the Isefjord, and the Sound the load was the lowest registered in the period for which overall loads are available. The low nitrogen load is due to low run-off. Precipitation over North-Western Europe was very low during the winter of 1995-1996 and as the volume of freshwater run-off is primarily dependent on the precipitation, run-off was very low. The trend in the loading of Danish marine waters is shown in Table 1.1.

Table 1.1

Changes in the calculated input of nitrogen (Tot N) and Phosphorus (Tot P) from direct point source discharges, watercourses, and the atmosphere ***to*** *Danish marine waters.*

Year	Tot-N	Tot-P [1)]
	tonnes	
1989	170,700	7,070
1990	218,700	6,910
1991	188,800	5,070
1992	210,800	4,250
1993	198,200	3,870
1994	232,300	4,770
1995	190,000	3,330
1996	150,010	2,007

1) Exlc. atmospheric deposition

Nutrient salts

In the winter months of 1996, low nitrogen concentrations were registered in almost all Danish marine waters. Phosphorus concentrations, too, were low in 1996 – generally speaking on the same level as or slightly below those of recent years. As a long-term trend, there is a marked reduction of phosphorus concentrations.

Plankton algae

In many areas, the phytoplankton biomass, chlorophyll concentration and primary production were markedly lower than in the previous years. The period during which the phytoplankton might have been restricted by nutrient salt seems to have been longer than in previous years, and the frequency of mass efflorescence of plankton algae was also significantly lower.

In keeping with the lower phytoplankton biomass a considerable increase in the Secchi depth was registered in almost all areas.

Oxygen conditions

In 1996, the oxygen conditions were considerably better than previously, and in areas of oxygen depletion, such as the Limfjorden, areal extension and length of occurrence were limited. In addition, oxygen depletion in general started later.

Vegetation

The macrophyte vegetation which, like the benthic vegetation, must be expected to respond more slowly to improvements in its environmental conditions such as a greater Secchi depth, is reported to have improved in some areas. In a few places, the depth limit for macro vegetation has increased.

Trends

However, seen in a wider perspective, the environmental conditions of Danish waters have not improved significantly since the Action Plan for the Aquatic Environment was passed. The basis for the occurrence of considerable oxygen depletion in summer and autumn is still present in a number of areas, in the form of relatively high nitrogen concentrations in the run-off from the open land. It is only a question of meteorological conditions before oxygen depletion will develop.

Trends in nutrient discharges

The aquatic environment receives nutrients from a large number of different sources. The most important inputs in relation to the environmental problems with Danish ground water and surface water are diffuse inputs from cultivated areas and from atmospheric depositions, as well as discharge from point sources.

Cultivated areas

When the Action Plan for the Aquatic Environment was passed in 1987, the Tot-Nitrogen discharge from agriculture was estimated to be 260,000 tonnes. The reduction requirement was specified as 127,000 tonnes, or 49%. It was anticipated that the field contribution (leaching from the root zone) would be reduced by 100,000 tonnes, the remainder of the reduction coming from farmyard leaching. Changes in the nitrogen load since the mid-80s are shown in table 1.2.

Table 1.2

Changes in the calculated nitrogen leaching from agriculture

Year	Farmyard contribution	Leaching from fields
	tonnes	
1985	30,000	230,000
1996	5,000[1]	200,000[2]

1: According to Aquatic Environment-90 (The Danish EPA 1990) the farmyard contribution was

of this magnitude which was considered the minimum achievable in practice at the time.
2: The Government report of March 21, 1996, estimated that measures so far had resulted in a reduction of 20,000-30,000 tonnes of nitrogen.

It follows that the reduction targets for nitrogen leaching from agriculture had not been reached.

All measures completed

At the same time it may be concluded that all central measures to reduce leaching of nitrogen from agriculture had been completed. In spite of this, only a limited reduction of the field contribution had been achieved. Consequently, no significant further reduction is to be expected from the regulations in force.

Model calculations

Model calculations based on measurements in specific monitored catchment areas have shown a calculated 17% drop in the leaching of nitrogen from the root zone since the Action Plan for the Aquatic Environment was launched. Further calculations indicate that the reduction may rise to 32%, if the full potential of all reduction measures is utilised.

Deposition over the sea

The aquatic environment also receives nutrients via the atmosphere. Since the amount of input depends on the size of the aquatic area, atmospheric input is particularly important in marine areas.

Nitrogen deposition from the atmosphere

The calculated deposition from the atmosphere to the sea in the period from 1989 to 1996 is shown in table 1.3.

Table 1.3

Calculated atmospheric nitrogen deposition to Danish waters

Year	Tonnes
1989	92,300
1990	106,500
1991	97,000
1992	106,900
1993	90,000
1994	104,200
1995	96,800
1996	101,700

Long-term trend

The values indicated in the table result from a number of model calculations based on a number of measurements. However, since the calculations are rather uncertain, and the measurements vary greatly from year to year, it cannot be stated categorically that there has been a clear development since 1989.

Phosphorus deposition from the atmosphere

The annual atmospheric input of phosphorus to the inner Danish waters is estimated to be approx. 280 tonnes. This is a relatively small amount in comparison with the input of phosphorus from point sources and watercourses. Phosphorus deposition is mainly due to natural factors.

Point sources

In this connection point sources are municipal sewage treatment plants and individual discharges from industry, both of which have concrete reduction targets, storm water outfalls, discharges from sparsely populated area, and freshwater, marine and terrestrial salt-water fish farms.

Sewage treatment plants

When the Action Plan for the Aquatic Environment was passed in 1987, discharges from municipal sewage treatment plants were an estimated 25,000 tonnes of nitrogen and 7,200 tonnes of phosphorus a year. The Plan aimed at reducing discharges of nitrogen by 60% and of phosphorus by 72%.

In 1990, when the first results of the monitoring programme of the Plan were available, it was realised that the 1987 discharge level had been overestimated. Consequently, the starting points were fixed at 18,000 tonnes of nitrogen and 4,470 tonnes of phosphorus. The percentage reductions were maintained which meant that the targets were now 6,000 tonnes of nitrogen and 1,220 tonnes of phosphorus a year. Table 1.4 shows the reductions in discharges from municipal sewage treatment plants from 1989 to 1996.

Table 1.4
Changes in discharges from sewage treatment plants 1989-1996.

Year	Tot-N	Tot-P	BOD5
		tonnes	
1989	18,000	4,470	36,400
1990	16,885	3,714	29,215
1991	16,109	2,799	24,171
1992	13,071	2,263	21,272
1993	10,785	2,762	14,120
1994	10,239	1,573	10,231
1995	8,900	1,240	7,800
1996	6,386	904	4,979

Discharges of nitrogen and phosphorus have now been reduced by approx. 65% and 80%, respectively, and the reduction objectives of the Action Plan for the Aquatic Environment have been reached as far as sewage treatment plants are concerned.

Individual industrial discharges

In 1987, discharges from individual industries were an estimated 5,000 tonnes of nitrogen and 3,400 tonnes of phosphorus a year. In the Plan it was decided that discharges from individual industries were to be reduced by 3,000 tonnes of nitrogen and 2,800 tonnes of phosphorus a year, or 60% and 82%, respectively. Consequently, the targets were to come down to annual discharges of 2,000 tonnes of nitrogen and 600 tonnes of phosphorus. Table 1.5 shows the reductions in discharges from individual industries from 1989 to 1996,

Table 1.5
Changes in discharges from individual industries 1989-1996

Year	Tot-N	Tot-P	BOD5
			tonnes
1989	4,978	1,125	43,722
1990	4,087	650	46,003
1991	3,997	577	35,821
1992	4,185	424	31,650
1993	2,575	245	26,030
1994	2,737	320	25,684
1995	2,472	206	13,768
1996	1,731	119	8,962

This corresponds to reductions of nitrogen and phosphorus by 65% and 97%, respectively, as compared with the level when the Plan was launched. Targets for both nitrogen and phosphorus have thus been reached.

Storm water outfalls

Table 1.6 shows the reductions in discharges from storm water outfalls from 1989 to 1996.

Table 1.6
Changes in discharges from storm water outfalls 1989–1996.

Year	Tot-N	Tot-P	BOD5
		tonnes	
1989	810	199	2,500
1990	1,082	266	2,400
1991	920	244	2,400
1992	881	223	2,400
1993	1,025	257	2,673
1994	1,207	306	3,061
1995	867	223	2,185
1996	845	216	2,174

Calculations of discharges are extremely uncertain, particularly as far as the early years are concerned. The main fluctuations in discharges are mainly caused by changes in the annual amount of precipitation.

Sparsely populated areas

Table 1.7 shows the reductions in discharges from sparsely populated areas from 1989 to 1996.

Table 1.7
Changes in discharges from sparsely populated areas 1989-1996.

Year	Tot-N	Tot-P	BOD5
		tonnes	
1989	1,280	440	4,850
1990	1,280	440	4,850
1991	1,280	293	4,850
1992	1,280	293	4,850
1993	1,280	293	4,894
1994	1,210	277	4,622
1995	1,141	262	4,379
1996	1,144	262	4,376

The load variations reflect changes and improvements of calculation methods during the period concerned.

Fish farms

Table 1.8 shows the reductions in discharges from fish farms from 1989 to 1996.

Table 1.8
Changes in discharges from freshwater fish farms 1989-1996.

Year	Tot-N	Tot-P	BOD5
		tonnes	
1989	2,192	238	6,246
1990	1,900	217	5,600
1991	1,729	169	4,367
1992	1,549	142	3.807
1993	1,372	115	3,602
1994	1,378	117	3,569
1995	1,384	107	3,545
1996	1,213	94	3,123

Discharges of nitrogen have been reduced by approx. 45% and those of phosphorus by approx. 60%. The Action Plan for the Aquatic Environment did not set concrete reduction targets for freshwater fish farm discharges.

Since 1989 when the Statutory Order on Fish Farms came into force and in the years up to 1993, total discharges have dropped considerably. Since 1993, total discharges have been stable and further reductions as a consequence of the Order are unlikely.

Salt-water fish farms

Production of fish in marine and terrestrial salt-water fish farms inflicts nutrient losses on the aquatic environment. This was calculated as 332 tonnes of nitrogen and 354 tonnes of phosphorus in 1996. The loss of organic matter through the operation of marine fish farms is estimated to be approx. 1,332 tonnes.

Table 1.9
Calculated input of nitrogen (Tot-N), phosphorus (Tot-P) and organic matter (BOD5) from marine and terrestrial salt-water fish farms 1989-1996

Year	Tot-N	Tot-P	BOD5[2]
		tonnes	
1989	322	44	-
1990	332	40	-
1991	265	36	-
1992	361	39	-
1993	366	38	-
1994	306	32	-
1995	351	37	1,397
1996	332	35	1,332

1: Data from salt-water fish farms were not included until 1992.
2: Includes discharges from marine fish farms and from terrestrial salt-water fish farms.

After a drop during the period from 1989 to 1993, the annual input of nutrients from saltwater fish farms is now presumed to be stable at a level about 350 tonnes of nitrogen and just under 40 tonnes of phosphorus.

Perspectives

A number of factors are expected to influence developments in the different areas during the coming years.

Watercourses

If the objectives for watercourses are to be met, efforts during the coming years should focus more on the improvement of physical conditions. Effect studies of watercourse restorations and of environmentally friendly maintenance show that these can result in a general improvement of the watercourse quality. It is, however, still important also to reduce waste water discharges.

The Amendment to the Act governing waste water purification in the open country in 1997 forms the basis of a solution to the problems of discharging waste water in the open country so that the targets may be reached during the coming years, for smaller watercourses in particular.

A combination of changes in farming methods within certain areas and the re-establishment of water meadows capable converting large amounts of nitrogen, would probably further reduce the nitrogen loading of watercourses.

Lakes

Previous and present inputs of nutrients from, among other sources, the open country are the main reason why the environmental conditions of many Danish lakes are still unsatisfactory and have not yet reached the objectives set.

Thus, if the objectives are to be met in future, it is necessary to uphold the target reductions from point sources and at the same time to increase efforts to counteract discharges from the open country. If the input of phosphorus to lakes from the open country were reduced by 50%, the Secchi limit in the majority of lakes in the monitoring programme would be increased to around 4 metres.

Ground water

In certain parts of the country it may become necessary to purify the ground water of nitrate and pesticides etc. for a limited period.

Preventive efforts must, however, be given a higher priority than subsequent purification of the ground water. It is an important element of the future strategy for ground water protection to designate areas with special drinking water interests. At the same time, a high general level of protection for the rest of the country must be maintained.

In 1996, a Drinking Water Committee was established, chaired by the Danish EPA, with the task of evaluating the present ground water protection regulations. The Committee must present its recommendations for stricter measures to protect the ground water used for drinking water.

Marine areas

If the reduction objectives of the Action Plan for the Aquatic Environment were to be reached, other things being equal, it would result in marked and lasting improvements in most of the fjords and other coastal areas receiving nutrients via watercourses or from direct discharges. The nitrogen concentration of heavily loaded waters would be lowered by up to 40%. A drop of this magnitude may result in:

- a 20 to 40% reduction of the plankton algae biomass
- a 30 to 40% increase of the depth limit of eel grass
- a 30 to 100% increase of the depth distribution of other benthic flora
- an up to 70% increase of the area covered by eelgrass
- a marked reduction of the number and duration of oxygen depletion periods.

In the other parts of the Danish waters the Action Plan for the Aquatic Environment will, in combination with near-similar reduction plans in the other countries sharing the North Sea and the Baltic countries, lead to improvements.

Within the framework of the Marine Research Programme 90 it has been calculated that if the objectives of the Action Plan for the Aquatic Environment are met and similar reduction plans in other Baltic and North Sea countries are implemented, oxygen conditions will be improved in years of typical precipitation, run-off, wind and water exchange. In a normal year, there would thus be no pronounced oxygen depletion (<2mg oxygen/l) in the open parts of inner Danish waters, with the exception of the Little Belt. The Sound and the Fehmern Belt would maintain oxygen concentrations below 4 mg oxygen per litre.

Seen as a whole, there is no doubt that meeting of the reduction objectives of the Action Plan for the Aquatic Environment of 50% for nitrogen and 80% for phosphorus would produce an improved marine environment. The effects of the Action Plan for the Aquatic Environment would of course be greater in the waters where the Danish input is most important. Environmental conditions in the open waters would also be improved. Marked improvements in the open waters require that the countries around the Baltic and the North Sea implement the agreed reduction plans, and that initiatives are taken to reduce atmospheric nitrogen contributions.

Cultivated areas

The monitoring programme of the Action Plan for the Aquatic Environment has shown that the use of commercial fertilisers must be further reduced if the objectives of the Action Plan for the Aquatic Environment and thus of the Nitrate Directive and the 10 Point Programme, are to be met. The monitoring programme pinpoints the following:

- over-fertilisation still amounts to approx. 35,000 tonnes of N
- the norms for the nitrogen needs of crops are still determined on the basis of the optimum agro-industrial level
- existing harmonisation rules lead to a structurally based over-fertilisation with phosphorus

According to its agenda of March 21, 1996, the Folketing will in 1998 discuss the further measures required to ensure that the objectives will be reached. However, the Government has already decided to table a proposal that a nitrogen levy be introduced. This is an example of a new initiative which would serve to reduce the use of commercial fertilisers and to exploit the use of farmyard manure more efficiently, to the benefit of ground water and environment.

Atmospheric deposition

The importance of input of nitrogen, in particular, from the atmosphere will increase in relation to the drop in discharge from point sources and from agricultural leaching. Consequently, in view of the desire to improve the environmental conditions of the open sea it is important that the international agreements to reduce nitrogen oxides be implemented, on national as well as international levels.

Point sources

Following the Waste Water Report of the Danish EPA, 1995a and White Paper No. 3, 1996 (The Danish EPA,1996a), the Folketing in May 1997 passed amendments to the Environmental Protection Act and the Payment Regulations Act which primarily concern waste water disposal from sparsely populated areas, ref. Consolidated Act No. 325 of May 14, 1997.

The expected effect is a significant reduction in waste water discharge from sparsely populated areas with the result that a large number of watercourses which cannot meet the set objectives today will be able to do so in future.

Conclusions

No significant improvement of the state of the environment

The state of the Danish aquatic environment in 1996 had as a whole not improved significantly compared with the immediately preceding years. There was, though, an improvement in the marine areas. The reason was very low precipitation which resulted in an extremely low nitrogen run-off.

The theme of this year's report is the environmental conditions of freshwater areas. The conclusion is that:

- the environmental conditions of watercourses are influenced by unfavourable physical conditions and waste water loading,
- in general, the phosphorus concentration in watercourses fell during 1989-1996 as a result, among other things, of improved waste water purification,
- for the first time since 1989, there is a trend towards lower nitrogen loading of watercourses from cultivated catchment areas,
- if the objectives set for watercourses are to be reached, measures to improve the physical conditions and to further limit waste water loading are required,
- the environmental conditions of Danish lakes are today influenced by nutrient pollutants,
- today, the open country is the main source of nutrient inputs to lakes,
- the achievement of the objectives set for lakes requires increased measures in particular to further limit the phosphorus loading from sparsely populated areas and from cultivated areas,
- the state of Danish fjords is affected by nutrient pollutants
- in more than half of the fjords the concentrations of phosphorus in the water have been reduced as a result of improved sewage treatment
- the state of the environment of fjords can only be improved permanently if the reduction objectives for both nitrogen and phosphorus are achieved,
- achievement of the reduction objectives will result in a markedly improved environment in fjords.

Point source targets have been achieved

The overall conclusion is that the objectives of the Action Plan for the Aquatic Environment on reduction of nitrogen and phosphorus discharge from point sources have been achieved.

The effects of targets achieved

The year of 1996 may be considered “nature's own huge experiment”, which showed that a reduction of the nitrogen load to the level aimed at in the Action Plan for the Aquatic Environment will improve, under normal meteorological conditions, the environmental condition of Danish waters significantly.

Lasting improvements will be achieved through active co-responsibility

It must also be concluded that significant and lasting improvements of the aquatic environment are possible only if the impact from agriculture is reduced. The monitoring programme has proved that over-fertilisation of a minor part of the agricultural areas results in considerable run-off, and that further reductions cannot be expected under the present regulations. Consequently, there is a clear need for a reduction of the use of commercial fertilisers and improved utilisation of farmyard manure

2 Discharges from point sources

Point sources normally include all direct discharges. In the monitoring programme of the Aquatic Environment Plan the term covers:

- Outfalls from sewage treatment plants
- Individual industrial discharges
- Storm water overflows – i.e. discharges from sewers during storms
- Outfalls from freshwater and salt-water based fish farms and
- Outfalls from houses and farmyards in rural or sparsely populated areas

Basis of the surveys

The surveys of discharges from the various point sources are based partly on measurements, partly on theoretical calculations. For sewage treatment plants and large, individual industrial discharges, the surveys are based on measurements of substances and water flow. Theoretical calculations are used for storm water overflows and discharges from sparsely populated areas. Finally, discharges from fish farms – both freshwater and salt-water based – are based on information on the production facilities and feed consumption.

Total discharges

In the picture of the total point source discharges sewage treatment plants dominate as regards nitrogen and phosphorus where they account for 55%. Discharges of organic matter come especially from the industry which is responsible for about 35% of this discharge (see Figure 2.1).

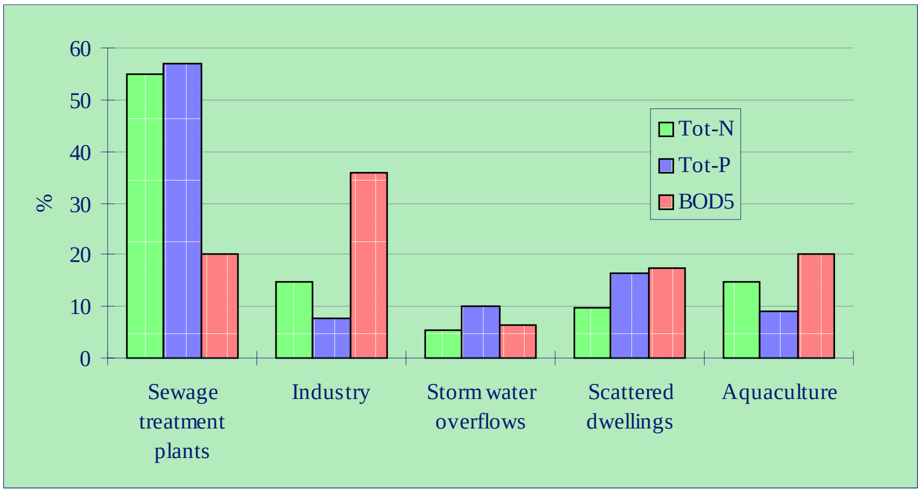

Figure 2.1
Percentage distribution of total discharges of nitrogen (Tot-N), phosphorus (Tot-P) and organic matter (BOD5) from point sources in 1996.

Discharges to freshwaters

Industrial discharges to freshwaters are largely insignificant. In terms of organic matter, sparsely populated areas and fish farms are most significant. About half the nitrogen comes from sewage treatment plants, followed by fish farms and sparsely populated areas. Sewage treatment plants are also the main source of phosphorus, sparsely populated areas providing the next largest amount (see Figure 2.2).

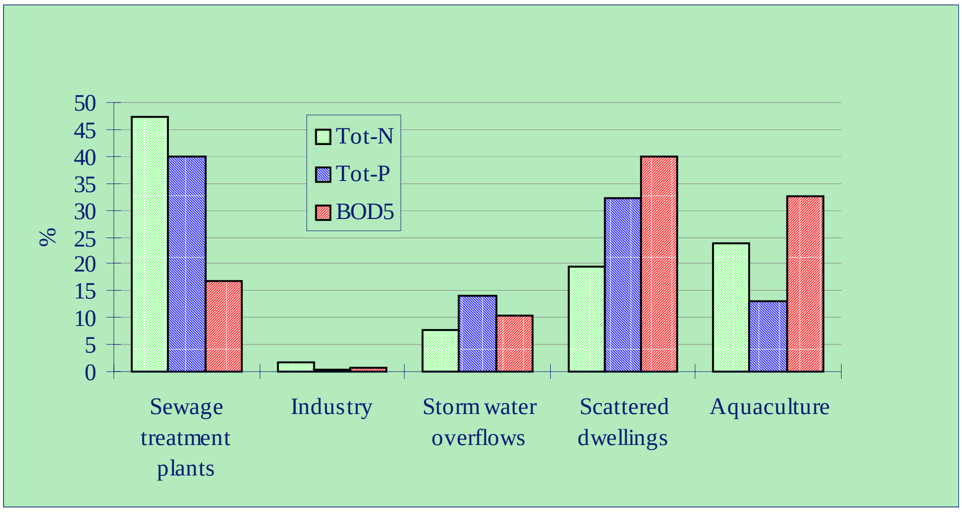

Figure 2.2
Percentage distribution of nitrogen (Tot-N), phosphorus (Tot-P) and organic matter (BOD5) from freshwater point sources in 1996

Discharges direct to the sea

Point source discharges direct to marine areas are totally dominated by sewage treatment plants as far as nitrogen and phosphorus are concerned, while industrial discharges are responsible for most of the organic matter. The 29 marine fish farms provide more than 10% of the discharges of organic matter (see Figure 2.3).

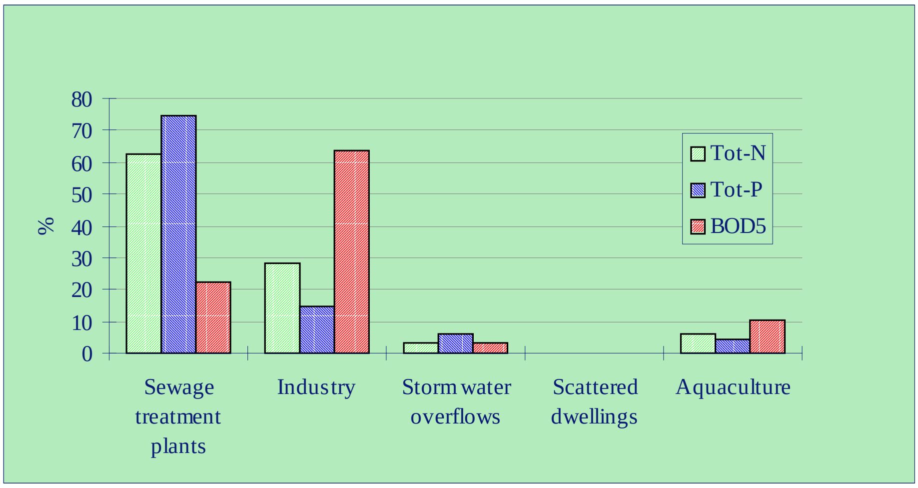

Figure 2.3
Percentage distribution of nitrogen (Tot-N), phosphorus (Tot-P) and organic matter (BOD5) from point sources direct to the sea in 1996

2.1 **Sewage treatment plants**

All municipal and private sewage treatment plants with a capacity of more than 30 person equivalents (PE) are covered by the monitoring programme of the Aquatic Environment Plan (30 PEs correspond to about 10 households). 1 PE from households comprises 4.4 kg of total nitrogen, 1.0 kg of total phosphorus and 21.5 kg of organic matter expressed as

BOD5, which means biochemical oxygen demand over 5 days.

Table 2.1

Distribution of sewage treatment plants >30 PE by county

	Number
Bornholm	18
Frederiksborg	106
Funen	125
Copenhagen	13
North Jutland	123
Ribe	77
Ringkøbing	116
Roskilde	62
Storstrøm	241
South Jutland	166
Vejle	94
West Zealand	160
Viborg	101
Aarhus	232
Total	1,634

The counties each year report a series of key figures for all sewage treatment plants to the Danish EPA. These figures form the basis of calculations of the discharges of nitrogen, phosphorus and organic matter from the plants.

The Aquatic Environment Plan includes a provision that all large municipal sewage treatment plants should be expanded in accordance with the requirements of the Plan by January 1, 1993. This means that all plants with a capacity of more than 15,000 PEs should remove nitrogen down to a level of 8 mg/l, phosphorus to 1.5 mg/l and BOD5 to 15 mg/l. All plants between 5,000 and 15,000 PEs are also required to reduce phosphorus to 1.5 mg/l.

The total number of sewage treatment plants covered by these requirements is just under 300. Of these, about 175 are only covered by the phosphorus requirements while the remainder of the plants have to meet phosphorus, nitrogen, and BOD5 requirements.

A summary by county of the distribution of sewage treatment plants is shown in Table 2.1.

2.1.1 **Waste water volumes and sewage treatment plant sizes**

Most of the population of Denmark is connected to sewers and thereby also to a sewage treatment plant. Industrial as well as domestic waste water is also passed to such plants, in addition to a certain volume of rain-water in combined sewerage areas. Infiltration and exfiltration also occur as a result of leaking sewers. Seen as a whole, there is thus a net inflow of ground water which is fed to the sewage treatment plants.

Waste water volumes

In 1996, the total amount of pollution fed to sewage treatment plants was about 8.3 million PEs.

Based on the number of houses not connected to sewers (see section 2.4) and the total number of inhabitants in Denmark, it is concluded that approx. 85% of the population is connected to the sewer network.

Industrial share

The remainder, about half of the total load on sewage treatment plants, comes from industry.

Distribution of plants by size

Sewage treatment is carried out in many large and small plants. There are only about 25 plants bigger than 100,000 PEs, but these treat more than 45% of the total quantity of sewage.

2.1.2 Treatment provisions and degrees of treatment

With the exception of a very small amount (< 1%) discharged without treatment, waste water is subjected to varying degrees of treatment.

Types of plants

Mechanical treatment takes place by settling of particulates, which are removed as sludge. Larger objects are removed by screens and sand and fat by traps.

Biological treatment takes place by means of micro-organisms, and chemical treatment, particularly directed at removal of phosphorus, takes place by precipitation with lime, iron or aluminium salts.

Nitrogen removal is a further biological process whereby the nitrogen compounds in the sewage are converted to free nitrogen (N_2).

The different treatment methods can be combined to a varying extent, although a mechanical treatment stage will always be included.

Distribution of plant types

72% of the total waste water volume was subjected to mechanical-biological purification and removal of nitrogen and phosphorus in 1996. The remainder was treated biologically or biologically-chemically with the exception of 3% which was only mechanically treated.

Degrees of purification

Mechanical purification removes about 30% of the organic matter and 10-20% of the phosphorus and nitrogen content. The addition of biological purification reduces organic matter by more than 90% and nitrogen and phosphorus by 30-40%.

Treatment processes specifically designed to remove nitrogen and phosphorus can typically remove more than 80% of nitrogen and more than 90% of phosphorus.

2.1.3 Nutrient discharges

Table 2.2 shows that the total discharges of nutrients and organic matter amounted to about 6,400 tonnes of nitrogen, 900 tonnes of phosphorus and 5,000 tonnes of organic matter measured as BOD5.

Table 2.2

Discharges from sewage treatment plants 1996

County	Water	Tot-N	Tot-P	COD	BOD5
	mill. m^3	tonnes			
Bornholm	7	84	19	317	82
Frederiksborg	35	292	39	1512	194
Funen	56	327	35	1692	222
Copenhagen	121	2,055	369	9093	1648
North Jutland	57	489	51	3245	347
Ribe	29	281	40	1075	121
Ringkøbing	36	326	27	1378	189
Roskilde	22	145	29	1059	127
Storstrøm	30	336	61	1871	390
South Jutland	29	369	52	1628	377
Vejle	49	401	38	2324	222
West Zealand	29	305	45	2043	342
Viborg	31	353	37	1747	393
Aarhus	71	623	63	2468	323
Whole country	603	6,386	904	31,453	4,979

Exemptions

When the Plan was adopted, the intention was that all sewage treatment plants were to be extended by January 1, 1993. It was subsequently acknowledged that it might be difficult to achieve this objective in certain situations and for this reason it was made possible for the Danish EPA, on recommendation by the counties, to make exemptions from this deadline.

2.1.4 **Status and development**

Development from 1989 to 1996

Discharges from sewage treatment plants of nitrogen, phosphorus and organic matter have been reduced since 1989, when national figures were first compiled. Discharges of nitrogen have been reduced from about 18,000 tonnes to 6,400 tonnes, of phosphorus from 4,470 tonnes to 900 tonnes and, finally, BOD5 from 36,400 to 5,000 tonnes.

These figures represent nitrogen and phosphorus reductions of 68% and 85%, respectively, from the discharge levels when the Action Plan for the Aquatic Environment was adopted.

Targets met

The objectives set for reduction of discharges of nitrogen and phosphorus when the Action Plan for the Aquatic Environment was adopted were met by the end of 1996.

2.2 Individual industrial discharges

The monitoring programme of the Aquatic Environment Plan for individual industrial discharges embraces all industrial enterprises with discharges exceeding 30 PEs. In 1996, the monitoring programme contained 100 discharge points.

Nutrient discharge figures are submitted annually by the counties to the Danish EPA, and they are used to compile the total industrial discharge figures (see Table 2.3).

Note that industrial point sources from where waste water is sprayed on forestry or agricultural areas have not been taken into account.

2.2.1 **Discharge of nutrients**

Discharges of phosphorus and nitrogen direct from industries remain low as compared with other discharges. Especially the fish processing industry is responsible for the discharges of nitrogen and phosphorus. Thus, this industry is responsible for 39% of the nitrogen discharges and 53% of the phosphorus discharges.

Table 2.3

Individual industrial discharges in 1996.

County	Water	Tot-N	Tot-P	COD	BOD5
				tonnes	
Bornholm	3	11	2	99	189
Frederiksborg	1	4	0	3	3
Funen	5	184	2	29	399
Copenhagen	3	116	0	74	77
North Jutland	18	373	45	2,074	3,388
Ribe	6	205	3	365	403
Ringkøbing	12	93	14	310	744
Roskilde	9	298	19	1,079	13,374
Storstrøm	10	104	7	3,315	5,708
South Jutland	7	27	5	53	177
Vejle	1	0	0	5	5
West Zealand	10	151	6	1,083	1,990
Viborg	7	103	11	346	545
Aarhus	8	62	5	127	1,324
Whole country	100	1,731	119	8,962	28,326

2.2.2 Status and development

Compared with 1989, the nitrogen discharges have been reduced by about 65%. Phosphorus discharges have been reduced by 90% and organic matter by about 80%. The objectives set in the Plan have thus been met.

2.3 Storm water outfalls

A large part of the rain falling on roofs, roads, and other paved areas ends up in the sewer system. Depending on the technical design of the sewer system involved, it is then passed either directly to the environment or to a sewage treatment plant, taking along part of any polluted matter met on the surface on its way. To reduce pollution from storm water outfalls, the sewer system may be provided with basins. Such basins will, depending on the technical design of the system, make it possible to store storm water, thus preventing overloading and allowing pollutants to settle. Finally, attempts may be made to remove from the sewer system as much rain-water as possible and instead let it percolate. This will have beneficial effects on ground water formation.

2.3.1 Sewer systems

The total sewered area of Denmark is 238,500 hectares and the total surfaced area is 71,700 hectares.

Combined sewerage

About half of the surfaced area is drained by combined sewerage, i.e. both surface and foul water is passed through the same pipes. Such systems may be overloaded by heavy rainfall, and through built-in “safety valves” in the form of overflow structures a mixture of untreated waste water and rain-water is discharged to the environment. In 1996, there were 5,260 overflow structures.

Separate sewerage systems

The other half of the surfaced area is separately sewered, i.e. rain-water and foul sewage are passed through separate piping systems and, consequently, waste water and rain-water are not mixed as in the jointly sewered areas. On the other hand, rain-water is not passed to sewage treatment plants in these areas. Nevertheless, separate sewerage is generally considered the best option for the environment. There were 8,911 separate outfalls in 1986.

7.3.2 Basis of calculations

Storm water overflow discharges are calculated in accordance with the instructions of the Danish EPA. Account is taken of the contributing area, rainfall intensity and duration and, in jointly seweraged catchments, the volume of water passed to the sewage treatment plant. To allow for annual rainfall variations, calculations are based on a “normal year”. In this manner it is possible to see an effect, if any, of improvements of the sewerage systems. In 6 selected counties an intensive flow metering programme has been carried out in a number of surface water outfalls and overflow structures. The results of these meterings confirm the calculations for the jointly sewered areas.

2.3.3 Nutrient discharges

Discharges of water and nutrients from separate water outfalls and overflow structures are shown in Table 2.4.

Table 2.4

Discharge of water volumes, organic matter, and nutrients from separate outfalls and overflow structures in a normal year (Danish EPA, 1997b)

County	Tot-N	Tot-P	BOD5
		tonnes	
Bornholm County	4	1	9
Frederiksborg County	52	13	138
Funen County	77	20	192
Copenhagen County	62	15	175
Copenhagen District	70	19	170
North Jutland County	112	27	281
Ribe County	40	10	100
Ringkøbing County	53	13	148
Roskilde County	24	6	58
Storstrøm County	71	19	146
South Jutland County	55	15	148
Vejle County	55	14	146
West Zealand County	38	10	104
Viborg County	46	12	122
Aarhus County	86	22	233
Whole country	845	216	2174

2.3.4 Status and development

In 1996, the discharges of water, nitrogen, phosphorus, and organic matter were about 25% less than in a normal year. The reason for the drop was the low precipitation in 1996.

2.4 Sparsely populated areas

Sparsely populated areas include isolated houses or clusters of houses, villages, summer-house and allotment areas and other houses with waste water discharges comparable to domestic waste water. In other words, it typically refers to dwellings in the countryside.

The summation of the loading from sparsely populated areas is based on the counties' reports on waste water loading by houses outside sewered areas. It is not based on meterings, but on the number of houses with a waste water loading of up to and including 30 PEs.

2.4.1 Nutrient discharges

Number of houses

The basis of the assessment is the number of houses in unsewered areas, which in 1996 amounted to 353,000. 118,700 of these were in summer-house and allotment areas and 234,800 in sparsely populated areas and villages.

The latter houses are the main contributors to the impact on the aquatic environment.

Purification methods

The purification methods registered (known or estimated) are distributed as follows: 52% of houses in sparsely populated areas had soakaways, 3% had cesspools and the remaining 45% had a purification method followed by discharge to surface water.

Uncertainty of figures

The data submitted are subject to a varying degree of uncertainty. About ¾ of the returns are based on known number of houses and purification methods or known number of houses and a qualified estimate as regards purification methods. The remaining ¼ are based on estimates only.

Quantities discharged to

The 1996 calculations show that 4,376 tonnes of organic matter (BOD5), 1,444 tonnes of nitrogen and 262 tonnes of phosphorus were discharged from sparsely populated areas to *surface water*

surface water. These discharges are shown by county in table 2.5.

Table 2.5
Discharges to surface water from sparsely populated areas in 1996. The totals are based on unrounded figures

County	Tot-N	Tot-P	BOD5
		tonnes	
Bornholm County	19	4	73
Frederiksborg County	10	2	38
Funen County	180	41	687
Copenhagen County	4	1	16
Copenhagen municip.	<1	<1	<1
North Jutland County	107	24	407
Ribe County	61	14	230
Ringkøbing County	79	18	305
Roskilde County	25	6	95
Storstrøm County	134	31	514
South Jutland County	111	25	422
Vejle County	101	23	386
West Zealand County	137	32	532
Viborg County	78	18	298
Aarhus County	97	23	373
Whole country	1,144	262	4,376

Discharges to the soil

As mentioned, a large proportion of waste water from unsewered housing is disposed of by percolation into the soil. The total quantities disposed of in this manner in 1996 was 1,658 tonnes of nitrogen, 377 tonnes of phosphorus, and 6,328 tonnes of organic matter (BOD5).

2.4.2 **Status and development**

No change has been established since 1995 as the figures for the two years are identical. Within individual counties, however, figures have altered as generally the assessment method has been improved.

2.5 Freshwater fish farming

There were a total of 456 fish farms in Denmark in 1996, all but one located in Jutland. In 1996, they consumed 31,500 tonnes of feed to produce 32,472 tonnes of fish, i.e. more than 1 kg of fish meat per kg of feed.

Nutrient discharges are regulated by the Statutory Order on freshwater fish farming (Ministry of the Environment and Energy, 1994). Requirements are laid down for, among other things, maximum feed consumption, feed quality, purification measures, and maximum permissible feed coefficient.

The impact by individual fish farms on the aquatic environment depends on many factors including scale of production, feed quality, and degree of utilisation as well as on the purification measures provided.

2.5.1 **Nutrient discharges**

Surveys of discharges of nutrients from freshwater fish farms have since 1989 been made using standardised methods based on feed consumption and production.

Total discharges in 1996 are estimated as 1,213 tonnes of nitrogen, 94 tonnes of phosphorus and 3,123 tonnes of organic matter expressed as BOD5. Table 2.6 shows these figures by county.

Table 2.6

Calculated nitrogen (Tot-N), phosphorus (Tot-P) and organic matter (BOD5) from freshwater fish farming in 1996

County	Tot-N	Tot-P	BOD5
		tonnes	
North Jutland	162	11	397
Ribe	302	23	818
Ringkøbing	357	27	961
South Jutland	28	3	66
Vejle	162	13	422
Viborg	116	10	262
Aarhus	86	7	197
Whole country	1,213	94	3,123

2.5.2 **Status and development**

Total feed consumption in fish farms has been falling between 1989 and 1996, while production has been more or less constant. Thus, in 1989, 1 kg of fish was produced spending on average 1.25 kg of feed, whereas in 1996 less than 1 kg was needed.

Since the Statutory Order on fish farming came into force in 1989, discharges were reduced up to 1993, when they stabilised, leading to the conclusion that its effect has now been fully realised. As compared with 1995 feed consumption per kilo of fish produced has fallen by about 10%, which is the main reason why discharges of organic matter, nitrogen and phosphorus have fallen by about 12%.

2.6 Mariculture

Salt-water based fish farming in Denmark is concentrated on rearing of rainbow trout in marine or terrestrial salt-water fish farms. Marine fish farming is defined as “rearing system comprising netting cages, wire boxes or similar equipment placed in marine waters, and whose operation necessitates the use of feed”. Terrestrial salt-water fish farming – also known as pumped supply installations – is defined as “rearing system on land using a salt-water intake, including cooling water from power stations and suchlike, and whose operation necessitates the use of feed”.

2.6.1 **Nutrient discharges**

Feed consumption, size of production and losses of nitrogen and phosphorus to the marine environment are calculated on the basis of returns from the companies to the counties and the Environmental Protection Agency.

The specific discharge (discharge per tonne of fish produced) was for marine fish farms 44.1 kg of nitrogen, 4.7 kg of phosphorus and 256 kg of organic matter. For terrestrial salt-water fish farms the figures were 47.3 kg of nitrogen and 4.7 kg of phosphorus.

The calculated losses of nitrogen, phosphorus, and organic matter are shown in Table 2.7.

Table 2.7

Calculated losses of nitrogen (Tot-N), phosphorus (Tot-P) and organic matter (BOD5) *from salt-water-based fish farms[1] in 1996.*

County	Number	Tot-N	Tot-P	BOD5[2]
		tonnes		
Bornholm	2	1	~0	1
Funen	1	6	1	33
Ringkøbing	8	34	3	37
Storstøm	7	72	8	402
South Jutland	6	52	6	83
Vejle	10	55	6	360
West Zealand	6	96	10	355
Viborg	2	3	1	
Aarhus	1	12	1	62
Whole country	43	332	35	1,332

1: Discharges from salt-water fish farms have only been calculated for
terrestrial ones. Those with purification systems have not been included.
2: Discharges of organic matter (BOD5) have only been calculated for salt-
water fish farms.

2.6.2 **Status and development**

The total losses of nutrients to the marine environment from salt-water fish farming in 1996 was about 332 tonnes of nitrogen, 35 tonnes of phosphorus and 1,332 tonnes of organic matter.

Compared with 1995, the nitrogen losses have dropped from 351 tonnes to 332 tonnes, and the phosphorus contribution has also dropped from 37 tonnes to 35 tonnes.

At the start of the Aquatic Environment Plan in 1989, 322 tonnes of nitrogen and 44 tonnes of phosphorus were lost to the marine waters. As far as nitrogen is concerned, the loss level is stable around 350 tonnes per year. The phosphorus loss has fallen since 1989 and is now stable at about 35 tonnes per year.

2.7 Offshore activities

Danish hydrocarbon production

The Danish sector of the North Sea produced a total of 7.25 billion normal m³ of gas and 10.3 million tonnes of oil in 1996.

The output from a total of 11 fields comprised in 1996 just 5% of the total North Sea production. A total of 18 new horizontal or highly curved wells for production or water injection were completed in 1996 in connection with expansion of the Danish fields.

Emissions to water and air

Activities connected with prospecting, extraction, production, processing, and transportation of hydrocarbons lead to discharge of a number of ancillary substances and materials, partly to the sea and partly to the air. The operators report annually to the Danish EPA their estimates of the quantities involved in such activities.

2.7.1 **Emissions to the atmosphere**

Emissions to the atmosphere

The offshore industry's emission of substances such as CO_2, SO_2, CH_4, NO_X, polyaromatic hydrocarbons (PAH) and volatile organic compounds (VOCs) to the atmosphere occurs in connection with flaring of surplus gas and oil from e.g. test operations and hydrocarbon production, and from using diesel oil and gas in connection with energy production on the platforms and drilling rigs.

Table 2.8
1996 emissions to the atmosphere from fixed installations

Substance	Tonnes emitted

CO_2	1.35×10^6
CH_4	1.88×10^3
SO_2	0.08×10^3
NO_X	6.77×10^3
VOC	0.74×10^3

Table 2.8 shows the total emissions to the air from fixed installations in the Danish North Sea sector in 1996 for the above substances, with the exception of PAH compounds, for which no figures exist.

2.7.2 Emissions to the sea

The sources of discharges of oil to the sea from offshore activities are mainly production water, drilling, and spills.

2.7.3 Oil

Production water

Along with the production water (reservoir water) which is produced together with the hydrocarbons, a variable volume of oil is discharged every year. Water, gas, and oil are separated on the platforms in the water treatment plant with a view to achieving the minimum of oil content possible, with an absolute top limit of 40 mg/l before the production water is discharged to the sea.

Oil-based drilling mud

In situations where oil-based drilling mud (OBM) is used in drilling activities, oil attached to boring chips may be discharged to the sea. OBMs have not, however, been used in the Danish North Sea sector since 1991, thus reducing oil discharges significantly. Irrespective of type of mud used, a certain amount of oil from the reservoir is likely to be discharged along with the boring chips.

Spills

Finally, varying amounts of oil are discharged as spills. In 1996 the amount was in the order of 8.5 tonnes of oil.

Oil discharged with production water

Due to the growth in hydrocarbon production and the general ageing of the Danish oil and gas fields, the amount of production water has grown steadily over recent years. This tendency is expected to continue in future as production is planned to increase. The amount of oil discharged with production water may therefore also be likely to increase in the coming years. This means that the reductions in the total discharge achieved by avoiding the use of OBMs may be much reduced unless special steps are taken.

Figure 2.4 shows the trend in amounts of oil discharged from offshore activities between 1989 and 1996 split between source types. Oil from reservoirs discharged with boring chips is not included as up to now this has not been reported to the Danish EPA.

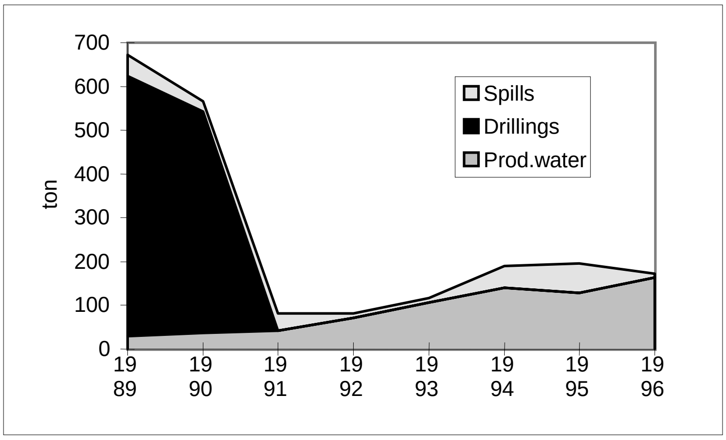

Figure 2.4

Oil discharged to sea between 1989 and 1996 from production water, drillings, and spills.

2.7.4 **Contaminants**

The offshore industry uses a broad spectrum of substances and materials (including a large number of chemicals) as ancillary materials for activities such as drillings, stimulations, maintenance of wells, separation of oil, gas, and water, and by handling and landing of hydrocarbons from the fields.

Substances and materials discharged to the sea

In 1996, a total of 76,031 tonnes of substances and materials were used in the Danish sector, of which 36,224 tonnes (47.6%) were estimated to be discharged directly to the sea. The remainder were disposed of by other means, i.e. by bringing it ashore or admixing chemicals to the oil which is removed via pipeline or vessels. In addition, a certain amount of the chemicals used remains in the reservoirs in connection with operations carried out. They may later be refluxed together with production water and discharged with it. The amount of refluxed chemicals discharged with production water is at present unknown.

Heavy metals

Drilling mud containing impurities in the form of heavy metals and discharging of production water containing metals are the main sources of discharge of heavy metals to the sea from offshore activities. Metals discharged with production water originate partly from the reservoir and partly from impurities in the chemicals used.

Table 2.9

Heavy metals discharged to the sea from drilling in 1996

Heavy metal	Discharge (kg)
Mercury	25
Cadmium	22
Zinc	636
Lead	1,606
Chromium	126
Nickel	49
Copper	110

In 1996, the total discharges of mercury (Hg), cadmium (Cd), zinc (Zn), lead (Pb), chromium (Cr), nickel (Ni), and copper (Cu) from drillings are set out in Table 2.9. There are no figures available for heavy metals discharged with production water in the Danish North Sea sector.

2.7.5 **Environmental regulation**

Environmental regulation

Environmental regulation in the offshore industry will in the coming years occur by the issuing of general approvals/permits which will promote the use of cleaner technology, for example by requiring the development and/or testing of environmentally better equipment and chemicals. Regulation of the application and discharge of chemicals offshore is primarily based on the Oslo-Paris Commission Decision 96/3. This decision requires all North Sea countries, for a test period of three years, to “pre-screen” and “rank” all offshore chemicals for environmental hazards with the overruling aim of reducing to the maximum extent discharges of environmentally harmful substances to the sea from offshore activities.

3 Total discharges to freshwater and the sea in 1996

This chapter presents the most important key data for discharges to freshwater and the sea in 1996. Figure 3.1 shows the marine waters and their associated catchments for which discharges are calculated. The detailed figures cover only discharges of nitrogen, phosphorus, and organic matter.

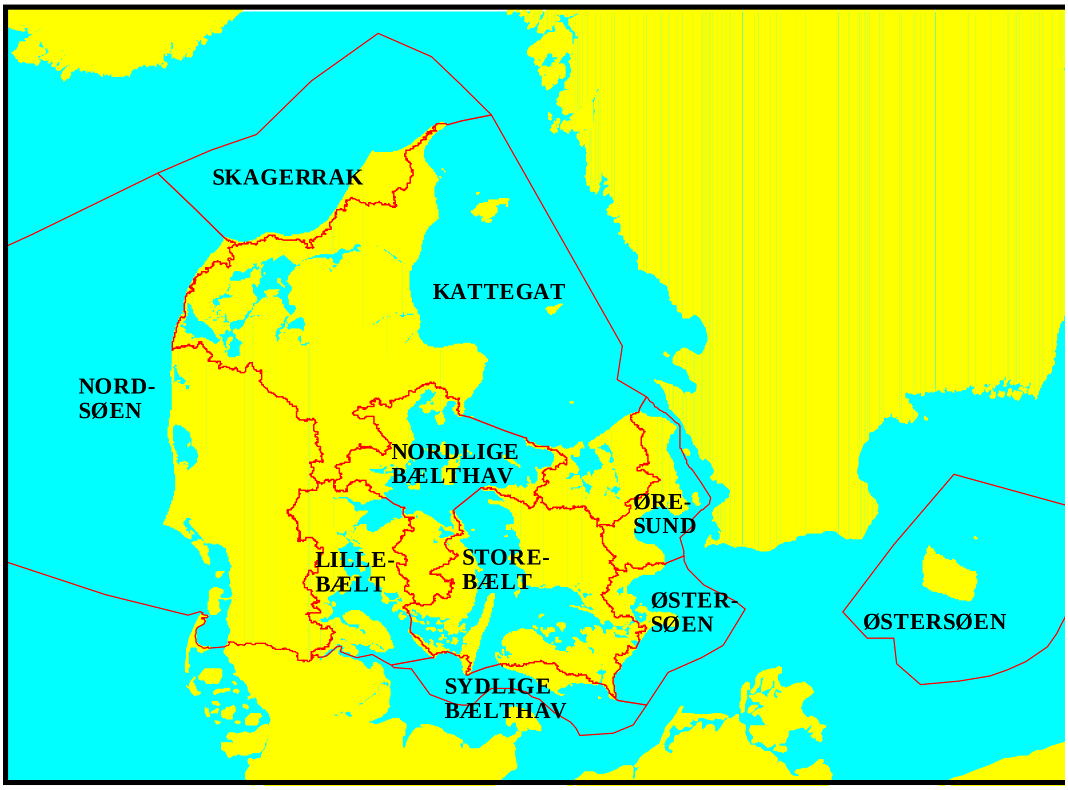

Figure 3.1
Map of first order sea areas and their associated catchments for which discharges are calculated.

Discharges to the sea are reported to HELCOM (Kattegat, the Belt Seas, the Sound, and the Baltic) and OSPARCOM (the North Sea, Skagerrak and Kattegat).

3.1 Discharges to the freshwater areas

Point sources

The total discharges from point sources to freshwater areas are shown in Table 3.1, split up into the marine areas to which they drain. The relative significance of the individual point sources is discussed in chapter 6.

Table 3.1
Point source discharges of nitrogen (Tot-N), phosphorus (Tot-P), and organic matter (BOD5) to the freshwaters in 1996

Nitrogen	Sewage treatment plants	Industry	Storm water overflows	Sparsely populated areas	Fish farming	Total

1. North Sea	643	32	76	194	716	1,661
2. Skagerrak	118	0	9	16	7	150
3. Kattegat	958	56	126	311	394	1,845
4. N. Belt Sea	321	5	54	133	5	518
5. Little Belt	234	1	43	156	90	524
6. Great Belt	326	10	59	239	0	634
7. The Sound	97	0	68	28	0	193
8. S. Belt Sea	19	0	3	20	0	42
9. The Baltic	47	0	5	43	0	95
Whole country	2,763	104	443	1,140	1,212	5,662
Phosphorus						
1. Noth Sea	78	2	19	44	55	198
2. Skagerrak	9	0	2	4	1	16
3. Kattegat	109	1	32	72	30	244
4. N. Belt Sea	29	0	14	31	0	74
5. Little Belt	24	0	11	35	7	77
6. Great Belt	49	0	15	55	0	119
7. The Sound	13	0	17	6	0	36
8. S. Belt Sea	4	0	1	5	0	10
9. The Baltic	9	0	1	10	0	20
Whole country	324	3	112	262	93	794
BOD5						
1. North Sea	383	12	201	737	1,914	3,247
2. Skagerrak	183	0	24	63	25	295
3. Kattegat	552	36	337	1,195	950	3,070
4. N. Belt Sea	160	0	134	514	9	817
5. Little Belt	124	5	116	593	223	1,061
6. Great Belt	276	5	152	913	0	1,346
7. The Sound	61	0	155	108	0	324
8. S. Belt Sea	24	0	7	77	0	108
9. The Baltic	71	0	14	164	0	249
Whole country	1,834	58	1,140	4,364	3,121	10,517

Distribution by source

The relative significance of loading of lakes by the different types of sources is shown on Figure 3.2. Open land is most important for both nitrogen and phosphorus, stemming mainly from agriculture, but also from natural sources.

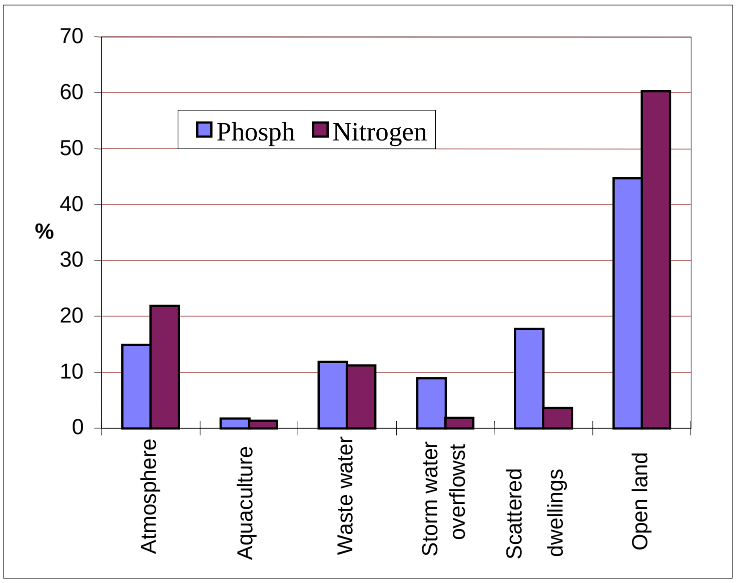

Figure 3.2
Percentage significance of loading of lakes by various sources (after Windolf, J. et al., 1997)

The relative significance of loading of watercourses by the different types of sources is shown on Figure 3.3. Open land is most important for nitrogen while phosphorus stems mainly from the various point sources.

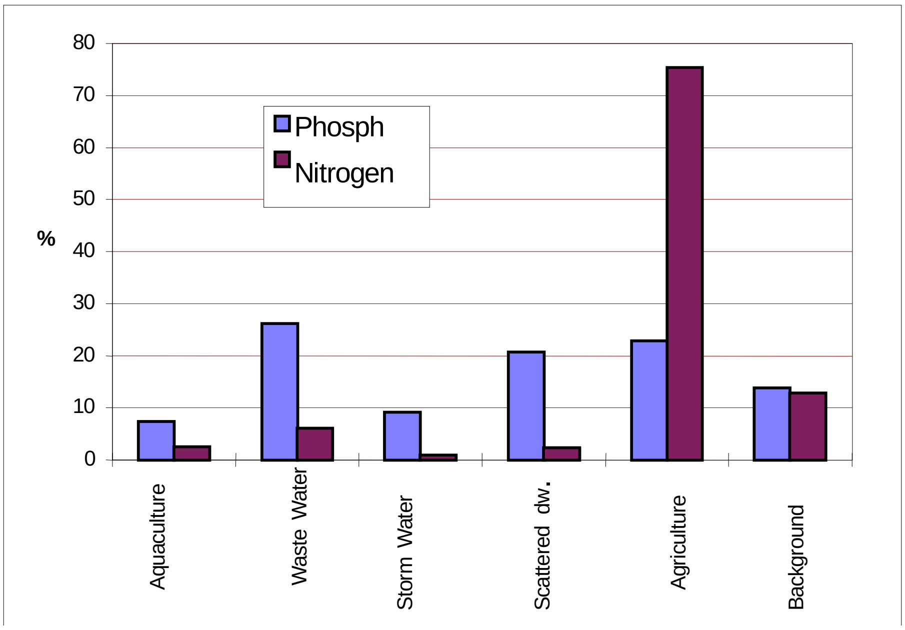

Figure 3.3
Percentage significance of loading of watercourses by various sources (after Windolf, J. et al., 1997).

3.2 Marine discharges

Nutrients are discharged to Danish marine areas by direct waste water outfalls, via watercourses, and by atmospheric deposition. Large quantities of nutrients are also received from marine currents.

3.2.1 **Direct discharges**

Nutrient inputs to the individual Danish sea areas from direct discharge from sewage treatment plant outfalls, industrial discharges, storm water overflows, sparsely populated areas, and fish farms are shown in Table 3.2.

Nitrogen	Treatment works	Industry	Storm water overflows	Sparsely populated areas	Fish farming	Total

1. North Sea	93	206	7	0	35	341
2. Skagerrak	11	97	1	0	2	111
3. Kattegat	517	501	58	2	0	1,078
4. N. Belt Sea	161	166	15	1	70	413
5. Little Belt	324	38	13	0	76	451
6. Great Belt	255	234	25	0	147	661
7. The Sound	2,154	370	59	0	0	2,583
8. S. Belt Sea	16	0	2	0	0	18
9. The Baltic	93	13	5	0	1	112
Whole country	3,624	1,625	185	3	331	5,768
Phosphorus						
1. North Sea	13	10	2	0	3	28
2. Skagerrak	3	11	0	0	1	15
3. Kattegat	48	55	14	0	0	117
4. N. Belt Sea	21	2	4	0	8	35
5. Little Belt	46	6	3	0	8	63
6. Great Belt	37	12	6	0	15	70
7. The Sound	389	19	16	0	0	424
8. S. Belt Sea	2	0	1	0	0	3
9. The Baltic	21	2	1	0	0	24
Whole country	580	117	47	0	35	779
BOD5						
1. North Sea	76	393	17	0	37	523
2. Skagerrak	7	616	3	0	0	626
3. Kattegat	400	2,188	149	7	0	2,744
4. N. Belt Sea	103	29	44	5	441	622
5. Little Belt	356	37	37	0	380	810
6. Great Belt	315	4,229	62	0	622	5,228
7. The Sound	1,753	1,139	141	1	0	3,034
8. S. Belt Sea	13	0	5	0	0	18
9. The Baltic	122	258	12	0	1	393
Whole country	3,145	8,889	470	13	1,481	13,998

3.2.2 **Discharges via watercourses**

Inputs of nutrients to the individual Danish sea areas from watercourses in 1996 are shown in Table 3.3.

Table 3.3

Input of nutrients from watercourses in 1996

Sea body	Tot-N	Tot-P	BOD5
		tonnes	
1. North Sea	11,866	273	3,533
2. Skagerrak	1,590	54	873
3. Kattegat	17,888	483	7,502
4. N. Belt Sea	2,665	83	978
5. Little Belt	3,625	117	1,194
6. Great Belt	2,543	127	926
7. The Sopund	582	36	323
8. S. Belt Sea	271	11	98
9. The Baltic	1,512	44	375
Whole country	42,542	1,228	15,802

Distribution by source

By deducting the known point source discharges to freshwater from the total discharges to the sea via watercourses, an impression can be gained of the magnitude of run-off from open land. Calculated in this way, discharges from open land amount to approx. 77,700 tonnes of nitrogen, 1,250 tonnes of phosphorus, and 17,900 tonnes of organic matter (BOD5). As during the passage through watercourses and lakes there is a certain retention and removal of inputs, these figures represent the minimum contribution.

3.2.3 Atmospheric deposition and emissions to the atmosphere

The aquatic environment does not only receive nutrients from discharges and losses from cultivated areas. A not insignificant input of nitrogen to the sea comes from the atmosphere, originating from both Danish and foreign sources. The magnitude of this deposition is based on measurements and model studies. The degree of uncertainty is assessed as about 40% in open sea areas and about 60% in fjords, coves, and bights. The uncertainty about phosphorus deposition is higher.

Nitrogen emissions

Nitrogen emissions to the atmosphere from Danish sources comprise oxides of nitrogen (NO_X) and ammonia (NH_3). The sources of NO_X are power stations, industry and traffic, while ammonia comes from agriculture. These emissions of oxides of nitrogen tend to fall, due to flue gas cleansing at power stations and in industry, and catalytic converters in motor cars. About 80,000 tonnes of nitrogen in the form of NO_X is emitted annually to the atmosphere from Danish sources. Ammonia emissions amount to approx. 105,000 tonnes of nitrogen and they have largely remained unchanged between 1989 and 1995.

Atmospheric nitrogen deposition

The total deposition of nutrients from the atmosphere to Danish waters is shown in Table 3.4.

Table 3.4

Total deposition of nutrients by sea area. Nitrogen quantities from (Ellermann et al., 1997

	Tot-N	Tot-P
Sea area	tonnes	
1. North Sea	48,400	
2. Skagerrak	9,300	
3. Kattegat	15,000	
4. N. Belt Sea	4,100	
5. Little Belt	2,800	280[1]
6. Great Belt	4,800	
7. The Sound	1,300	
8. S. Belt Sea	2,500	
9. The Baltic	13,500	
Total	101,700	

1: inner Danish waters (areas 3-8).

Distribution by source

For Danish waters as a whole, by far the greatest part of nitrogen deposition comes from foreign sources. Thus, only 16 % comes from Danish sources (Ellermann et al., 1997). In coastal areas, a higher proportion, up to 50%, may be of Danish origin.

70-80% is presumed to come from agriculture and the remainder from burning of fossil fuels (Ellermann et al., 1997), i.e. 76,000 tonnes come from farming, and 26,000 tonnes from industry, power stations, and traffic.

The deposition of phosphorus to inner Danish waters is estimated at about 8 kg./km^2, equivalent to approx. 280 tonnes/year. This estimate is an upper limit of deposition. Based on this, the total phosphorus deposition to Danish sea areas can at most be 1,000 tonnes/year. A large part of the phosphorus presumably originates from biological sources.

3.2.4 Grand total of substances to first order waters

The total amounts of nutrients and organic matter input to Danish sea areas in 1995 are shown in Table 3.5.

Table 3.5

Total inputs of nutrients and organic matter to the sea from direct outfalls, watercourses and the atmosphere in 1995, all figures in tonnes

	Atmosphere	Watercourses	Direct point sources	Total
Nitrogen				
1. North Sa	48,400	11,866	341	60,607
2. Skagerrak	9,300	1,590	111	11,001
3. Kattegat	15,000	17,888	1,078	33,966
4. N. Belt Sea	4,100	2,665	413	7,178
5. Little Belt	2,800	3,625	451	6,876
6. Great Belt	4,800	2,543	661	8,004
7. The Sound	1,300	582	2,583	4,465
8. S. Bekt Sea	2,500	271	18	2,789
9. The Baltic	13,500	1,512	112	15,124
Whole country	101,700	42,542	5,768	150,010
Phosphorus				
1. North Sea		273	28	301
2. Skagerrak		54	15	69
3. Kattegat		483	117	600
4. N. Belt		83	35	118
5. Little Belt	280[1]	117	63	180
6. Great Belt		127	70	197
7. The Sound		36	424	460
8. S. Belt Sea		11	3	14
9. The Baltic		44	24	68
Whole country		1,228	779	2,007
BOD5				
1. North Sea	n/a	3,533	523	4,056
2. Skagerrak	n/a	873	626	1,499
3. Kattegat	n/a	7,502	2,744	10,246
4. N. Belt Sea	n/a	978	622	1,600
5. Little Belt	n/a	1,194	810	2,004
6. Great Belt	n/a	926	5,228	6,154
7. The Sound	n/a	323	3,034	3,357
8. S. Belt Sea	n/a	98	18	116
9. The Baltic	n/a	375	393	768
Whole country	n/a	15,802	13,998	29,800

n/a: *not available*

1: *inner Danish waters (areas 3-8). Atmospheric phosphorus deposition not included in the total figure.*

In 1996, 70% of the total land-based inputs came from cultivation losses from agriculture, 19 % from waste water discharged directly to watercourses and coastal areas, while the natural background inputs contributed about 11%. The significance of waste water outfalls was thus relatively high in 1996, because of the low run-off and therefore nitrogen run-off into watercourses too.

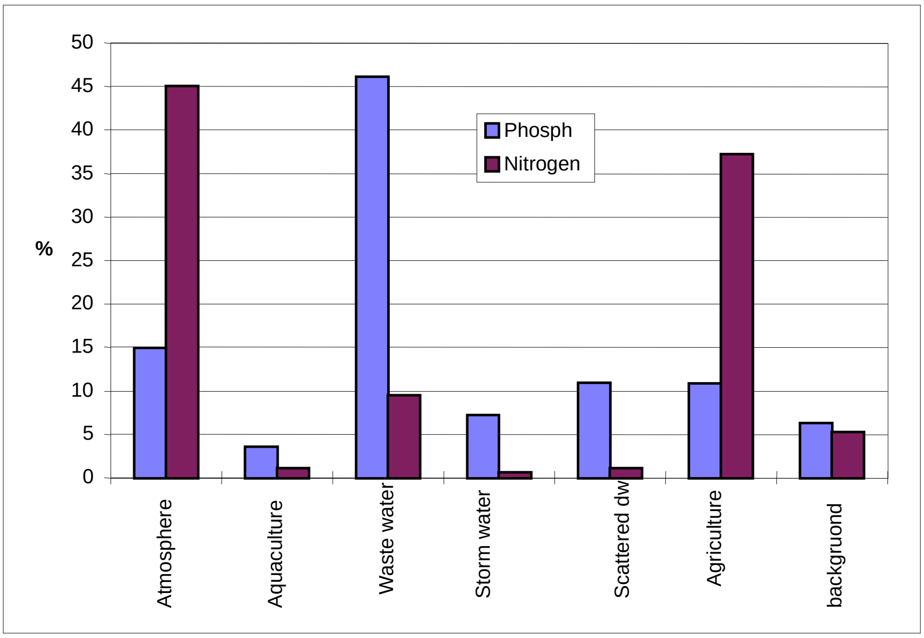

Figure 3.4
Percentage significance of loading on inner Danish waters from different sources.

Atmospheric deposition and agricultural inputs are the most significant sources of nitrogen. Phosphorus inputs arise especially from waste water.

Distribution by sectors

It is possible to make a rough estimate showing how inputs are distributed on various community sectors. Table 3.6 provides a survey of this.

Table 3.6
Percentage distribution by sectors of total inputs to Danish waters of nitrogen and phosphorus

	Nature, agriculture, forestry	Industry, traffic, sewage treatment plants
	%	
Nitrogen	75	25
Phosphorus	53	47

4 Watercourses and springs

Springs, brooks and watercourses form a natural system for transporting surface water from land and draining ground water. They are also an important element of the Danish landscape, with varied and extensive plant and animal life.

This section has been prepared with the aim of giving a picture of the current environmental condition of the Danish watercourses in relation to their man-made and natural features. Documentation is provided via the results of the monitoring programme and the regional supervision programme.

4.1 Watercourses and springs in Denmark

The idealised watercourse

The very beginning of a watercourse is known as the spring, where ground water is drawn to the surface and runs on in the headwater. Springs often contain animal life (fauna) specially adapted to the constant temperatures which characterise springs.

From the spring and immediately downstream, the water input rises due to surface water run-off and the watercourse becomes a brook. Great gradients, stone beds and shallow depths are some of the characteristics of the appearance of a watercourse. The gravel in a brook is often covered by a thin layer of invertebrates and plants which help to clean the water running over it. Gravel is therefore important in a watercourse, forming a built-in purification system. Brooks function as spawning and nursery areas for salmonoids, and many species of invertebrates inhabit their gravel beds.

Further down the watercourse system, more and more water is added from the catchment area, making the watercourse bigger and slower running than in the brook. Now it is called a watercourse, which is home to large trout. Further down, the idealised watercourse becomes a river, which has slow currents and greater depth. Rivers are typically unsuited as habitat for trout and are dominated instead by cyprinoids such as bream and roach. There are also particular species of invertebrates associated with the lower reaches of a watercourse system.

63,500 km watercourses in Denmark

There are approx. 63,500 km of watercourses in Denmark (Windolf et al., 1997). Most are small watercourses less than 2.5m wide (Table 4.1)

Table 4.1
Km of watercourses by width in Denmark (Windolf et al., 1997)

Width of watercourses (m)	Watercourses (km)
Less than 2.5	48,000
2.5-8	14,000
Over 8	1,500
Total	63,500

Classification of watercourses

Watercourses are classed under the Watercourse Act as private, local authority or county watercourses, respectively.

The classification of the individual watercourses determines who is the watercourse authority. The district council is the authority for private and local authority watercourses and the county council for county watercourses. The watercourse authorities lay down guidelines for administration of watercourses including the maintenance of each public watercourse. Private watercourses are maintained by the riparian owners.

Most small

In principle, the small watercourses are private, the slightly larger ones local authority *watercourses are private*

watercourses and the biggest in Denmark are county watercourses. Thus the length of private watercourses is presumed to be about twice that of public watercourses, because most are small.

4.1.1 Watercourse quality

Today most watercourses are far from the idealised state as described. Watercourses have been utilised for many centuries, in farming and in other ways, improved drainage being a prerequisite for being able to cultivate the fields. When the meadows and lowlands began to be cultivated, it became necessary to straighten, to install piping and to deepen watercourses and to subject them to heavy-handed clearance in order to speed up the drainage. They also came to be used to remove unpurified waste water from industries and towns.

The prerequisite of a good environment in the watercourses were thus eliminated, there being no clean water or enough of it, nor any physical variation with diverse habitats for plants and animals.

Clean water

The cleanliness of water in watercourses depends primarily on: organic or oxygen-consuming matter, nutrients, contaminants, ochre etc.

Organic matter arrives in watercourses e.g. from municipal sewage treatment plants, sparsely populated areas, fish farms, and industries. The problem of organic matter in watercourses is that oxygen is consumed in its decomposition, so organic matter can be harmful to the watercourse quality.

Nutrients such as nitrogen and phosphorus mainly leach to watercourses from cultivated areas and various waste water outfalls. Nitrogen and phosphorus do not influence the environmental conditions in watercourses to any significant extent, but may have negative effects in high concentrations in the lakes and the sea receiving discharges from them.

Pesticides and heavy metals are examples of contaminants which can enter the aquatic environment. Pesticides originate mainly from agriculture, while the sources of heavy metals have not yet been fully elucidated.

Adequate flows

Many watercourses have too low flows, some are even drying out in summer, thereby degrading the environmental conditions. This occurs naturally in some watercourses, but in others it is a result of human activity such as water catchment for drinking or industrial use.

Good physical conditions

By physical conditions is meant what can be seen in the watercourse, i.e. its shape.

Watercourses should have a varied form with bends, deep and shallow sections, and beds changing between stone, gravel, and mud.

They should be free of obstructions which hinder the free movement of water fauna up and down the watercourse.

Straightening and heavy-handed maintenance have ruined the physical conditions in many watercourses and turned them into straight, uniform canals.

4.1.2 Legislation

The three aspects of watercourses, water quality, physical conditions, and flow are protected by several acts. The most important of these are outlined below.

The Environmental Protection Act

This ensures clean water for the watercourses by prohibiting the discharge of polluting substances to watercourses, lakes or the sea. The authorities may, however consent to the discharge of waste water.

The Watercourse

The “new” 1982 Watercourse Act protects the physical conditions of watercourses. The

Act

protection is based on the introductory paragraph stipulating that when utilising watercourses the various environmental as well as commercial interests involved are to be considered.

For example, a watercourse must not be regulated, i.e. its line, levels or dimensions altered without the consent of the relevant watercourse authority.

Regulations

Regulations have to be prepared for all public watercourses to form the legal basis of their administration. They lay down rules on the shape and maintenance of the watercourses, clearance of areas along them, operation of weirs, fencing, and discharge of drainage waste and waste water outfalls etc.

The Nature Protection Act

The Nature Protection Act also protects the physical conditions by prohibiting alterations to protected watercourses or parts of them that have been classified as protected watercourses. Ordinary maintenance is excepted.

The Water Supply Act

The Water Supplies Act ensures that surface or ground water catchment may not occur without the consent of the authorities. Environmental and nature protection, including preservation of the quality of the surroundings, is to be a focal point in this connection.

Moreover, draining-off of ground water or lowering of the water table for building and construction work and extraction of clay, gravel, lignite, chalk etc. may not take place without consent.

The Ochre Act

The Ochre Act protects the water in the watercourses by requiring that agricultural ditching and drainage within the mapped areas of ochre potential be approved in advance by the County Council.

Other acts and regulations

Watercourses are also covered by other legislation such as the EU Bird Sanctuary and Ramsar sites regulations, which aim at protecting types of habitat and wetlands etc., and the Planning Act which requires regional plans to include objectives for the quality and utilisation of watercourses.

4.1.3 **Objectives**

The County Councils’ regional plans are required by the Planning Act to include guidelines for the quality and utilisation of watercourses in relation to an overall assessment of their development. That is, objectives are set for the quality and use of each watercourse, based on biological conditions, existing outfalls and the desired future usage, which then form the basis of the counties’ administration of the individual watercourses. The “Guidelines for recipient quality planning” No. 1, 1983, published by the Danish EPA describes the objective setting system to be followed by the counties. Table 4.2 shows the types of objectives used.

Table 4.2
Outline of watercourse objectives (Danish EPA, 1983)

Objective		Description
A	Special scientific interest	Watercourses where special natural features are to be protected
B_1	Salmonoid spawning and nursery areas	Watercourses which are to be suitable as spawning and nursery areas for trout and other salmonoids
B_2	Salmonoid waters	Watercourses which are to be suitable as growth area and habitat for trout and other salmonoids
B_3	Cyprinoid waters	Watercourses which are to be suitable as growth area and habitat for eels, perch, pike and other cyprinoids
C	Watercourses used only to convey water	
D	Watercourses affected by waste water	
E	Watercourses affected by ground water catchment	
F	Watercourses affected by ochre	

Quality requirements to the setting of objectives

In the setting of each objective, the counties lay down quality objectives to be met. Some water quality objectives are laid down in accordance with the requirements of the EU Fishing Water Directive of 1978 and appear from the above-mentioned guidelines of the Danish EPA. It is also a requirement that waste water outfalls, water catchment, water flow, alterations of the physical conditions of the watercourse, maintenance, etc. are acceptable only as long as they do not hinder the meeting of the objectives set.

In principle, this means that A-targeted watercourses shall be free from the effects of any human activity. B-targeted watercourses may only be mildly affected, whereas C, D, E and F indicate a certain degrees of human influence on these watercourses.

Assessment of compliance with objectives

To assess the extent of compliance of a watercourse with its target, a parameter is selected which is easy to quantify and which can be used as an indicator of the environmental conditions of the watercourse. The counties' regional supervision uses various methods for biological assessment, based in principle on the same fauna classification (fauna class) I-IV. Fauna class I denotes an unpolluted and IV a heavily polluted watercourse.

In A-targeted watercourses, fauna class requirements are set for each watercourse depending on the state to be maintained. Generally, the fauna classification shall be II or better in fishing-targeted waters (B1, B2 and B3). Fauna class II-III can only be accepted in a few cases of canals or river-like watercourses without falls. The fauna class must not be poorer than II-III in waters affected by water catchment or waste water discharge and used to convey water.

4.2 Water balance and freshwater run-off

The water cycle is the most important factor for transporting nutrients etc. from land to the sea. Precipitation containing nutrients etc. ends up in watercourses, lakes, and ground water. Annual fluctuations in precipitation are therefore reflected in variations in the biological, physical, and chemical conditions in the aquatic environment.

Man-made effects on the hydrological cycle

Man-made effects on the hydrological cycle take the form of water catchment, drainage, watercourse straightening, etc. The most significant factor is water catchment of drinking water and for commercial use. In Jutland, 5% of the total watercourse flow volume is recovered compared with 11% in the islands (Windolf et al., 1997). Flows in watercourses are affected by water catchment and the geology of their catchment areas and can therefore vary greatly. Some are especially strongly influenced by low flows as a result of water catchment around large towns. Kristensen and Rasmussen (1997) thus reveal that the median minimum flows in watercourses draining to Køge Bight have been reduced by 50-90% as a result of water recovery.

Drainage, watercourse straightening and surfaced areas cause water to enter watercourses quicker, leading to large fluctuations in flows in the watercourses with increased watercourse erosion.

Low precipitation in 1996

As stated in Chapter 1, 1996 was the driest year in the period monitored. As a yardstick for the low precipitation, the hydrological year of 1995/96 was the driest in Funen in this century with precipitation 48% below normal (Wiberg-Larsen et al., 1997).

The driest and wettest years in the monitoring period

The precipitation distribution in the period 1989-1996 has in general not differed from the norm (Windolf et al., 1997). There was on average 25 mm less than normal during that time, with an annual average of 712 mm. All the same, there were large variations, with two very dry years in 1989 and 1996 and the wettest year ever in 1994.

However, variations within the years did not differ significantly from normal conditions, with most precipitation in the third and fourth quarters.

Low run-off in 1996

There was also record low run-off in 1996 (Table 4.3). Many watercourses dried out or were directly threatened by drying out in the summer of 1996. 25% of the whole watercourse length in Funen dried out (Wiberg-Larsen et al., 1997).

The average run-off in the monitoring period 1989-1996 was lower than normal and also featured extreme conditions with very high run-off in 1994 and very little in 1996.

Water balance in 1996

The difference between precipitation and run-off is called the water balance, which is an overall measure of evaporation and percolation into the ground. In 1996, it was 100 mm, which is one third of the normal level and the lowest in the whole monitoring period. Ground water reserves thus shrank in 1996.

Evaporation

Variations in evaporation affect flows in watercourses. Put simply, low evaporation results in more water for the watercourses. Human activity such as drainage and lowering the water-table combined with a 3-4% reduction in hours of sunshine mean that evaporation in Denmark has fallen by 6% since the 1920s.

Table 4.3
Average annual values of precipitation, freshwater run-off and potential water balance in 1989-96. Average values for 1989-96 and normal values for 1961-90 are also given (rewritten from Windolf et al., 1997).

Period	Water balance	Precipitation	Run-off	
	(mm)	(mm)	(mm)	$10^6 m^3$
1989	142	581	252	10,800
-90	433	812	327	14,000
-91	239	654	296	12,700
‘92	244	706	294	12,600
‘93	354	758	325	14,000
‘94	487	880	455	19,600
‘95	212	652	363	15,600
‘96	100	505	190	8,200
1989 - 96	276	693	313	13,400
1961 - 90	300	712	327	14,000

4.3 Water quality in watercourses and springs

Nitrogen and phosphorus are the most important nutrients for plant growth in the aquatic environment. Elevated concentrations of nitrogen and phosphorus in watercourses may have negative influences on the remote environment of lakes, coastal areas and the sea, while having less effect on the watercourses because the staying time is so short that watercourse plants have not got time to consume them before the outflow. This is also the case in watercourses in catchment areas in the open land, where concentrations of nutrients are low. However, it has been established that high concentrations of phosphorus may contribute to increased growth of filamentous algae in watercourses.
Nutrient run-off is monitored in the monitoring programme by water quality measurements in approx. 260 watercourses and 58 springs to elucidate the occurrence, transportation, and sources of loading.

Nutrient sources

Nutrients are input to watercourses from a number of natural and man-made sources, which may generally be divided into the main headings of point and diffuse sources as defined below:

Point sources:
- Municipal sewage treatment plants
- Individual industrial discharges

- Storm water overflows
- Fish farms
- Waste water from sparsely populated areas

Diffuse sources:

- Natural background loads
- Waste water from sparsely populated areas (also considered a point source)
- Effects of human activity in cultivated areas
- Others, precipitation, particle deposition, etc.

4.3.1 **Phosphorus**

The significance of the individual sources for the total phosphorus transported by watercourses varies greatly.

Significance of point sources for phosphorus in watercourses

There are geographical variations in the significance of point sources for total phosphorus transported by watercourses depending on both natural and man-made circumstances. They are highly significant in densely populated areas compared with the rest of the country because of major waste water outfalls. In wet years, such as 1994, their contribution to total phosphorus transport was less in relation to diffuse sources due to subsequently large phosphorus-bearing run-offs from the open countryside.

Diffuse losses are the major source of phosphorus

Diffuse losses are today generally the major source of phosphorus inputs to watercourses, although these vary very much depending on both natural and man-made circumstances. Inputs of phosphorus from agriculture in both wet and normal years contribute over half the total of diffuse losses. In comparison, waste water from sparsely populated areas make up 25% of the phosphorus contribution (Windolf et al., 1997). Agricultural inputs are thus significant. If the loss of total phosphorus from cultivated catchment areas in clayey and sandy soils is considered separately, the input, in terms of flow-weighted concentrations and catchment area losses, was highest in watercourses in clayey soil in 1996. This can be ascribed to surface water run-off and drainage water. The loss of phosphorus can be related to the agricultural usage of the land, in that the loads rise significantly with increasing proportions of cultivated land in the watercourse catchment areas.

Bank erosion liberates particle-bound phosphorus to the watercourse in significant quantities. One study shows that erosion over two years contributed 30% and 14%, respectively, of the total phosphorus transported by a watercourse. For this reason, it is important to enforce the two metre border as an uncultivated area and apply environmentally friendly maintenance to the watercourse to ensure bank stability (Rebsdorf et al., 1994).

Phosphorus load in 1996

The phosphorus concentrations in Danish watercourses are still high, typically more than 0.1 mg/l. In July 1996 catchment area losses measured both as concentration in water and as catchment area loss of phosphorus were lowest in watercourses with natural catchment areas, 3-4 times higher in cultivated areas and 6-8 times higher in catchment areas including waste water sources (Figure 4.1). Phosphorus loads in watercourses which mainly drain surfaced areas were similar to those found in watercourse with catchment areas loaded by waste water.

Besides, the concentrations of total phosphorus were significantly higher in Zealand than in watercourses in Funen and Jutland, which was ascribed to higher point source loads with lower dilution in Zealand. The point sources were the major source of phosphorus in 1996 in Zealand. In Funen and Jutland, diffuse sources were predominant.

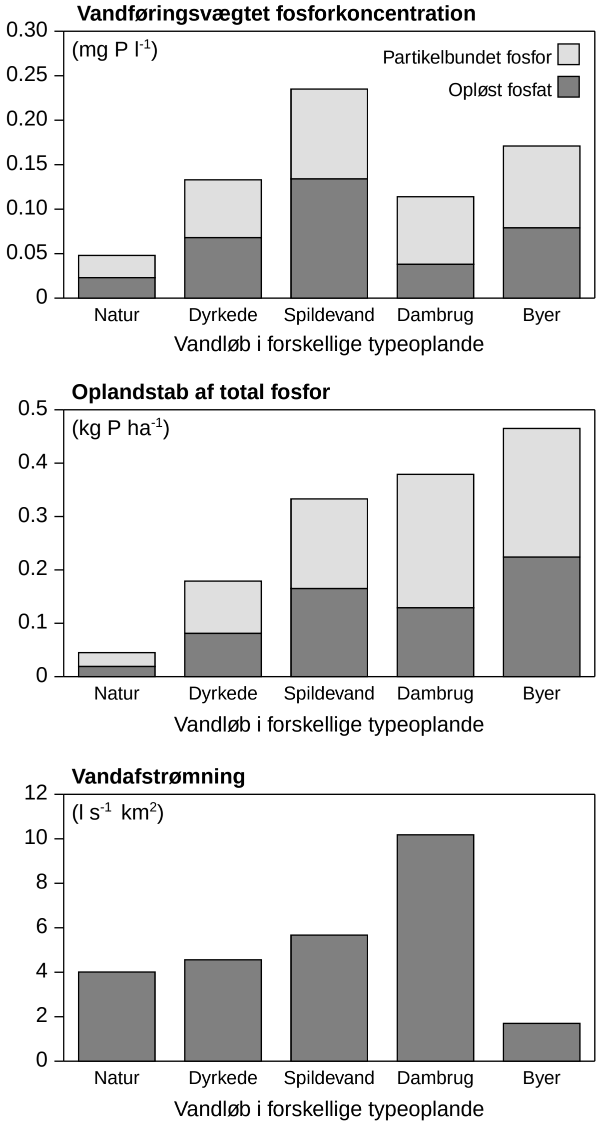

Figure 4.1

Average flow-weighted concentration of catchment area losses of total and dissolved phosphorus and run-off to watercourses in five different types of catchment areas in 1996 (Windolf et al., 1997)

Reduced phosphorus concentration in watercourses

A general fall in the total phosphorus concentration in watercourses has been confirmed both 10 years before and 8 years after the introduction of the monitoring programme of the Aquatic Environment Plan in 1989. Data from 36 watercourses collected via the counties' regional supervision show a mean fall in the concentration of total phosphorus of 16% in the period 1978-88, which is, however, only statistically certain in half of the watercourses.

From the coming into force of the Aquatic Environment Plan in 1987 till today a fall in phosphorus concentration of 31% has been established in catchment areas affected by waste water and of 10% in cultivated catchment areas, where phosphorus inputs from cultivated land typically constitute more than half of the total diffuse phosphorus loss. The development of phosphorus losses to watercourses from diffuse and point sources are shown in Figures 4.2 and

4.3, respectively.

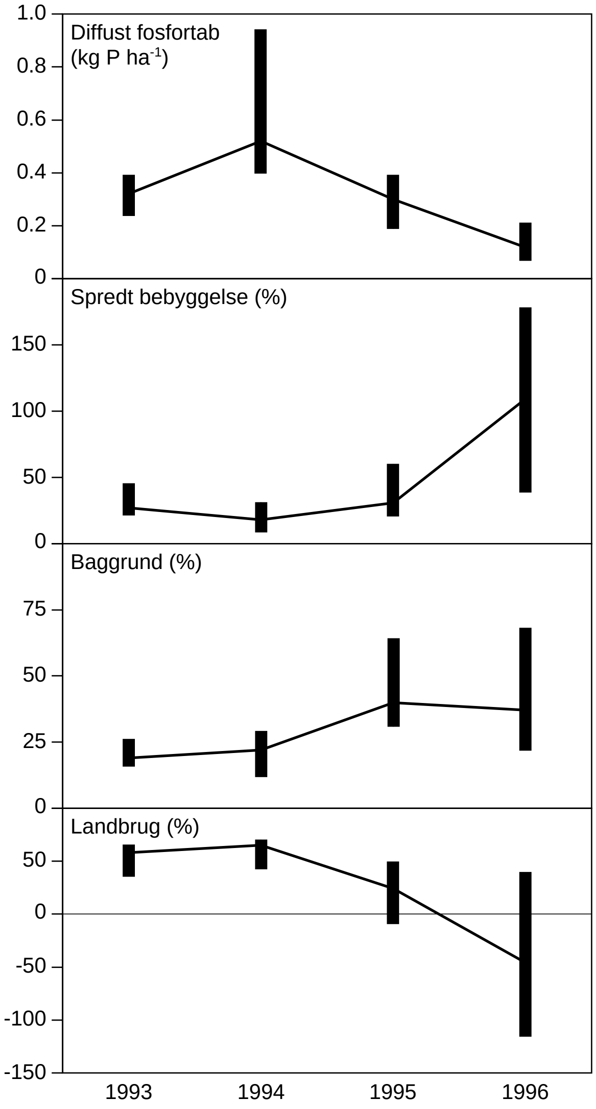

Figure 4.2
Development of annual diffuse phosphorus loss and significance of inputs from agricultural, sparsely populated and uncultivated areas. The figure shows median values – the fully drawn line – and the 25% and 75% quartiles (Windolf et al., 1997).

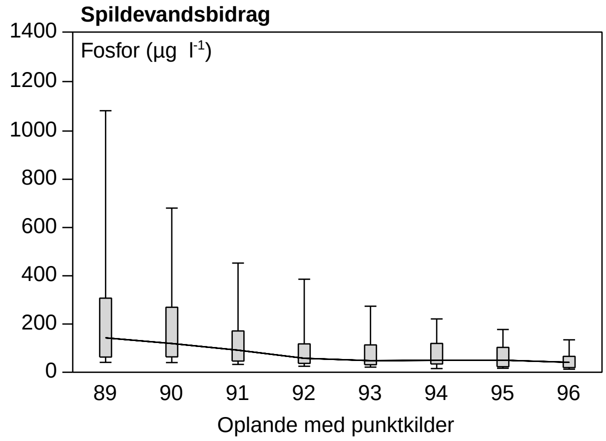

Figure 4.3
Development of phosphorus input from point sources to watercourses loaded by waste water. The figure shows the median value as a fully drawn line with 90% and 10% percentiles (Windolf et al., 1997).

A small total increase in the phosphorus concentration of 7% has, however, been noted in watercourses in natural catchment areas between 1989 and 1996, which may be attributed to natural occurrences and/or man-made disturbances in the catchment areas such as tree-felling, traffic along watercourses, etc.

The general fall is only statistically certain in some of the watercourses examined, so the figures should be treated with some caution. Monitoring over the next few years should give a more precise picture of this positive development.

Fall greatest in Zealand

There are geographical differences in the development of total phosphorus concentrations in watercourses. Up to 1988, the greatest falls were mainly in small and large watercourses in Jutland and Funen. This development did not take hold in Zealand until in 1989-96, the fall being 50% and 19% higher than in Funen and Jutland, respectively (Windolf et al., 1997). The fall was also three times greater in clayey areas than in sandy ones.

Reasons for reduced phosphorus before and after the Aquatic Environment Plan

Reduced phosphorus inputs to many watercourses during 1978-88 were due mainly to improved waste water purification in municipal sewage treatment plants. Considering small and large watercourses separately, it turns out that the fall in large watercourses is due in fact to improved waste water purification in the sewage treatment plants of the towns and reduced industrial and fish farm inputs. Improved purification requirements for organic matter, diversion of waste water from smaller communities to larger sewage treatment plants and reduced household phosphorus outfalls are the main reason for phosphorus reductions in smaller watercourses over the same period.

The reasons for the results of the Aquatic Environment Plan in respect of phosphorus reduction in watercourses may be found in conditions such as improved storage of liquid manure, firm stable manure and silage (watercourses in agricultural areas), reduced use of phosphate-containing washing and cleaning products (sparsely populated areas) and improved waste water treatment (point source areas).

The reduction in phosphorus loading of watercourses from agricultural areas has not been as marked as in watercourses in the other types of catchment areas subject to human activity, presumably as a result of continuing country-wide phosphorus surpluses in cultivated areas. An effort is therefore required to reduce phosphorus-containing discharges from cultivated areas.

Phosphorus concentrations still too high

In spite of the reductions noted over about 20 years, the phosphorus concentrations in watercourses are still over 100 mg/l in most Danish watercourses, which is regarded as a high level of phosphorus in watercourses.

4.3.2 Nitrogen

There is great variation in the significance of different sources of total nitrogen transported by watercourses.

Cultivated areas are the major source on nitrogen input

The principal diffuse source of nitrogen inputs to watercourses is cultivated areas. This applies to both normal and wet years. Cultivated areas typically contribute over 80% of the diffuse nitrogen inputs to watercourses from catchment areas compared with about 6% from point sources in normal and wet years. Nitrogen is leached from the root zone in cultivated areas and transported via drains, upper and lower aquifers with more or less delay. More nitrogen is typically leached from clayey than from sandy soils, because the run-off is quicker and more direct from clayey soil. Inputs from diffuse sources therefore vary from year to year depending on the amount of water percolating through the soil, and thus the total amount of precipitation.

Point sources are less significant to nitrogen inputs

Input of nitrogen from point sources is less significant to the total loading of surface water by nitrogen than the loading from cultivated areas. In normal and wet years, where there is substantial nitrogen leaching from soil, the input from point sources is typically less than 6% of the nitrogen transported by small and large watercourses (Windolf et al., 1997). Even in watercourses affected by waste water outfalls, the waste water contribution comprises only a small percentage of the Tot-Nitrogen concentration. In a dry year such as 1996, however, their relative significance increases due to the lower inputs from diffuse sources as a result of lower percolation through the soil. There are also geographical differences: in densely populated areas such as Zealand, point sources are more significant than in the rest of the country.

Nitrogen run-off from nitrogen leaching

The mean annual concentration or the catchment area loss of total nitrogen in 1996 was significantly higher in watercourses draining catchment areas affected by agriculture, waste water or fish farms than those serving natural catchment areas (Figure 4.4).

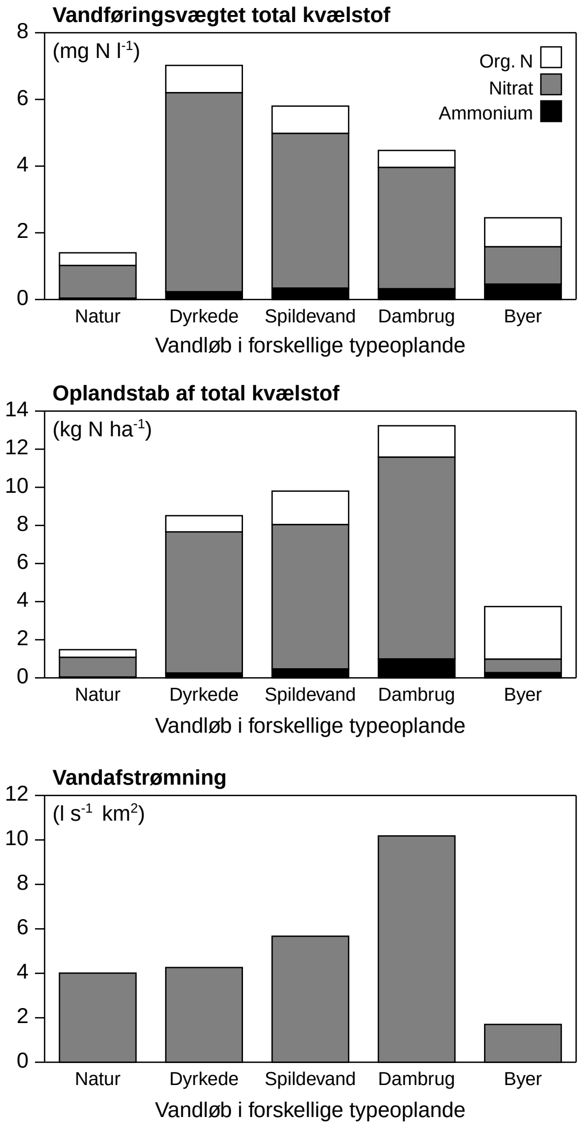

Figure 4.4
1996 average of flow-weighted concentration and catchment area loss of total nitrogen split up in ammonium, nitrate and organic nitrogen and water run-off in five different types of catchment areas (Windolf et al., 1997).

The total nitrogen expressed as flow-weighted concentration was slightly higher in agricultural catchment areas than in watercourses in the other three human-affected types of catchment area in 1996. This applies to the whole monitoring period. On the other hand, the loss of nitrogen measured as kg/ha of catchment area was lower in the cultivated catchment areas than in watercourses affected by waste water or fish farms. The latter was only registered in 1996 due to the extremely low precipitation and correspondingly low leaching from cultivated areas.

The highest total nitrogen concentrations were measured in 1996 in East Jutland and the islands and in a belt south of Limfjorden from the North Sea to Kattegat, where there are large livestock holdings today.

Nitrogen inputs from paved areas, for example in large towns, make up a very small part of the total input.

Small reduction in nitrogen loading of watercourses

There is a clear tendency for the flow-weighted total concentration of total nitrogen in watercourses to have fallen over the last four years as compared with the average before the Aquatic Environment Plan. Treating type of catchment area separately, the concentration of total nitrogen in watercourses fell from 1989 to 1996 by 3% in natural catchment areas, by 9% in cultivated areas, by 18% in catchment areas affected by waste water and by 7% in those affected by fish farming. It should be pointed out that overall there is not a statistically reliable fall in total nitrogen concentrations in the Danish watercourses due to large variations in the development of nitrogen concentrations in the various watercourses studied. The development of nitrogen loading from diffuse and point sources is shown in Figures 4.5 and 4.6, respectively.

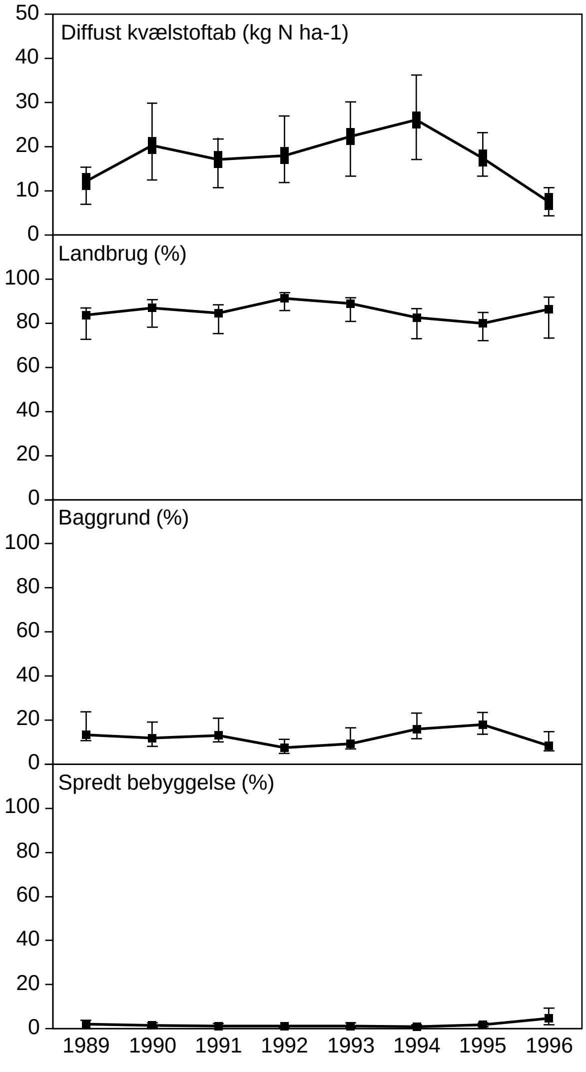

Figure 4.5
Development of annual diffuse nitrogen loss and significance of inputs from agricultural, sparsely populated and uncultivated areas. The figure shows the median values as a full line together with 25% and 75% quartiles (Windolf et al., 1997).

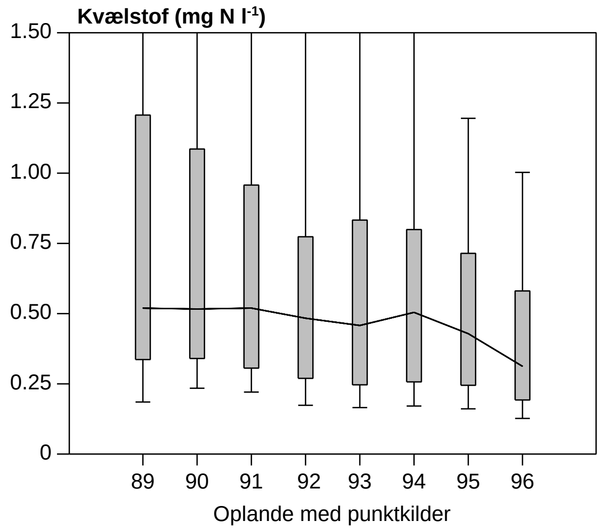

Figure 4.6
Development of annual point source nitrogen inputs to watercourses affected by waste water. The figure shows the median values as a full line together with 10% and 90% percentiles (Windolf et al., 1997)

The reduction in nitrogen concentration in watercourses in agricultural areas can be explained by a fall in leaching of nitrogen or by particular climatic conditions in the past couple of years.

A wet year in 1994 and a very dry one in 1996 can be one of the main reasons. For example, during the very dry 1996 with very little nutrient leaching there has presumably been a large accumulation of nitrogen in cultivated soil which will run off to watercourses in connection with any subsequent high precipitation, resulting in a flow-weighted corrected rise in nitrogen concentration. The rise in level of transportation of nitrogen in watercourses in cultivated catchment areas in 1996/97 already indicates that climatic conditions may be the reason for the fall during the preceding years. Analyses over the next few years will presumably elucidate this point better than has been possible to date.

The large reduction in total nitrogen concentrations in watercourses affected by waste water outfalls reflects investments made in improved waste water treatment.

A combination of modified agricultural practice in certain areas and re-establishing of water meadows, where large amounts of nitrogen may be converted, should be considered in future with a view to further nitrogen reductions.

4.3.3 Organic matter

Organic matter occurs naturally in watercourses, e.g. as dead plants and animals, but readily degradable organic matter also enters watercourses via waste water. When organic matter decays, oxygen is consumed, the quantity of the oxygen consumed being expressed as BOD5 (biological oxygen demand over 5 days). When waste water containing organic matter enters a watercourse, oxygen consumption increases, which may have negative effects on animal life in the watercourse. The invertebrates that can only live in clean, oxygen-rich water disappear, and are replaced by the few species which are able to survive under polluted conditions.

Reduced inputs of oxygen-consuming substances

Waste water from sewage treatment plants was the most significant point source of organic matter in freshwater in 1996 and comprised 49% of the total point source inputs (Table 4.4). Point sources only provided about 20-25% of the volumes discharged in the mid-80s (Windolf et al., 1997).

Table 4.4

Inputs of organic matter (BOD5) to freshwater from waste water by source

Source	BOD5 (tonnes)	% of total
Sewage Treatment plants	2,763	49
Industry	104	2
Storm water run-off	443	8
Sparsely populated areas	1,140	20
Fish farming	1,212	21

In this context the BOD5 content in major watercourses has dropped significantly (Figure 4.7) to a level where benefits from further reductions as a result of additional waste water purification are minimal. For example, in major watercourses in Funen BOD5 has been reduced by 94% since 1987 (Wiberg-Larsen et al., 1997). The expansion, including centralisation, of waste water purification plants is the explanation of the reduced discharges of oxygen-consuming substances found in outfalls, especially to major watercourses.

Small watercourses affected by sparsely populated areas

Small watercourses, on the other hand, are still subject to problems caused by inputs of oxygen-consuming substances from sparsely populated areas, as a result of which many small watercourses are still in a too badly polluted condition.

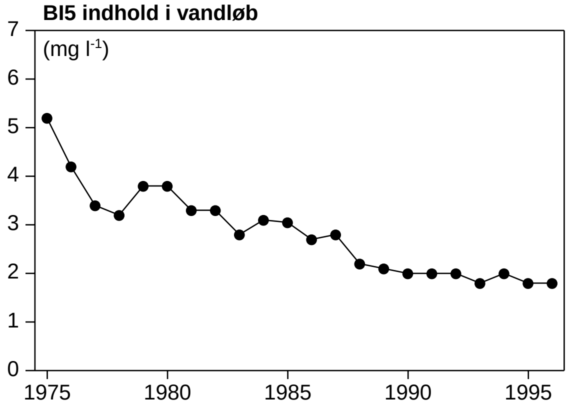

Figure 4.7

Development of BOD5 content in major Danish watercourses (Windolf et al., 1997)

4.3.4 Heavy metals and contaminants

Occurrence of heavy metals

A range of heavy metals and contaminants are used to such an extent that there is a potential risk that they will end up in the aquatic environment. Agricultural practices can also alter the leaching and acidification processes in soils, allowing pre-existing heavy metals to be more easily released. There has, however, been no systematic nation-wide study to date of the occurrence of heavy metals and contaminants in Danish watercourses.

A few studies have shown that there are local problems with increased heavy metal concentrations in Denmark.

Fish farming sludge

A study of the heavy metal content in sludge from 22 fish farms undertaken in 1992-1993 in Ringkøbing County showed cadmium and nickel levels in many samples to be too high for spreading on farmland, whereas lead and mercury caused no problems (Ringkøbing County, 1993).

Further studies are needed to establish whether the heavy metals come from the fish feed or the surrounding environment.

Ochre purification systems

Another study of mud and sediment samples drawn in and near 31 ochre purification systems in water courses showed the cadmium threshold values to be exceeded at 10 sites.

The study showed that concentrations can be affected by catchment area, soil conditions and possibly lime admixture to the system (Jensen & Nielsen, 1996).

Waterweeds

Heavy metals are also found in weeds in watercourses in quantities exceeding the permissible threshold values for spreading on farmland. Viborg County, which annually collects about 2,000 m³ of weed sap from watercourse maintenance, analysed the juice for heavy metals in 1996 and found that the weeds could not be used on farmland due to excessive mercury content.

Cadmium in weeds and mercury in the weed sap are presumably concentrated during storage for subsequent spreading on farmland.

Current studies

The Ministry of Food, Agriculture and Fisheries and the Danish EPA have instituted studies to find the sources of and reasons for these high heavy metal levels in and around watercourses.

Waste water loading

It has been established that waste water outfalls to freshwater areas from sewage treatment plants, industrial plants and sparsely populated areas contain varying amounts of heavy metals and contaminants. The retention and/or conversion of most substances by sewage treatment plants is generally very high and the inputs are small in relation to the potential amounts (Danish EPA, 1994).

There is no overall measuring programme for the input of heavy metals and contaminants in industrial waste water, but it was estimated in 1994 that a significant reduction of the total input has occurred since the mid-80s, including the input to freshwater areas (Danish EPA, 1994).

Similarly, there is no overall programme for sparsely populated areas. In 1994, the Danish EPA, however, produced a small survey indicating input of heavy metals (Danish EPA, 1994). Purification of waste water from sparsely populated areas, in conjunction with product regulations, is expected to reduce the loading significantly.

Loading by surface water run-off from paved areas

It has turned out that surface water run-off from paved areas such as roads may contain significant amounts of heavy metals and contaminants. Lead, zinc and copper and PAH-compounds were found in one study in concentrations comparable with those in untreated sewage. Concentrations of lead, chromium, copper and zinc exceeded quality limits for freshwater areas (Kjølholt et al., 1997). The study also showed that particulate matter in the run-off contained much higher concentrations than the run-off itself. For this reason, it cannot be ruled out that run-off from roads may have detrimental effects on the aquatic environment, especially long-term effects on benthic organisms caused when contaminated particulate matter settles in a restricted area.

Pesticides

Pesticides differ from other contaminants in that they are intentionally toxic to flora and fauna and are deliberately spread in the environment. Irresponsible use leading to pollution of watercourses and lakes can therefore be expected to be very harmful to the aquatic environment. Several counties have in recent years found pesticides and their break-down products in selected watercourses, and a co-ordinated study was launched in the autumn of 1996 with the aim of achieving an overview of the extent of the problem.

In 1994-96 the Funen County studied six watercourses in mixed catchment areas, farmland and forest areas. The watercourses were tested for 99 different pesticides, of which 30 were detected in one or more watercourses (Wiberg-Larsen et al., 1997). In 1995, four springs were also tested for 88 pesticides, of which two and traces of a third pesticide were found in two of the springs

(Wiberg-Larsen et al., 1997).

Ringkøbing County studied twelve watercourses in farmland, towns and natural areas in 1996. The watercourses were tested for 28 different pesticides, of which 22 were detected in one or more watercourses. Remnants of pesticides were found in all 12 watercourses (Ringkøbing County, 1997a).

The Copenhagen County found pesticides in 12 out of 28 watercourse locations studied. The watercourses were tested for 24 pesticides, of which four were detected in one or more watercourses (Nielsen, 1997a).

Sources of pesticide loading

Ringkøbing County detected pesticides after extended drought, when the flows consisted almost entirely of seeping-out of ground water. As wind drift was not a likely explanation at the time, this may indicate that pesticides also find their way into watercourses via upper aquifers and/or drains.

Effects of pesticides in watercourses

No actual studies have been undertaken of the environmental effects of pesticides in the aquatic environment, but as they have been detected in concentrations known to be harmful to flora and fauna, they are likely to be environmentally damaging. Funen County has estimated that the invertebrate fauna in watercourses has been affected to such an extent that in 20% of the cases this is the main reason for failure to meet objectives in the county’s small watercourses (Wiberg-Larsen et al., 1997).

4.3.5 Ochre pollution

Pyrite

Many low-lying soils contain the mineral pyrite (a compound of iron and sulphur), which is stable in water-saturated soil. When pyrite is oxidised, the iron is liberated as water-soluble ferrous iron. This leads to a risk of pollution of watercourses by iron-bearing water.

Dissolved iron

Dissolved iron (ferrous iron) is harmful to aquatic fauna in very low concentrations, i.e. from 0.2 mg/l, whereas ochre particles washed into the watercourse affect its physical condition by ochrous slime on stones, gravel, watercourse beds, and plants destroy the habitats of benthic algae and microfauna.

Ochre

Ochre can also form a layer over gravel spawning beds, where it kills fish eggs or causes malformations in those larvae that do hatch under ochrous conditions.

Oxidation

Oxidation of pyrite is highest in summer, when the water table is low. Iron concentrations in watercourses are highest in autumn and winter (November-April) when the run-off is greatest.

Extent of ochre pollution

Ochre pollution is highest in the area west of the Jutland ridge, where the soil contains large amounts of pyrites and is also very low in lime ($CaCO_3$), etc.

There are some 300,000 ha of potentially ochrous soil in Jutland, about 10% of the total area (see Table 4.5) (Andersen, 1993b).

Table 4.5

Potentially ochrous areas in Jutland

County	Potentially ochrous area (ha)
North Jutland	79,000
Viborg	40,400
Ringkøbing	59,900
Vejle	9,478
Ribe	30,080
South Jutland	45,452
Aarhus	32,200

The area of watercourses inside or downstream of the mapped potentially ochrous areas was assessed in 1986 to comprise approx. 28% of the total Danish watercourse area. Ochre pollution is worst in Ribe, Ringkøbing, and the South Jutland counties.

Legislation

The Ochre Act aims at preventing and combating ochre nuisances connected with agricultural ditching and drain-laying activities. Among other things, it stipulates that drainage within the prescribed ochre potential areas may only take place with the approval of the county councils.

Administrative practice to date

When the Ochre Act was passed in 1985 it was anticipated that drainage activities would cover about 1,000 ha p.a., and that as a rule approval would be granted (about 65% of cases), with only exceptional refusals (10-15%). In practice, the Act has turned out to be less restrictive than expected, with 79% of applications approved and only 8% refused (Andersen (ed.), 1993b).

Revision of mapping

It was decided in connection with the passing of the Act to redefine the designated potentially ochrous areas at a later date, and in 1992-93 about 12,000 ha were proposed to be removed from and a further 9,500 ha added to the mapping. In reality, this adjustment would bring in several areas of agricultural interest (Andersen, 1996a). At the present time no significant administrative benefits are connected with adjusting of the mapping (Andersen, 1993b).

Financial consequences of the Act for agriculture

The financial consequences of the Act to the agricultural sector have been minimal, as the Danish EPA has paid all costs of setting up ochre purification plants and paid equity compensation corresponding to the loss of value of the land affected where drainage has been prohibited.

In the period 1985-96, this compensation has been paid at an average level of DKK 4,225/ha. If the average compensation is capitalised over a 15-year period, this corresponds to a marginal return of DKK 460/ha compared with the DKK 300/ha annual additional income resulting from drainage of problematical potentially ochrous land (Andersen & Christensen, 1996).

Subsidy to ochre projects

The Danish EPA has set aside DKK 4.3m each year since 1990 to combat ochre pollution and the main part of its support of more than DKK 28m is dedicated to watercourse improvements and studies (Figure 4.8) (Andersen, 1996b).

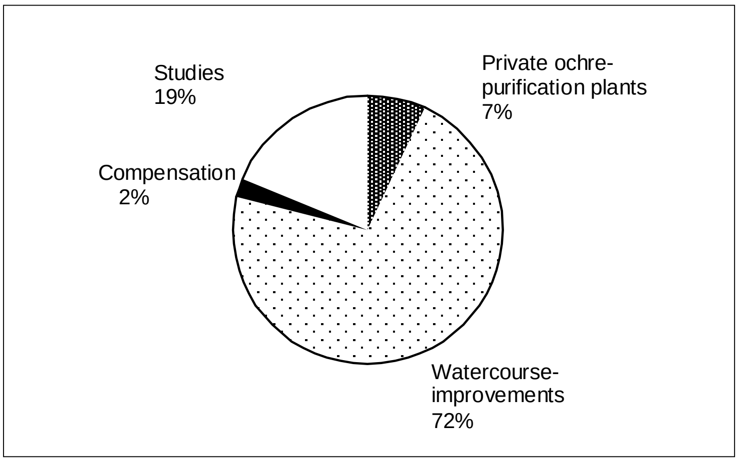

Figure 4.8

Percentage distribution of support under the Ochre Act January 1, 1990 to December 31, 1996.

Watercourse improvements

Since the passing of the Ochre Act, the Danish EPA has contributed to the financing of 35 projects and a study of the biological effects at 20 purification plants shows that downstream conditions have improved. The Hoager Brook plant, for example, removed 39 tonnes of iron from the Brook in 1994 and is now relieving the downstream water areas of this loading which, apart from impairing life in the watercourses, has also made them unsightly (Nielsen, 1997b). Most plants have a positive effect locally or some distance downstream, and it is important to see the plants as a purification measure for the whole water system, not just locally.

Private ochre purification systems

The costs of setting up and running private ochre purification systems are relatively high, for example a lime precipitation plant costs DKK 40,000/ha or more with annual operational costs of about DKK 18,000/ha (Andersen, 1993a), while the removal efficiency is generally low (Christensen, 1997). These costs should be compared with the expected additional income of about DKK 300/ha as a result of draining potentially ochrous land.

Perspectives

The Ochre Act has had the effect that in the designated areas ochre pollution has stabilised or fallen slightly, whereas many ochre-polluted watercourses have been found outside these areas. The reason for the limited effect is that the Act only regulates new agricultural drainage whereas many watercourses are subject to pollution from earlier drainage and regulation projects.

In those watercourses where pollution is a result of heavy-handed and/or illegal maintenance, it can be significantly reduced simply by compliance with maintenance regulations, as raising the water table will reduce ochre leaching.

The Danish EPA support scheme has improved the water quality in the watercourses already loaded by ochre. This development seems to continue as the counties and the local authorities in Jutland with westward-flowing watercourses are providing increased resources for ochre reduction.

When the Aquatic Environment Plan and the Waste Water Purification Act have had an effect in the open land, ochre pollution will be the only reason for many watercourses failing to meet their objectives.

4.3.6 Acidification

Sulphur dioxide and various nitrogen compounds are released when oil and gas are burnt. The different SO_X and NO_X compounds are oxidised in the atmosphere, forming sulphuric and nitric acids. These acidify the precipitation, leading to the risk that watercourses and lakes become acidified in certain locations. Between the onset of industrialisation and the present day, the pH, which is a measure of the acidity of water, has fallen from about 7 (neutral) to around 4.5 (acid) (Sand-Jensen & Lindegaard, 1996). The problem in Denmark is not of the same order as in Norway or Sweden, as the soil in many parts contains lime which can neutralise acid precipitation, acting as a buffer system.

In Central and West Jutland, which contains moraines of sand and gravel low in lime, acidification may arise in watercourses in certain places, leading to impoverished plant and animal life in them.

4.4 Physical conditions

Needs for increased agricultural output in earlier times meant that areas near watercourses, which formed extensive meadows and grasslands, were turned over to arable land with crop rotation. As these crops cannot stand flooding, the need for effective drainage rose sharply. To meet this need, it was necessary to straighten, to install piping and to deepen about 98% of Danish watercourses (Kern-Hansen, 1987) and to maintain them heavy-handedly, whether or not they met regulatory appearance requirements. Nothing was allowed to remain in the watercourses which might impede flows. On top of this, many watercourses came to be utilised over the years for fish farming, turbine and mill power which caused problems in terms of obstructions, water quality and water catchment. Combinations of these were disastrous to the watercourses. They became uniform canals transporting nutrients, sand and water as quickly as possible to the sea, with no shelter or habitats for normal aquatic plant and animal life, which often disappeared as a result.

During the 70s and 80s attitudes towards the exploitation of nature changed. Now human activity had to be adapted to suit nature. This changed attitude also led to the passing of the present Watercourse Act of 1982, which takes account of both drainage and the environment in watercourses. It required the authorities to recreate good natural conditions in watercourses, including more environmentally friendly maintenance schemes, restoration by removal of obstructions and replacement of gravel beds, etc. Progress on improving physical conditions is slow, but the environmental effects of the many steps taken are beginning to show.

4.4.1 Maintenance practice

The main aim of maintenance was previously to ensure effective drainage. Plant growth on banks and in the watercourses was cut back and the bed and sides were mechanically regraded, usually beyond permitted limits, leaving no room for nature. The present Watercourse Act has put a stop to such heavy-handed maintenance, requiring account to be taken also of environmental quality objectives. Watercourses are to be brought to a physical state meeting the objectives of the regional plans. This has made it possible to introduce more environmentally friendly operational practices.

Environmentally friendly maintenance

The principle of environmentally friendly maintenance is to limit weed cutting to a meandering channel, leaving alternate weed areas along the banks for the benefit of aquatic fauna. Bank and side-slope cutting is limited to the absolutely necessary minimum, and bed digging-up is only to be undertaken when needed. Counties and local authorities have developed and improved environmentally friendly methods since the passing of the Act and can now choose from a variety of schemes depending on the objectives and current or intended forms of the watercourses.

Development towards use of gentle maintenance methods by counties

Schemes have often been changed to be gentler as a result of the new regulations. This has brought about the result that, where about 50% of county watercourses were heavy-handedly maintained in 1985, about the same percentage are now managed in an environmentally friendly manner and only 7% harshly (Figure 4.9). In many counties, maintenance is adapted to the objectives set for each watercourse, i.e. it is carried out more gently the higher the target (Baatrup-Pedersen, 1997).

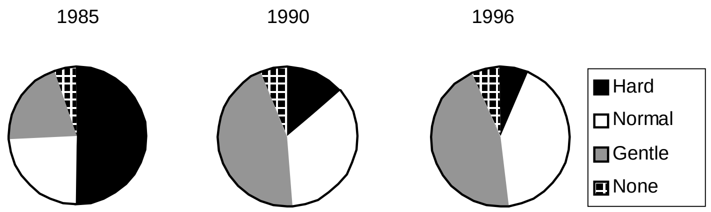

Figure 4.9
Distribution of application of various maintenance methods in county watercourses from 1985 to 1996 (Baatrup-Pedersen, 1997).

Local authorities lagging behind

Unfortunately it has also turned out that a number of local authorities have not made as much progress, in spite of their being the land drainage authorities for about 75% of the high-target watercourses (Danish EPA, 1995d). In Funen, for example, gentle maintenance practices are used on less than 24% of the local authority watercourse lengths (Figure 4.10).

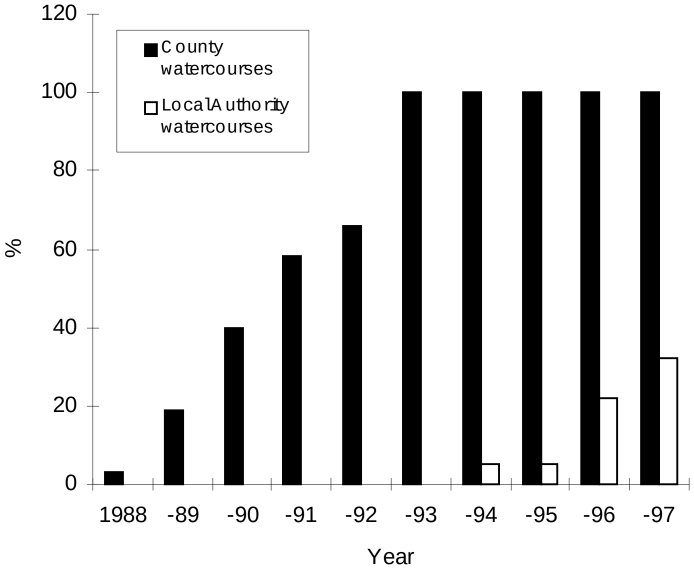

Figure 4.10
Extent of maintenance in accordance with the new regulations in county and local authority watercourses in Funen (Wiberg-Larsen et al., 1997).

Watercourse regulations

In connection with the passing of the Watercourse Act it was decided that all watercourse regulations should be reviewed. One aim of this review was to ensure that they were brought into line with the plans for the individual watercourses. Counties and local authorities have received more than DKK 90m to revise these regulations.

Time schedule

The deadline for preparation of new watercourse regulations was initially set at January 1, 1993, but on request by the National Association of Local Authorities in Denmark it was extended to July 1, 1996.

As a result of a question from the Parliamentary Environmental and Planning Committee in the spring of 1997, it became clear that not all local authorities and counties have completed the revision of their regulations.

Environmentally friendly maintenance does not impair flow capacity

The many experiments with gentle weed-cutting in the form of flow channels and cutting as needed have shown that the required capacity can be maintained in summer even when weeds remain in the watercourse. Over the whole summer, the water surface is generally lower than previously, when weeds were cut once or twice a year (Cueto, 1997).

Experiments since 1982 in Surbæk in South Jutland County have shown that cutting weeds in a narrow channel, leaving them along the edges, does not significantly affect the drainage capacity and over recent years the maintenance has shrunk to the removal of sporadic clumps of weeds when requested by riparian owners. Over the whole experimental period, the summer water level has become more constant and stabilised at a lower level.

A study of the flow in 8 watercourses where, according to riparian owners, the capacity is insufficient compared with before, has shown that the flow capacity of 4 is the same or greater than under the previous scheme, 1 has a slightly lower flow capacity (though this was due to an adjustment to the actual conditions), and in the remaining 3 the flow capacity is in all probability as great or greater after the new regulations (Cueto, 1997).

The new maintenance methods can thus meet both capacity and environmental needs.

Development of new maintenance methods

The aim for the next few years must be to collect and expand knowledge about environmentally friendly maintenance so that the state of watercourses may continue to be improved with more varied conditions. Weed clearance must be suited to the parameters which specifically affect the capacity and environment of each watercourse in relation to the utilisation of the surrounding landscape. Efforts must also be made to apply sensitive schemes to a greater extent than at present in both local authority and private watercourses so that conditions here can also meet the requirements applying to small watercourses, which are often salmonoid spawning and nursery areas.

4.4.2 Watercourse reinstatements

The Watercourse Act of 1982 allowed the authorities to improve the physical conditions by various reinstatement measures. Conditions may for example be improved by laying stone and gravel to form spawning and nursery areas, restore bends in straightened watercourses, remove obstructions caused by fish farming, mills and generators, and reopen piped lengths etc.

Passage in watercourses

One of the major problems in watercourses is obstructions in the form of dams, dead lengths, piped lengths and irrigation systems, which destroy the continuity of the watercourses and hence their important functions as links between other areas. In 1993, there were 380 dams causing obstruction problems from fish farming alone, and a further 30 as a result of hydro-electric plants. In addition there are a large number of obstructions by irrigation plants and dams with ineffective fish stairs. In Vejle County alone, there are about 200 obstructions in high-target watercourses where no fauna passages have yet been created (Vejle County, 1997).

New classification system for registering of reinstatements

To achieve a nation-wide picture of restoration work, a system of classifying and registering the different reinstatement models in Denmark was developed in 1995. Restorations are split into three main types according to their location in the watercourse. Type 1 covers restoration of single lengths. Type 2 includes all measures which create passages between lengths to ensure the continuity of watercourses, and Type 3 those which improve conditions in valleys. Table 4.6 shows the principles of the three types with examples of methods for each type.

Table 4.6

Number of projects completed in counties by the three main restoration types.

Type 1	Type 2	Type 3
Habitats	Passage	Valleys
Gravel banks Sand traps Stone Reopening piped lengths Bend restoration Hides for fish and invertebrates	Rapids at obstructions Evening out small steps Fish ladders Bypasses at obstructions Reopening piped lengths	Raised water levels with rapids Raised water levels with bend restoration Drains cut off at foot of brink Narrowing of channel
181 projects	**740 projects**	**15 projects**

Current situation of reinstatement work

Most watercourse authorities have been engaged in reinstatement work to improve the physical conditions in watercourses for some time, but only in recent years has it really taken off. Nation-wide, the counties have completed a total of 936 restoration projects up to and including 1996. Most of these, i.e. 740 projects, have been aimed at creating passages for fish and invertebrates between lengths of watercourses (Table 4.6, Type 2).

Jutland leads in restoration work

Most watercourse restorations have taken place in Jutland (Figure 4.11). Zealand has lagged behind with only 11% of projects, in spite of having 22% of the watercourses, many with poor environmental conditions. More and more local authorities have also started, which is important because they are the authorities for a large number of high-targeted watercourses which include salmonoid spawning and nursery areas.

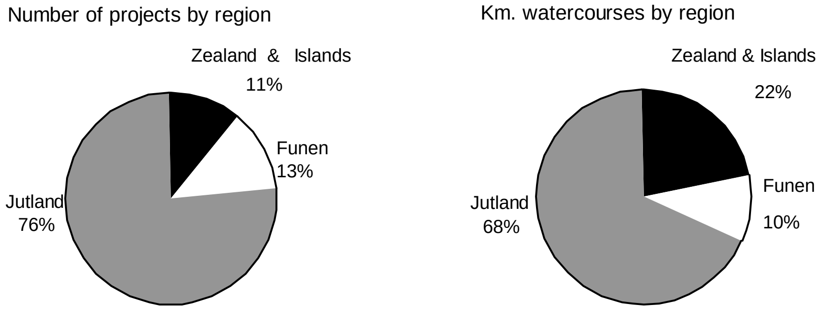

Figure 4.11

Distribution of the number of completed restoration projects in major watercourses up to 1996 (Windolf et al., 1997) and km of watercourses in the three regions (Danish EPA, 1995).

Restoration of whole valleys

In recent years, there has been a trend towards restoration measures addressing whole valleys (Table 4.7), i.e. where, for example, bends are reinstated and areas near the watercourses are restored to water meadows in contact with the watercourses. Up to and including 1996, 15 of these Type 3 projects have been recorded (Table 4.6). The Nature Reinstatement Project in Brede Watercourse, which included bend restoration, is a good example. A large part of the National Forest and Nature Agency's nature protection resources are devoted to total solutions in valleys (National Forest and Nature Agency, 1997), among other things.

Table 4.7

Distribution and development of the Danish EPA support for restoration projects 1984-1995 (Moth & Andersen, 1996)

	Number of projects	Trend
Fish ladders	**39**	→
Spawning grounds	17	→
Rapids	86	↑
Bypass rapids	15	↑
Reopening of piped lengths	16	→
Bend restoration	26	↑
Other	43	↓

§ 37a of the Watercourse Act on dead lengths

Great environmental improvement is expected when flows are returned to 13.5 km of dead lengths resulting from fish farming, and when passages are restored to a whole 126 km of high-targeted watercourses upstream of them (Table 4.8). This will be the result of the Danish EPA's provision of DKK 10m of support since the start of 1996 to 43 restorations at obstructions with so-called dead lengths (§ 37a of the Watercourse Act). As 4,000 km of high-target watercourses upstream of fish farming obstructions still exist, there is yet a long way to go from the achievements of 1996-97 to the target of creating adequate passages at all obstructions.

Table 4.8

Dead lengths in km restored to flowing and free passage to upstream lengths by projects supported by the Danish EPA under §37a in 1996-97

Year	Number of projects	Dead lengths (km)	Free passage (km)
1996	22	9.5	166
1997	21	4.0	260
Total	43	13.5	426

Resources for restoration

The Danish EPA has supported watercourse restorations since 1984, providing about DKK 33m up to 1996 to a total of 252 restoration projects around the country costing in all about DKK

88m.

4.4.3 Water flow

Many watercourses dried out in 1996

Many watercourses have problems with drying out or reduced flows as a result of utilisation of surface and ground water resources for drinking, irrigation etc., or where most of the flow stems from surface or near-surface run-off. Many dried out in 1996 due to low precipitation in the first half of the year. As many as 25% of the watercourse stations studied in Funen dried out, while the run-off was 59% of normal with disastrous results for the fauna in the watercourses. The very rare stone loach died out in Hellerup Watercourse in Funen as a result of drying out (Wiberg-Larsen et al., 1997).

Changes in water flow affect the ecology of watercourses as the sizes of accessible and useable habitats for fauna are affected (Lund, 1997), resulting in changed species compositions. A study in Roskilde County has shown, among other things, that reduced flow in Elverdam Watercourse reduced the number of habitats for older trout and thus the number of fish (Lund, 1997). The invertebrate fauna in dried-out watercourses has been reduced so much that it has not been possible to determine the fauna class.

As it is not sustainable for so many watercourses to dry out in summer, presumably as a result of water catchment and low precipitation, there is a need to take steps to ensure adequate all-year flows. Included in this must be positioning of boreholes at a suitable distance from watercourses and adjusting water catchment to suit conditions in them.

4.4.4 Interplay between watercourses and areas near watercourses

A watercourse should preferably be in balance with its surroundings, i.e. low-lying areas nearby, which in simple terms form an important part of its own purification system. In heavy flows, especially in winter, water floods in the adjacent meadows, transporting nutrients such as nitrogen and phosphorus, sediment and organic matter to them, where it is naturally deposited when the water retreats. Hereby, nutrients such as nitrogen and phosphorus, but also organic matter are retained and converted in areas near the watercourse instead of being washed out to sea.

High consumption of nitrogen in areas near watercourses

Deposited nitrogen can be converted in areas near watercourses, provided they are wet. There are many examples of this. Studies show that nitrogen removal varies from about 50-99% of the amounts deposited on areas near watercourses (Hoffmann, 1996).

Phosphorus retention in areas near watercourses

The retention and conversion of phosphorus in areas near watercourses is a complex process depending in part on soil conditions and the phosphorous compounds concerned, making it hard to give a clear picture (Rebsdorf et al., 1994). Broadly put, dry mineral soils such as fields and commons bind phosphorus better than saturated areas such as water meadows, and therefore the retention of phosphorus by these areas is probably substantially less than the retention of nitrogen.

Areas near watercourses serve an important natural function as a kind of buffer for flows in the watercourses. Meadows retain surplus flows in winter, which can run off later when there is again spare capacity in the watercourses. Large variations in flow are avoided and erosion of beds and banks reduced.

Areas near watercourses have settled

Areas near watercourses have been drained and dewatered for several centuries, resulting in settling of the soils near the watercourses containing high levels of organic matter. Settlement means that organic matter has been oxidised and mineralised, reducing the volume of the soil and causing the surface to sink. The soil then becomes waterlogged and loses its value for cultivation. A study in Viborg County has shown that in many places settlement has reduced the depth of dewatering to the same levels as immediately before the latest regulation and drainage (Christensen et al., 1997). In the areas studied, as much as 54% had been subject to settlement, and in about 46% of these areas settlement has been of the order of 30-150 mm. Areas of high settlement adjoined all the watercourses studied.

The study shows that the benefits of the last watercourse regulations are about to be lost in large parts of the areas affected.

The heavy investments in dewatering and drainage appear to be written off over a period of 30-60 years, meaning that farmers must take account of the fact that the improved drainage conditions resulting from the great regulating and draining projects of the first half of this century have been wholly or partly lost. As this trend continues, conditions will deteriorate further and it is doubtful whether it will make private or socio-economic commercial sense to make new great investments in watercourse regulating or re-drainage projects of such large areas (Cueto, 1997). It is thus not so much a question of restoring water meadows as of when they will re-establish themselves.

The future of valleys

A future solution for areas near watercourses could be that agricultural practice returns to being more extensive, i.e. that they become what they were originally, viz. meadows with permanent grass. Such a solution would save public money and bring many environmental and landscape benefits.

4.4.5 Borders along watercourses

Uncultivated borders along watercourses are of great importance to the environmental conditions of watercourses, particularly the physical conditions. Such a strip with natural vegetation stabilises the banks, protecting them from collapse, etc. This minimises the number of environmentally damaging clear-ups needed as well as reducing the input of phosphorus, soil and sand. Sand can, for example, settle on stone and gravel spawning beds, reducing the ability of fish to reproduce. Phosphorus input as a result of bank erosion may be significant. Thus it has been established that bank erosion in a watercourse in two consecutive years caused 30% and 14%, respectively, of the total quantity of phosphorus transported by the watercourse (Rebsdorf et al., 1994).

A vegetated border will also reduce the transfer of phosphorus, soil and sand to the watercourse by surface run-off from adjacent soil. A study in Vejle County showed that a 2 m border retained 98% of suspended soil, over 95% of the Tot-Phosphorus and over 93% of the total nitrogen in surface water flows to the border (Nielsen, 1995).

Compliance with the 2 m border

The requirement for a 2 m border came into force on July 1, 1992, and as the Danish EPA is aware that such borders are not maintained along many watercourses, this was one of the themes of the 1996 Supervision Report.

Local authority feedback

A review of feedback from the local authorities reveals that the data quality is sub-standard. One local authority has, for example, stated that only 110 km of watercourse are covered by the border requirement, even though it earlier stated that the district contained 148 km of high-targeted watercourses as at January 1, 1993 (Danish EPA, 1995).

The Danish EPA will therefore require a number of local authorities to account for this difference. When this has been resolved, it will be possible to make an overall assessment of the length of watercourses covered by the border requirement.

Enforcement of the 2 m border

The Danish EPA is aware of 59 cases of failure to comply between 1993 and 1996. The riparian owner accepted a fine in 30 cases, and in 23 the courts have imposed fines, given two warnings and acquitted three landowners.

4.5 Environmental conditions in watercourses – status and development

The environmental conditions in watercourses are determined by a number of natural and man-made factors. Topography, subsoil and size of watercourses are examples of natural factors.

Alterations, waste water and toxic inputs of man-made ones.

In recent years efforts have been made to minimise man-made effects, e.g. by improving physical conditions and expanding waste water treatment. Flora and fauna often react rapidly when their living conditions are improved. Trends in biological state can thus indirectly provide a picture of the effect of the many improvements made.

4.5.1 Invertebrates

The composition of invertebrates, i.e. insects, snails, worms, etc. in a given length of watercourse reflects its current environmental condition, including whether it is loaded with organic matter, as these creatures have species-specific requirements in respect of a number of physical and chemical conditions. The number and diversity are generally greater in clean water and least in polluted watercourses. Their composition is a good environmental indicator.

Methods of assessment

A method called the Danish Fauna Index is used for biological assessment of watercourses, which classifies them according to fauna classes (degrees of pollution) I to IV. Fauna class I indicates an unpolluted watercourse and IV a heavily polluted one.

In the regional supervision of watercourse environmental quality, the counties use methods similar to this to determine the composition of invertebrates. This regional monitoring provides the major part of the information available (Windolf et al., 1997).

Environmental state of watercourses in 1996

Watercourse stations with acceptable environmental states, i.e. fauna classes I, I-II and II together comprised 39% of the assessments in the 1996 monitoring programme (Figure 4.12). Polluted watercourses classed II-III made up 50%. 11% were class III or worse in 1996.

By comparison, acceptable fauna classes, i.e. I, I-II, and II, were registered in 34% of the watercourse assessments in the regional supervision in 1996 (Figure 4.12). In the regional supervision fauna class II-III was also the most frequent one and was found in 39% of the watercourse stations. 9% of the stations were heavily polluted, i.e. fauna class IV. It was not possible to make a fauna classification at as many as 18% of the stations in 1996, since the invertebrate fauna was miserable due to drying out, ochre, pesticides etc. The non-assessable stations are not included in the calculation of percentage distribution of fauna classes.

Reasons for differences between national and regional supervision

The use of different assessment methods, frequency and sampling strategy as well as the fact that monitoring stations are generally placed in larger watercourses are presumably the reasons for the differences in data between national and regional monitoring results. Work is in progress to standardise environmental supervision of watercourses in order to reduce variations in data due to choice of methodology in future.

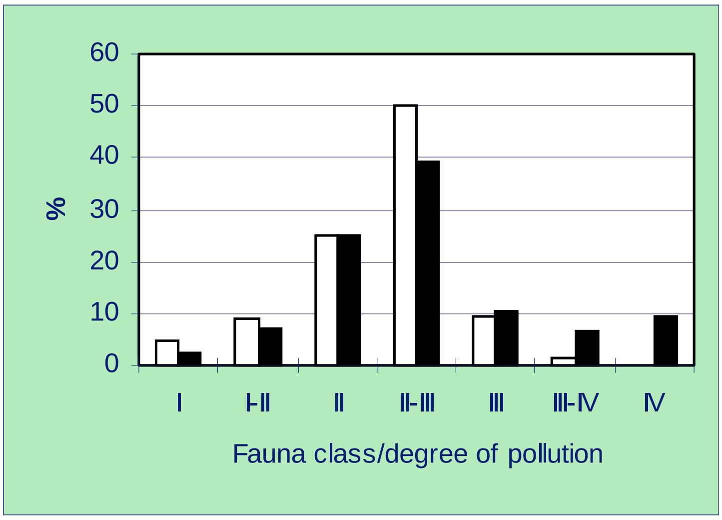

Figure 4.12
Distribution of fauna classes in 1996 from national (white) and regional (black) supervision (Windolf et al., 1997; the Danish EPA, 1997a).

Most watercourses in Jutland and Funen are in a good condition

Clean watercourses of fauna class II or better were found at 44% of stations west of the Great Belt studied in the 1996 regional supervision (Table 4.9). On Zealand and Lolland-Falster only 10% of the stations reached fauna class II or better. The wholly unaffected fauna class I stations are also more common in Jutland and Funen than in Zealand and Lolland-Falster.

Table 4.9
Distribution of fauna classes by county from the regional supervision (Danish EPA, 1997a).

	Fauna class						Not
County	I	]	II	II-III	III-IV	IV	determined
Copenh. mun.	0		**0**	**1**	**4**	**3**	**0**
Copenhagen	0		0	13	22	5	1
Frederiksborg	1		15	226	23	13	63
Roskilde	1		2	70	21	8	5
West Zealand	0		82	129	12	11	111
Storstrøm	6		38	247	114	379	71
Bornholm	0		15	23	0	0	1
Funen	27		179	201	12	27	302
South Jutland		**	156	203	**31		143
Ribe*	-		-	-	-	-	-
Vejle	42		166	170	9	13	92
Ringkøbing	8		168	228	8	6	70
Århus	52	1	414	495	116	75	140
Viborg	1		95	105	9	8	4
North Jutland	2		160	232	23	11	61
Whole country	140	4	1,490	2,343	404	559	1,064

* *Only pollution determinations made near sewage treatment plants, and fish farms figures are not included*
** *Data for fauna classes I and I-II and III-IV and IV are added up*

Composition of microfauna best in

Watercourses in natural catchment areas have, as might be expected, a better fauna condition that cultivated or point-source-affected ones (Frederiksborg County, 1997; Jensen et al., 1997b; and *natural catchment areas*

others). In Frederiksborg County most watercourses in natural catchment areas were in class I-II and in agricultural or waste water-dominated areas in class II-III.

Improvements in the environmental state of watercourses from 1989-1992 to 1993-1996

All counties report clear improvements in fauna classes in many watercourses covered by national supervision (Frandsen et al., 1992; Wiberg-Larsen et al., 1997; South Jutland County, Jensen et al., 1997b; and others) in spite of no improvements in their environmental conditions being established by the monitoring programme over the last four years (Windolf et al., 1997). Comparison of county supervision data from 1989-92 and 1993-96, using only stations where data is available from both periods, shows that there has been a nation-wide improvement in fauna classes (Windolf et al., 1997).

Improved conditions in larger watercourses

Conditions have improved most notably in the larger watercourses over 2 m in recent years. For example, the number of stations in Funen with a satisfactory classification (II or better) rose in 1989-96 (Wiberg-Larsen et al., 1997). The proportion of lengths with satisfactory quality in Funen doubled from 30% to about 60%, while those completely unacceptable fell from 20% to about 3%. Similar tendencies occur in many counties (Windolf et al., 1997).

Conditions in smaller watercourses still unacceptable

The state of smaller watercourses continues to be unacceptable in many parts of Denmark. The proportion of satisfactory lengths in Funen has thus only grown from about 15 % to 20% between 1984 and 1995. The most significant reasons are insufficient waste water treatment and waste water from sparsely populated area. An act on treatment of waste water from sparsely populated areas was passed in 1997, which is expected to lead to an improvement in quality of especially the smaller watercourses.

“Good” species advance in growth and extent

The above improvements can also be seen at the species level of clean water species. Ringkøbing County has established a positive trend in the occurrence of the clean-water stonefly *Isoptena serricornis* (Ringkøbing County, 1997b). In the forthcoming red list of threatened plants and animals in Denmark, this fly is designated as vulnerable and as a species for which Denmark is internationally responsible. It was recorded at 13 locations in Ringkøbing County in 1988-92 but at 26 in 1993-96. This county contains most of the world’s known finds of this species during the relevant periods.

A similar rise in growth and extent of many clean-water species has been noted, for example the mayfly *Heptagenia sulphurea* in Funen, the stonefly *Perlodes microcepala* and its genus *Leutra* in Ribe and Aarhus Counties (Wiberg-Larsen et al., 1997; Ejbye-Ernst & Jepsen, 1997; Wiggers et al., 1997). These registrations contribute to the general picture of improving environmental conditions in Danish watercourses in recent years.

Reasons for improved fauna classes

Improved municipal waste water treatment whereby loading with organic matter (BOD5) is reduced, accompanied by improved physical conditions as a result of environmentally friendly maintenance schemes are considered the main reasons for the improvements recorded.

4.5.2 Filamentous algae

Large growths of filamentous algae can have negative effects on the watercourse environment as they have a high oxygen demand for night-time respiration and decomposition after death. They are also of limited value as food source for the animals of the watercourse. Due to their negative impact, it is reasonable to seek to understand the influence of various parameters for their occurrence and growth. This is the reason why their occurrence in relation to chemical and other parameters was studied at about 100 watercourse stations in the 1993-96 monitoring programme.

Most filamentous algae in waste water-affected watercourses

Filamentous algae were not found at 24% of the stations in 1996. Filamentous algae covered 80-100% of the bed area at 25% of the stations, this being the most frequently found degree of coverage in 1996. More than 20% coverage was found in 6% of watercourses in natural catchment areas, 15% in agricultural catchment areas and 22% in catchment areas affected by waste water in 1996 (Windolf et al., 1997).

Unchanged extent of filamentous algae

There was no immediate change in the extent of filamentous algae coverage in the watercourses studied between 1993 and 1996 (Windolf et al., 1997).

Significance of parameters for filamentous algae coverage

The growth of filamentous algae depends on the relationship between several physical and chemical conditions, including phosphorus, flow and bed conditions, and light.

Large occurrences of filamentous algae in watercourses can also contribute to failure to meet watercourse quality objectives.

4.5.3 Fish

Fish – a good environmental indicator

Fish give a good picture of environmental conditions in a watercourse. A fish such as trout requires special surroundings for it to be able to live there. Trout needs – among other things - clean water, enough water, ample food and varied physical conditions. Thus, if there are natural populations of trout in a watercourse, the conditions are generally good enough for other fauna to live there as well, meaning that trout are generally a sign of a good, varied environment.

Progress in trout populations

In 1996 the Danish EPA instituted a study to establish the development of trout populations nation-wide during 1982-87 and 1988-94. The study was undertaken in more than 1000 targeted lengths of watercourse designated A, B1 and B2, of which most were studied in both periods. The study showed unambiguously that significant progress had been made in nearly all parts of the country in terms of numbers of trout fry in the watercourses (Figure 4.13) (Nielsen, 1997c). No general falling-off was found anywhere in the country.

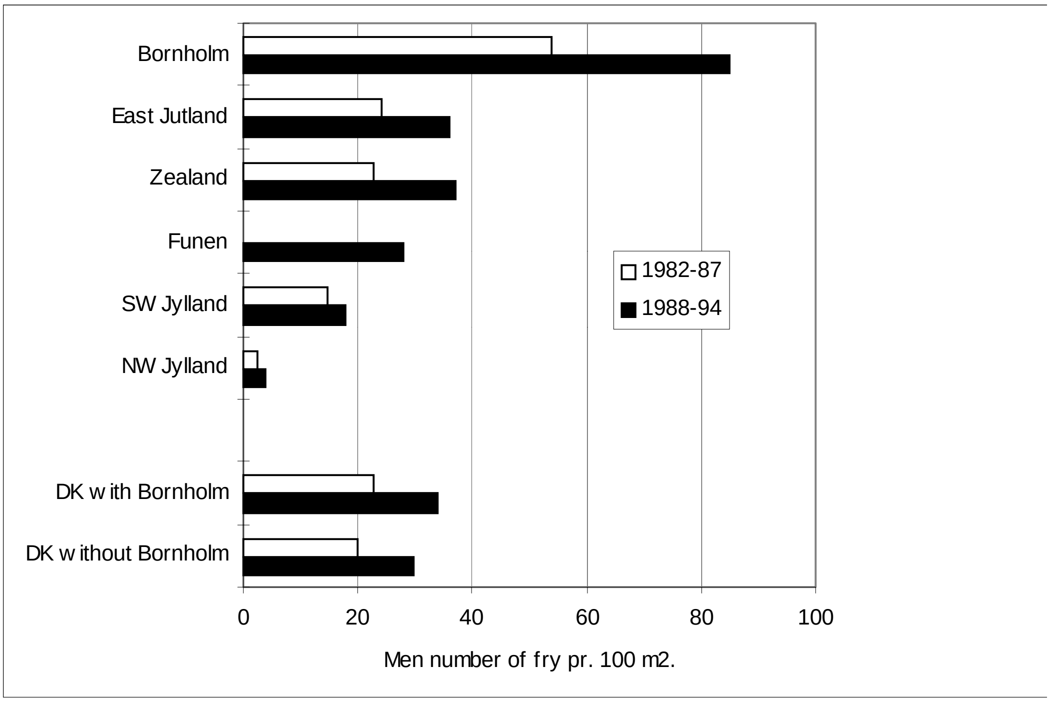

Figure 4.13
Development in trout fry populations in 666 watercourse lengths studied in both 1982-87 and 1988-94. Standard data is missing from Funen for 1982-87 (Nielsen, 1997c).

Nation-wide the trout fry average per 100 m² of watercourse was about 34 in 1988-94. In 40% of the stations, fry from natural spawning was found in 1982-87 and by 1988-94 the share had risen to 60%. The biggest populations were found in Bornholm, Zealand and East Jutland. It should be pointed out that fry captured during the study was naturally produced as stocking had ceased in advance of the study.

There were great differences in the occurrence of trout fry in the water areas. For example, there were four times as much fry in the watercourse systems of Gudenåen as in Skjern Watercourse even though they rise only a few hundred metres apart (Nielsen, 1997c).

Rare fish

Several counties are working hard to re-establish populations of red-listed fish species in watercourses, i.e. those which are rare or threatened with extinction in Denmark. Ribe and South Jutland counties have in part by rearing, stocking and watercourse restoration repopulated the larger watercourses near the Jutland Wadding Sea with houting (Ejbye-Ernst, 1993). The restocking has been stopped and natural populations are now found, although varying in size in certain places. A number of counties in Jutland and the Ministry of Food, Agriculture and Fisheries have co-operated to produce an action plan to recreate the Danish salmon populations (Ejbye-Ernst, 1993).

Reasons for increased fish populations

Changes of practice to more environmentally friendly maintenance schemes and the creation of free passage in many places contribute to increasing trout populations in watercourses. This is supported by a study in Funen which showed that many more trout arrive when watercourses are gently maintained by weed-cutting in flow channels only (Wiberg-Larsen et al., 1994).

Many counties also report that the improvement of the environmental state of the watercourses is reflected by the fact that trout have become frequent in the watercourses (Ejbye-Ernst, 1993).

Still some way to go

Studies of fish, in particular trout, also show that if environment conditions are improved, rapid increases in fish populations will follow. But Nielsen (1997c) also showed that unfortunately there is still some way to go before there are satisfactory trout populations in our watercourses. In 1988-94 there were still no trout at 40% of the locations where they ought to be found, so work to create the right environmental conditions still has to continue.

4.5.4 Setting watercourse objectives

The county councils set objectives for the quality and utilisation of watercourses in their regional plans.

In the last two nation-wide surveys of targets in 1993 and 1997, B1 (salmonoid spawning and nursery grounds) and B3 were the most frequently set targets (Table 4.10). The many B-level targets show the high priority given to the watercourse environment by the county councils – they want good watercourses back.

Table 4.10

Distribution of watercourse targets (in km) set by counties in 1993 (Danish EPA, 1995; Windolf et al., 1997)

Watercourses	**Target**									
	A	B_1	B_2	B_3	C	D	E	F	Other	Total (km)
% of total in 1993*	5	25	19	29	14	2	1	5		19,000
% of total in 1996	5	28	14	23	20	1	1	3	5(BO)	24,000

*** Bornholm County and the Copenhagen Municipality did not provide data in 1993.***

In 1996, the counties supervised the environmental quality in all 7,045 watercourse stations, but it was only possible to assess whether the objectives had been met on the basis of the composition of invertebrates in 5,981 stations due to drying out, poisoning, etc. This assessment showed that only 39% met their objectives in 1996, which does not differ significantly from previous years (Figure 4.15).

Despite this, marked improvements in the environmental quality at the individual stations have been recorded in recent years when using the fauna class as a measure rather than target compliance. The counties thus report clear improvements in fauna class in many watercourses.

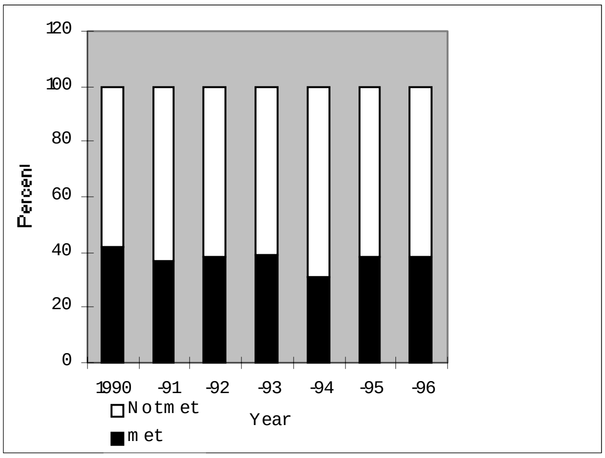

Figure 4.14
Development in watercourse target compliance assessed by the regional supervision in 1990-96

Improvements of the environmental quality of watercourses not reflected by target compliance

There are probably several reasons why the improvements of the environmental quality of watercourses do not reflect in higher levels of target compliance. Firstly, the conditions in many watercourses in earlier years were poorer than fauna class III, meaning that there was a long way to go before meeting objectives, which means fauna class II or higher for A or B targeted watercourses. This has meant that instead there has been a rise in the number of stations where there is only half a fauna class difference between current and target conditions (Frederiksborg County, 1997; Jensen et al., 1997b), meaning in principle that there is not "far" to go before these watercourses meet their objectives.

Secondly, there are reports that fauna classification is being assessed "tougher" today than previously because of a gradual change in methods (South Jutland County, 1997). The result is that watercourses today assessed as II-III would in principle have been considered class II before, which is actually the difference between meeting or not meeting the objective. Work is in progress to standardise procedures including the introduction of a new microfauna index called the Danish Watercourse Fauna Index so that variations due to choice of method will in future be reduced.

In addition, many B3-targeted watercourses have little gradient and thus poor flow, meaning that it is hard or nearly impossible to achieve the fauna class II required to meet their objectives. In such cases, the counties ought to set more realistic objectives.

Finally, there are indications that some targets have been raised in the revision of regional plans when a county council has taken measures to improve conditions in the long term. From a review of 11 drafts of the 1997 regional plan revisions it appears that six of them stated whether targets had gone up or down: about 60 % of these were revised upwards, with higher compliance requirements. This implies the risk that, in the short term, objectives will cease to be met even though conditions and therefore water quality have not altered.

Reasons for not meeting objectives

Waste water discharges and poor physical conditions are the main reasons for not meeting objectives (Table 4.11).

Table 4.11
Distribution of reasons for failure to meet targets in Danish watercourses in 1993-1996.

Main reason for failure to meet targets	Watercourses %

Sewered areas	15
Sparsely populated areas	27
Fish farming	4
Illegal discharges	4
Regulation/maintenance	23
Natural circumstances (little gradients)	3
Ochre	11
Toxicity	2
Drying out	9
Flow-in from lakes	2
Total	**100**

The reasons are different in large and small watercourses. In those less than 2 m wide, the most significant reason is waste water discharges from sparsely populated areas, compared with poor physical conditions as a result of regulations and heavy-handed maintenance in the large ones. Table 4.12 compares target compliance in small and large watercourses.

Table 4.12

Meeting of targets nation-wide in small and large watercourses in 1996.

Watercourse width (m)	Targets met (%)
0 – 2	37
over 2	47

Possibilities of improving watercourse quality

The shortfall in meeting targets is unsatisfactory from both environmental and administrative points of view, making further improvement efforts necessary. The modification of the Act on waste water purification in the open countryside is a good example of this, and it creates the basis of solving the problem of discharging waste water in the open countryside to help meeting objectives especially in minor watercourses in coming years.

Many counties indicate that physical conditions need to be improved if both small and large watercourses are to meet their objectives in the future. A great many watercourses which today are in fauna class II-III may be improved to meet their class II or higher targets by this means (South Jutland County, 1997; Jensen et al., 1997b). Jensen et al. (1997b) state that poor physical variety was the reason for failure to meet targets in 31% of a total of 1,095 watercourse stations studied in 1992-96.

Significant investments should therefore be made over the coming years in measures to improve physical conditions so that the form of the watercourses can match the improving water quality by now. A case in point is to change-over to more environmentally friendly maintenance practices, actual watercourse restorations, re-establishment of water meadows by altered agricultural practices, etc. There is also a need to prioritise what water areas are to be scrutinised, which would entail that the effects of the measures taken by the counties in freshwater areas are rendered more visible in that more watercourses due to the measures will meet the objectives set.

5 Lakes

5.1.1 Target setting

The Planning Act

The quality and usage of Danish lakes is determined by the regional plans under the Planning Act. The county councils set objectives for lakes in the regional plans, which then form the basis of the counties' management of the lakes. Objectives are chiefly set for the large lakes.

An objective is set for the quality and usage of individual lakes based on their biological background condition, existing outfalls and desired future usage.

Guidelines

The Danish EPA's Guidelines for recipient quality planning No. 1, 1983, contain a range of lake targets. In principle, the target setting system is subdivided into three types: strict, basic, and modified objectives (Table 5.2).

Table 5.2

Summary of lake quality objectives

	Target	Description
Targets with strict requirements	A_1, sites of special scientific interest	Lakes where particular natural conditions need to be preserved
	A_2, bathing waters	Lakes required to be used for bathing, etc.
	A_3, untreated water for water supplies	Lakes which provide untreated water suitable for drinking
Basic targets	B, natural, balanced flora and fauna	Lakes whose natural, versatile flora and fauna are unaffected or only slightly affected by waste water input or other human influence
Modified targets	C_1, lake affected by waste water, water catchment or other physical interventions	Lakes permitted to be affected by waste water outfalls or other influence
	C_2, lake affected by agriculture	Lakes where it would not be possible to meet basic targets by purifying or cutting-off waste water inputs into the catchment area because of nutrient inputs from cultivated areas into the catchment area.

Strict targets

Lakes containing particular flora and fauna in need of special protection are designated sites of special scientific interest, which is a strict target. These lakes are wholly or nearly unaffected by human activity and are naturally to be protected from man-made effects that could alter their environmental condition. Similarly, strict targets also apply to lakes designated as bathing waters and drinking water reservoirs.

Basic targets

Lakes, whose natural flora and fauna is to be preserved, are targeted B, i.e. basic targets. In these, the ecology may only be mildly affected by human activity.

Modified targets

These are set for lakes whose ecological state make it acceptable for them to be affected by lawful discharges.

Quality requirements for target setting

For each objective set by counties in their regional plans, some physical and chemical quality requirements are to be met in the lake for its objective to be considered met. For example, it may be required that waste water outfalls, water catchment areas, etc. are acceptable only if they do not prevent meeting the objective.

Assessment of compliance

In order to assess whether a target has been met, a parameter is often chosen which is easy to quantify and can be used as an environmental indicator for the lake. Counties often use the Secchi depth as an indicator of whether a target has been met or not. Thus, for most targeted lakes the regional plans stipulate requirements to the effect that the Secchi depth must exceed a certain depth. Typically, many algae are present in a polluted lake, leading to poor visibility, and few algae in unpolluted lakes therefore mean high visibility.

A lake must also have a multifaceted, balanced flora and fauna in order to meet its target. Benthic vegetation must be possible and there is to be a natural balance of predatory and non-predatory fish.

Regional lake supervision

The scope and character of supervision of lakes depends on the targets to be checked against. The supervision therefore varies between counties, from an extensive programme in which mainly Secchi depths are measured, to an intensive programme with many different biological investigations.

Lakes in the Danish EPA's monitoring programme

In the monitoring programme of the Danish EPA the environmental conditions of 37 lakes are investigated via an intensive programme consisting of many different biological tests, including nutrients, algae, and Secchi depth. The 37 lakes monitored are considered reasonably representative of the Danish lakes.

5.2 Water balance and weather

Section 4.2, ”Water balance and freshwater run-off”, contains a general description of the water cycle, precipitation, and run-off, water balance, and developments of these.

Influence of weather on environmental conditions in lakes

The weather has a very significant effect on conditions in lakes. Air temperature, amount of precipitation, sun irradiation, run-off and wind are all factors affecting conditions in a lake.

The amount of precipitation affects the volume of run-off via aquifers to the lakes and thus the nutrient transport to the lakes since nutrients are primarily supplied by freshwater run-off. In dry years such as 1996, nutrient inputs to lakes were very low compared with normal or wet years.

Sunshine and therefore also indirectly the air temperature influences the warming up of the lake water since the rate of all biological processes is influenced by temperature. Blooming and decomposition of algae, decomposition of other fauna and flora, reproduction of fish and invertebrates are all examples of processes affected by sun irradiation and temperature.

The wind affects the agitation of the water body in a lake. The lake size and depth and the wind velocity affect the agitation caused by the wind. In large, deep lakes, the wind will tend to only agitate the upper part, leading to stratification of the water body dependent on temperature and wind. Such stratification has great implications for the physical and chemical processes in a lake. By contrast, a shallow lake may experience complete wind-induced agitation.

Weather variations thus create large year-on-year variations in the physical, chemical, and biological processes in lakes and therefore their overall environmental conditions.

5.3 Water quality in lakes

37 lakes are included in the monitoring programme, but it has only been possible to draw up nitrogen and phosphorus balances for 22 of them.

Danish lakes are generally very rich in nutrients with high concentrations of nitrogen and phosphorus in their water.

5.3.1 Nitrogen

Nitrogen in 1996

The annual mean concentration of total nitrogen in water entering the monitored lakes was 7.6 mg/l in 1996, which broadly corresponds to the mean level in 1992-96. In 1996, the total input of nitrogen was very low due to the low precipitation and resultant low run-off to the lakes. (Jensen et al., 1997a).

The annual mean concentration of total nitrogen in lake water in 1996 was 2.2 mg/l.

Development in nitrogen input

The total input of nitrogen to the monitored lakes varied, totally seen, from 11 to 2,204 tonnes/year in 1992-96 (Table 5.3). The great variation is due to variations in run-off and the nitrogen content of the water input.

Table 5.3

Nitrogen input to 22 monitored lakes 1992-96 (Jensen et al., 1997)

	Mean	Median	Min.	Max.
Total nitrogen (tonnes N)	255	65	11	2,204
Total nitrogen (mg/m^2/day)	473	421	32	1,682
Flow-weighted input concentration (mg/l)	7.5	8.3	1.5	11.8

The total nitrogen input was largely unaltered in the monitoring period between 1989 and 96 (Figure 5.1) and follows variations in run-off to the lakes.

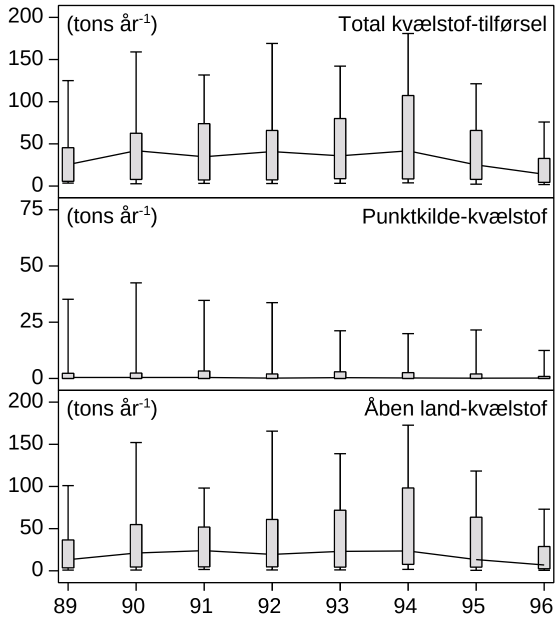

Figure 5.1

Nitrogen input to lakes (tonnes/year). Total input, input from point sources and inputs from open land. 25 and 75% quartiles are shown by a broad column, the 10 and 90% percentiles by thin horizontal lines (Jensen et al., 1997a).

The majority, i.e. 73.6% of the nitrogen input to the monitored lakes in 1992-96 comes from open land, especially farmland. Point source inputs from sewage treatment plants, fish farms, and storm water overflows provide only 8% of the total nitrogen load and were therefore far less significant compared with the contribution from cultivated areas. Atmospheric deposition is an important factor for the nitrogen balance of the lakes, contributing 17% of the total nitrogen loading of the lakes. Input of nitrogen from the atmosphere to the lakes is man-made and results from burning fossil fuels as well as evaporation of ammonia from agriculture.

Nitrogen input due to human activity thus make up a very high proportion of the total input to lakes.

Nitrogen balance in lakes

Most of the nitrogen retained in lakes is converted from nitrate to free nitrogen and escapes from the lake. Typically, 30 to 40% of the nitrogen is retained and converted, most of the remainder being removed from the lake via outflows, which is why nitrogen is not accumulated in lakes. Retention time in the lake, however, plays a role for the conversion of nitrogen, less being converted if the retention time is short.

In 1996, the nitrogen retention was relatively high because of the low water flow.

Development of nitrogen content of lakes

Total nitrogen concentrations in the lake water of the monitored lakes, both as annual and summer averages, were on the whole unchanged in 1989-96, nor could any changes in input concentrations be recorded.

5.3.2 **Phosphorus**

Phosphorus in 1996

The annual mean total phosphorus concentration in input waters to the monitored lakes in 1996 was 0.21 mg/l, which is slightly higher than the average in 1992-96 (Table 5.4). The low run-off in 1996 meant that total phosphorus input to the monitored lakes via surface run-off was small (Jensen et al., 1997a).

The mean annual concentration in lake water was 0.16 mg/l in 1996.

Development of phosphorus input to lakes

There are also great variations in the total phosphorus loading of lakes, which varied from 0.1 to 34.2 tonnes/year during 1992-96. The phosphorus concentration of input waters varied between 0.08 and 0.57 mg/l.

Table 5.4

Phosphorus input to 22 monitored lakes 1992-96 (Jensen et al., 1997a)

	Mean	Median	Min.	Max.
Total phosphorus (t)	5.0	1.2	0.1	34.2
Total phosphorus (mg/m²/day)	9.5	7.6	0.7	24.8
Flow-weighted mean input concentration (mg/l)	0.16	0.13	0.08	0.67

Falling phosphorus inputs to the most heavily loaded lakes

Phosphorus inputs to the monitored lakes expressed as median were largely unchanged between 1989 and 1996 (Figure 5.2), but there has been a fall in phosphorus inputs to the most heavily loaded lakes from 8-10 tonnes of total phosphorus a year up to 1991 to 2-4 tonnes thereafter. The main reason for the drop in phosphorus input is reduced point loading plus a fall in diffuse inputs.

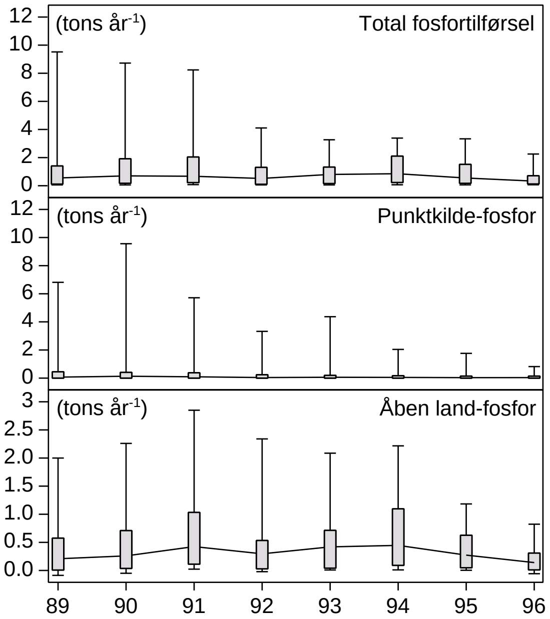

Figure 5.2
Phosphorus inputs to monitored lakes (tonnes p.a.). Total input, input from point sources and inputs from open land (Jensen et al., 1997a).

Open land is the main source of phosphorus loading of monitored lakes

Open land, cultivated areas particularly, is the main source of phosphorus inputs to the monitored lakes, comprising 57% of the total volume in 1992-96. Point sources contributed 33%, of which 14% came from discharges in sparsely populated areas. Waste water discharges from towns and industry only accounted for 10% of the total input of phosphorus to lakes.

The input from towns and industry was previously more significant to the total input of phosphorus to lakes than it is today. There has been a marked decrease in the phosphorous loading of lakes from point sources since the 1970s.

Phosphorus previously stored in sediments is significant

There is great variation in the retention of phosphorus in the monitored lakes as this depends in part on the water retention times. In some lakes more phosphorus is output than input, i.e. the retention is negative, while the opposite is true in others. The retention thus varied in 1992-96 between –50% and +90%, with an average of 4.8% of the phosphorus input to the lakes (Jensen et al., 1997a). When some nutrition-rich lakes discharge more phosphorus than is input, this is because phosphorus previously stored in the lake sediment is still being liberated. Thus, the lakes are not at equilibrium with the current loading.

The reduction in external phosphorus loading as a result of centralised and improved purification of sewage from towns and purification of industrial waste water thus has not resulted in improved environmental conditions in lakes because of phosphorus stored in the sediment.

Phosphorus retained in lakes is not converted and does not disappear, as is the case with nitrogen, but is stored in the sediment instead.

The phosphorus content of water in the monitored lakes is showing an overall falling tendency. The annual mean value of total phosphorus has thus fallen from 0.202 mg/l in 1989 to 0.157 mg/l in 1996, corresponding to a reduction of 22% in 1996 (Figure 5.3). The greatest drop in the phosphorus content of lakes has mainly taken place in 1987-1991. The reduction has again been greatest in the most nutrient-rich lakes corresponding to the fall in phosphorus input to them. The summer average has not fallen, however.

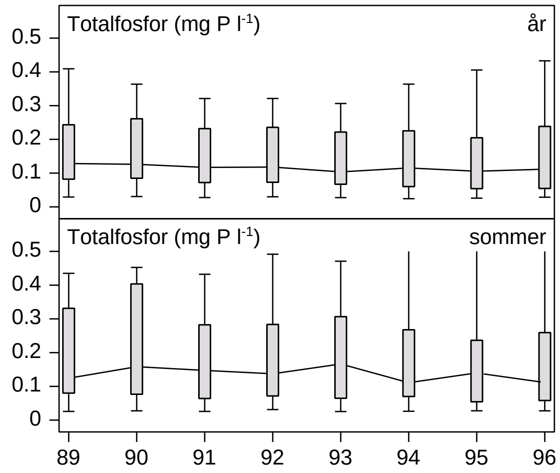

Figure 5.3
Total phosphorus in lake water (mg/l), annual and summer averages (Jensen et al., 1997a)

5.3.3 Heavy metals and contaminants

Occurrence

There are no systematic studies available on the occurrence and effects of heavy metals and contaminants in Danish lakes. The lake water concentrations are generally considered to be low, but will – dependent on the retention time – reflect the presence of the substances in the various inputs to and run-offs from the lake (watercourses, waste water outfalls, storm water run-off, percolation of ground water, etc.). Due to the low flow rate in the lakes, suspended particles will often form sediment leading to an accumulation of particle-bound heavy metals and contaminants at the bottom of the lake.

The possibility that accumulated heavy metals and contaminants in the sediment may have detrimental long-term effects especially on organisms living at the bottom cannot be ruled out.

Heavy metal content in sediment

There are several examples of heavy metals found in lake sediment. In connection with the restoration of Brabrand lake in Aarhus county, in which the sediment was dug out, it was estimated that a removal of sediment to a depth of 500 mm over an area of 1 km² would result in the removal of 144 kg of cadmium, 5,000 kg of copper, 159 kg of mercury, 2,700 kg of nickel, 6,300 kg of lead, and 36,300 kg of zinc (Brix & Schierup, 1987).

The same quantities of heavy metals in lake sediment would not necessarily be expected in other lakes as the content of heavy metals in sediment vary from lake to lake and depend on several factors.

A high content of humus in the sediment and much leaching of metals from catchments or input of soil particles may result in a content of heavy metals in the sediment that is higher than normal.

Sediments with a high content of organic matter will have a rather high content of heavy metals and, similarly, a low content of heavy metals if the content of organic matter is low.

Sources

Sources of heavy metals in lake sediments are partly natural background loads, and partly man-made sources.

Natural background loads of heavy metals in lakes are generally low due to the mineral composition of the Danish geology plus low natural atmospheric input.

The man-made sources of heavy metals in lakes are predominant, i.e. especially waste water outfalls and atmospheric input.

Waste water disposal, etc.

Heavy metal inputs from waste water disposal either directly to lakes or via watercourses etc., and increased levels of heavy metals can be detected in many lakes as a result of discharges over many years.

Atmospheric sources

Heavy metal input from the atmosphere has risen compared with the natural background input as a result of the widespread use of fossil fuels, lead additives in petrol, and the industrialisation in general.

Falling loads

Discharges of heavy metals with waste water have diminished noticeably over recent years as a result of improved sewage treatment brought about by the Aquatic Environment Plan. The atmospheric deposition on water surfaces has also been reduced in step with, among other tings, the phasing out of lead additives and improved industrial pollution-prevention measures. These discharges are expected in future to be further reduced, due partly to ever better purification measures and partly to the introduction of cleaner industrial technology.

5.3.4 Acidification

There are a number of acidified or acidification-threatened lakes in West-, North- and Central Jutland as a result of low lime content of the soil. Collection of data from about 100 lakes in the above regions threatened by acidification in 1991 showed that many of them had low pH values, i.e. less than pH 5 (Rebsdorf, 1991).

All the same, acidification as a result of acid rain is not a problem to the same extent as in Norway and Sweden, although changes in acidity of some lakes has been noted in recent years.

An older study of the development of acidification in Central and North Jutland lakes showed that their acidity had fallen by 0.6 pH units from the 1950s to 1979 (Rebsdorf, 1981 from Rebsdorf & Nygaard, 1991), presumably as a result of acid rain.

Data from 43 lakes in Central and West Jutland in 1991 showed that 18 of them had become more acid, 3 more basic and 22 showed no clear development since before the 1970s (Rebsdorf & Nygaard, 1991).

5.4 Biological conditions

Different plant and animal populations predominate in different parts of the water body and at the bottom of the lake. The composition, occurrence and linking of the various groups of flora and fauna in various areas of the lake can give a picture of the overall environmental condition of the lake because the biological populations in lakes vary considerably depending on nutrient inputs and levels in the lake water.

5.4.1 Flora and fauna

Phytoplankton

Microscopic plants called plankton or algae are found in the free bodies of lake water. They are called plankton or algae and consist of a number of different groups, e.g. green algae, diatoms and blue-green algae, all of which produce organic matter by photosynthesis. They are thus part of the primary production of a lake and the basic food for zooplankton. The various groups differ in form and biology. The number of algae in a lake can vary from thousands to billions of organisms per litre of water (Sand-Jensen & Lindegaard, 1996), and they are very important to the environmental state of the lake. The number of species in a lake averages 100 over the year.

Nutrient balance

The amount and composition of algae is affected by the nutrient balance in a lake. The amount of phytoplankton generally rises with the phosphorus concentration, but only some species of algae respond to the nitrogen levels.

The depth, biomass and amount of zooplankton also affect the amount and composition of phytoplankton.

Seasonal variation in production of algae

The amount of phytoplankton is controlled by the intensity of light and the temperature and therefore varies over the year. In spring, rising light input and water temperature accompanied by available nutrient often give rise to large blooms of particular algal groups (often diatoms) in the upper water strata. This provides food for zooplankton, whose biomass increases in May and June by grazing on the algae.

Similarly, lack of nutrients in a nutrient-poor lake may contribute to falling algae biomass in early summer, leading to clear water in the lake. A great many of the algae produced during the summer decompose later in the season, thereby again releasing nutrients to the water. As long as the light intensity is still high in autumn, this release may cause an autumn bloom of algal groups such as green and blue-green algae in many lakes. In autumn, when the light intensity reduces further, algal production follows suit and is typically minimal through the winter.

Zooplankton

Zooplankton similarly consists of a range of single or multi-celled organisms such as daphnia, water fleas (copepods) and protozoa. Their food is typically phytoplankton, bacteria or other organic matter. Their numbers are controlled by availability of food, but also by hunting by fish such as roach and bream or other animals.

The amount and composition of zooplankton has great impact on the biological process and therefore on the environmental condition of the lake. The size of individual subjects and the zooplankton biomass are affected by variations in the amount of nutrients in the lake. Studies of 60 lakes showed that the biomass of, among others, daphnia drops significantly with rising phosphorus concentration, while the reverse is the case for copepods (Jensen et al., 1997a).

Seasonal variation in the spread of zooplankton

The total biomass and composition of zooplankton changes with the seasons, controlled by availability of food and thereby the nutrient levels as well as by hunting by fish. In nutrient-poor lakes, where the number of zooplankton-eating fish species is limited, the amount of zooplankton follows changes in the population of phytoplankton on which they feed. The highest zooplankton biomass is thus found in May/June and in August when the phytoplankton biomass is at its highest. In a nutrient-rich lake there is a peak in phytoplankton around the end of June, so the zooplankton biomass level is high and reaches its peak in May-June when the phytoplankton biomass is also high.

Aquatic plants

Aquatic plants are also highly significant to the circulation of nutrients and biological processes in lakes and are generally regarded as beneficial. For example, they improve oxygen levels near the bottom and stabilise sediment, which therefore is not so easily stirred up resulting in increased phosphorus release. Aquatic plants also have positive effects on the composition of zooplankton, fish and other animals in a lake. Their effect on water quality and the biological interplay therefore depend on their coverage of the bottom of the lake.

The extent of aquatic plant growth depends on the lake depth and thus the possible extension area, water clarity and thus the number of algae. So an increased amount of algae in the lake water due to rising phosphorus concentration will reduce the light penetration down to benthic plants, reducing the depth limit for aquatic plants. At a phosphorus concentration of 0.15 mg/l, bottom plants will only be able to grow down to a depth of 1 m (Kristensen et al., 1990 after the Danish EPA, 1990).

5.4.2 **Fish**

The variety of fish in a lake often reflects the general condition as regards nutrient levels, size, climatic influence, etc. Fish also play an important role in regulating environmental conditions in a lake, including the clarity of the water.

45 fish species in Danish lakes

45 different species of fish have been recorded in studies of fish populations in Danish lakes over the last 10 years (Jensen et al., 1997a). The number of species in individual lakes depends in part on nutrient levels and depth, but they typically contain 6 to 8 different species. Input of large amounts of nutrients such as phosphorus often results in the number of species falling, but the biomass of the remaining species rising.

Many predators in a clean lake

Pike and trout do well in clean, nutrient-poor lakes. They hunt mainly by sight, and as clean lakes generally have clear water and plenty of aquatic plants, their hunting prospects are good. The hunting pressure on non-predatory fish such as roach and bream is high and their numbers are thus kept down. When this happens, there will often be large amounts of zooplankton, on which the non-predators normally feed, and which in turn “graze” on the phytoplankton or algae. The presence of enough predatory fish therefore contributes to keeping a clean lake clear.

Many non-predators in a polluted lake

On the other hand, the water in a polluted lake will be more turbid, to the detriment of the above predators. Hunting pressure by predators on roach and bream is less, and large populations of non-predatory may develop. A large population of roach and bream eats so much zooplankton, such as daphnia, that these cannot keep the algae down, and the lake becomes even greener. A polluted lake thus enters a vicious cycle.

Predatory fish thus tend to dominate in clean nutrient-poor lakes while others such as roach and bream predominate in nutrient-loaded lakes. The fish composition of Væng Lake in Vejle county is a good example of dominance by predators when the phosphorus level is relatively low (Figure 5.4). On the other hand, Dons Nørre Lake is nutrient-loaded and, consequently, non-predatory fish dominate.

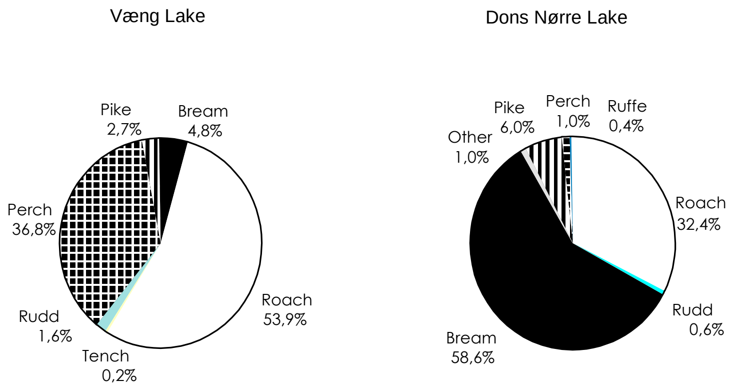

Figure 5.4
Percentage distribution by weight of fish species in clean lake (Væng Lake) and in a polluted lake (e.g. Dons Nørre Lake) in Vejle county, 1996).

Bio-manipulation

The effect of fish composition on the maintenance and stability of certain environmental conditions in a lake is used when lakes are being restored. This is called bio-manipulation and involves removal of roach and bream combined with stocking of predators such as pike.

5.5 Environmental conditions in lakes – status and development

The total phosphorus and chlorophyll-a contents and Secchi depths, averaged over the summer period, give an impression of the current environmental conditions in the monitored lakes in 1996 (Figure 5.5).

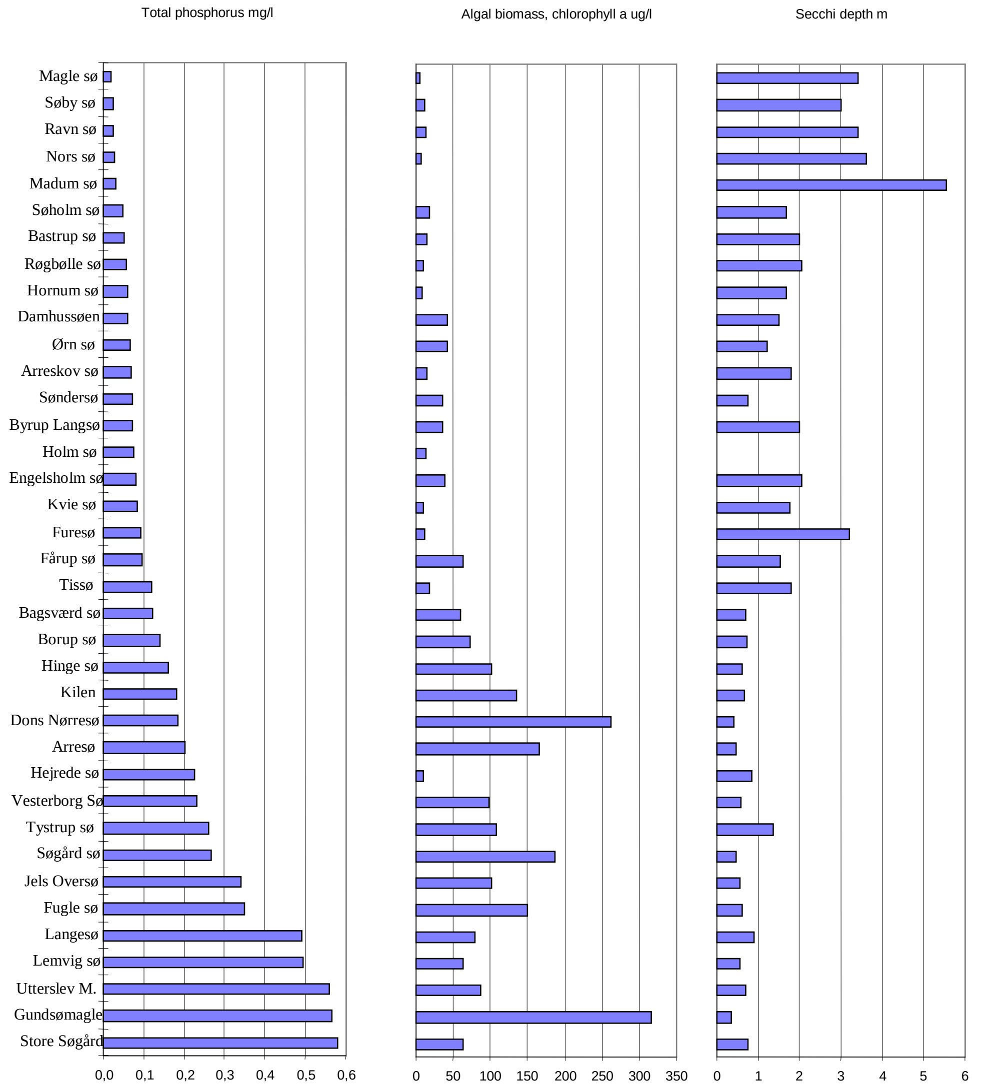

Figure 5.5
Contents of total phosphorus (mg/l), chlorofyll-a (µg/l), and Secchi depth (m) in the lake water in 37 monitored lakes. The values are the average throughout the summer.

Figure 5.5 shows that in lakes where the phosphorus concentration is high, the Secchi depth is low and chlorophyll-a content is high, i.e. the environmental conditions are poor. Furthermore, only when the phosphorus content is less than 0.1 mg/l in the lake water, Secchi depths of more than 1 m are expectable.

Low Secchi depths in lakes in 1996

There were great differences in Secchi depths in the monitored lakes in the summer of 1996, varying from 0.35 to 5.54 m. Expressed as summer and annual averages, the Secchi depth was 1.5 and 1.7 m, respectively. In the 25% most polluted lakes included in the monitoring programme it averaged 0.64 m in 1996. The chlorophyll-a content also varied in the monitored lakes in 1966, and the yearly average was 49 mg/l in 1996.

Regional lake

The counties also measure the Secchi depth in lakes as part of their regional supervision. In 1996, *supervision*

the regional supervision included measurements of Secchi depths in 225 lakes, which are not necessarily representative of Danish lakes generally, but as the number of lakes in which Secchi depth is measured every year is quite high, the regional supervision is considered to provide a picture of the distribution of Secchi depths in Danish lakes.

Table 4.5
Distribution of Secchi depth measurements by county as recorded in the counties' regional monitoring in 1996 (Danish EPA, 1997a)

	Secchi depth					
County	0-0.5	0.5-1	1-1.5	1.5-2	2-3	>3
Copenhagen municip.	0	4	2	2	0	0
Copenhagen	0	2	7	0	0	1
Frederiksborg	1	4	1	3	0	0
Roskilde	2	4	1	0	0	0
West Zealand	9	9	6	2	1	2
Storstrøm	9	33	13	8	5	4
Bornholm*	-	-	-	-	-	-
Funen	1	8	3	2	0	0
South Jutland	0	10	4	1	6	2
Ribe	0	0	2	4	3	0
Vejle	4	4	4	2	3	1
Ringkøbing	1	4	3	0	1	0
Aarhus	1	2	4	1	1	1
Viborg	0	4	0	1	0	2
North Jutland**	-	-	-	-	-	-
Total	28	88	50	26	20	13

* *Data not reported to the Danish Environmental Agency.*
** *Lakes not studied in 1996.*

Over half the lakes have a Secchi depth less than 1 m

The regional supervision found the Secchi depth to be less than 1 m in 52% of the lakes. The most commonly measured Secchi depth was within the 0.5-1 m interval, which must be considered unsatisfactory in most lakes. In only 6% of the lakes examined the Secchi depth was more than 3 metres.

Large amounts of plankton in 1996

As a result of the high nutrient levels in 1996, large amounts of plankton were measured in most of the 37 lakes monitored which is reflected above in the Secchi depths and chlorophyll-a content.

The phytoplankton biomass consisted mostly of algal species such as blue-green and green algae characteristic of nutrient-rich lakes (Figure 5.6). Expressed as a median, blue-green algae typically formed between 15 and 30% of the total biomass.

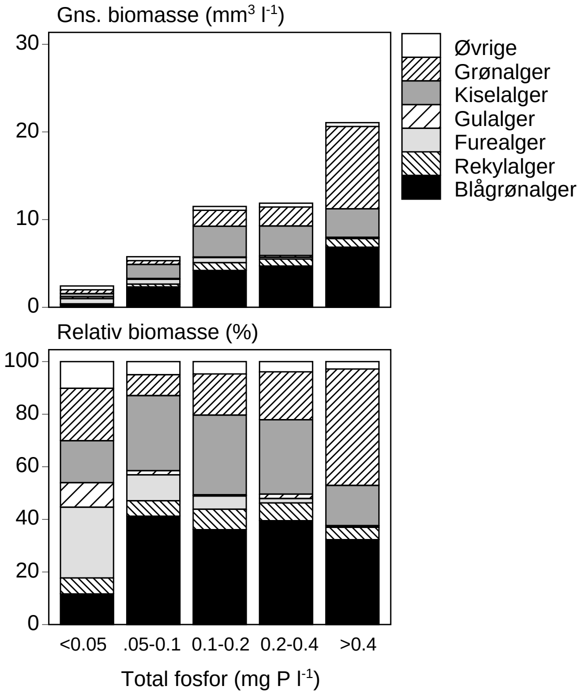

Figure 5.6

Composition of phytoplankton relative to total biomass at different total phosphorus concentrations in 1996 (Jensen et al., 1997a).

Slight improvement in Secchi depths since 1989

There have only been small changes in the Secchi depth and chlorophyll-a content of the monitored lakes between 1989 and 1996 (Figure 5.7). There has been, however, a slight rise in visibility accompanying a small drop in chlorophyll-a levels.

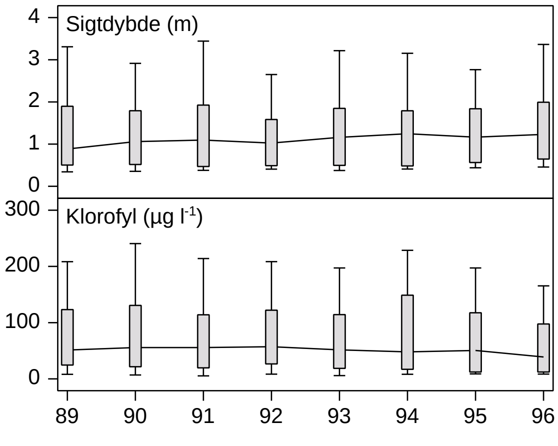

Figure 5.7

Secchi depth and chlorophyll-a content (summer averages) in lakes between 1989 and 1996 (Jensen et al., 1997a)

Changes in plankton biomass in 1989-96 were similarly limited. Nonetheless, there has been a downward trend in median values from 11.7 to 5.6 mm³/l. There have been statistically reliable reductions in annual mean total biomass in 13 lakes expressed as yearly average, while in no cases has it risen.

Zooplankton in 1996

The 1996 total summer biomass of zooplankton averaged 0.81 mg dry matter/l.

Zooplankton amount unchanged

The amount of zooplankton in the monitored lakes as a whole expressed as total biomass, has not altered significantly (Figure 5.8). The summer median value of the total biomass was between 0.56 and 0.87 mg dry matter/l during the monitoring period. If the total biomass is subdivided into species it is seen that the proportion of *Daphnia spp*. was relatively high, however, without any substantial change in the biomass throughout 1989-96.

The ability of zooplankton to "graze down" phytoplankton has thus not risen during the monitoring period. The median grazing pressure has been between 10 and 20% of the total phytoplankton biomass. Large specific differences do, however, exist between the development and occurrence of zooplankton in individual lakes.

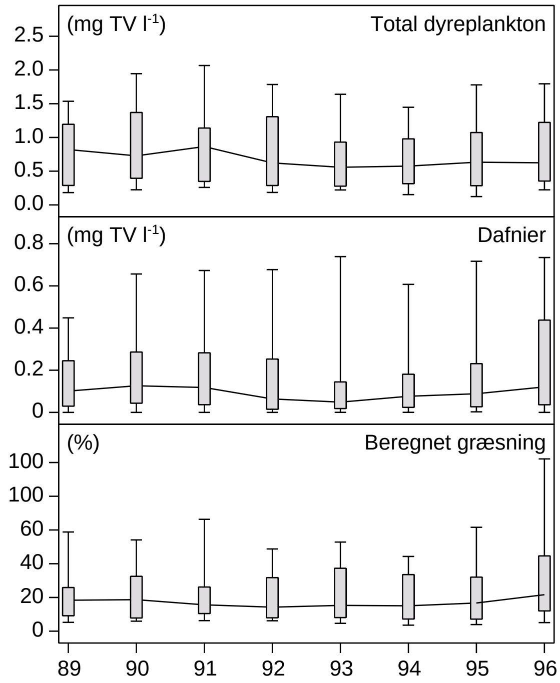

Figure 5.8
Summer average zooplankton total biomass (mg TV/l), Daphnia spp. biomass (mg TV/l) and grazing of phytoplankton (%) (Jensen et al., 1997a).

No change in extent of aquatic plants

Studies of the extent and composition of aquatic plants in the monitored lakes were not started until 1993. Since the, there have been no significant changes in how much of the lakes is occupied by aquatic plants (RPV). Similarly, there have been no substantial changes in their coverage of the lake bottoms (RPA) or their scope for growth in deeper or shallower water (depth limits) (Figure 5.8). At individual lake level, however, there were year-to-year variations in these parameters.

Table 5.5
General tendencies for changes in the relative plant-filled volume (RPV) of aquatic plants, relative plant-covered area (RPA), and depth limits of aquatic plants between 1993 and 1996. 0

denotes an unchanged situation, + and – denote positive and negative statistically certain trends, respectively (Jensen et al., 1997a)

Lake	RPV	RPA	Depth limit
Søby Lake	0	0	-
Maglesø Lake	0	+	0
Madum Lake	0	0	0
Nors Lake	0	0	-
Ravn Lake	0	0	+
Søholm Lake	0	0	0
Kvie Lake	0	0	0
Hornum Lake	0	0	0
Røgbølle Lake	0	0	0
Furesøen	0	0	0
Fårup Lake	0	0	0
Damhussøen	0	0	0
Hinge Lake	0	0	0
Tissø	0	0	0
Arreskov Lake	+	+	0
Utterslev Mose West	0	+	0
Utterslev Mose East	0	0	0

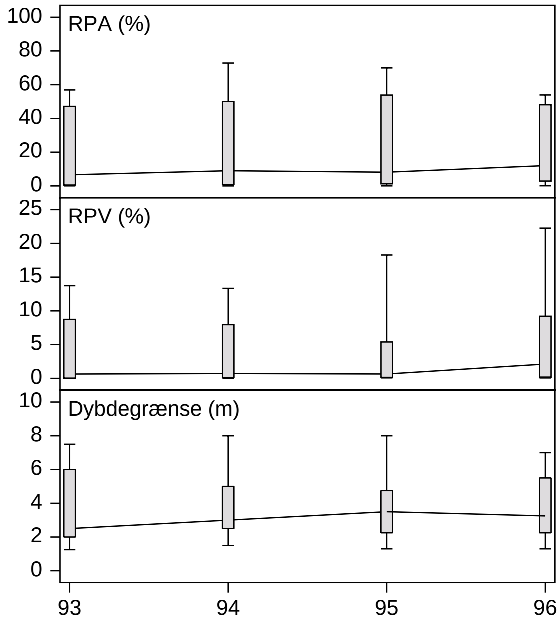

Figure 5.9
Trend in average coverage (% RPA), average plant volume (% RPV) and depth limit (m) of aquatic plants 1993-1996 (Jensen et al., 1997a).

Few studies of fish population development in lakes

Development in fish populations have only been studied in few lakes. These studies have been undertaken specially in lakes where intervention in the fish population has been carried out to improve conditions in the lake. In the absence of such an intervention, the composition of species is unlikely to change significantly over a few years.

One example of such a study is from Vejle county, where the fish population in Engelsholm Lake was studied in 1990 and again in 1992-96. In 1992 the county removed unwanted non-predatory fish such as roach and bream to improve the environmental conditions. About 20 tonnes of fish were removed over two years, reducing the fish biomass to about 12-17 tonnes.

This intervention resulted in the bream nearly disappearing followed by a rise in the biomass of ruff, trout and roach. After the removal trout comprise about 25% of the lake's predators.

The improved water quality in Engelsholm Lake as a result of the bio-manipulation has not been stabilised due to the absence of aquatic vegetation and excessive phosphorus load. Conditions will thus presumably return to those before the action was taken (Hald Møller, 1997).

Deliberate changes to fish populations do thus not often give rise to the intended improvement in environmental conditions unless phosphorus inputs are reduced as well.

Completely clean lakes today threatened by nutrient enrichment

Completely clean low-nutrient lakes are today threatened by nutrient enrichment, especially from atmospheric deposition, which is responsible for as much as 17% of the nitrogen loading of the monitored lakes. This nutrient load can tilt a clean lake's condition by an increase in plant biomass, reduced light penetration through the water and increased oxygen depletion at the bottom of the lake. The Secchi depth in one of Denmark's cleanest lakes, Grane Langsø, has been reduced from 12 m in the 1950s to about 6.5 m in the 1980s (Riis et al., 1996). In the long term this eliminates the basis of the rare flora and fauna of low-nutrient lakes.

To preserve our cleanest lakes in future, it will probably become necessary to take steps to reduce nutrient inputs to lakes, especially from atmospheric deposition.

Loading due to ammonia evaporating from farmyard manure is one of the problems to be addressed.

5.5.1 **Lake restoration**

In the last 5-10 years, attempts have been made to support the development towards bringing nutrient-rich lakes into a satisfactory environmental condition with clear water and extensive benthic flora by restorative measures. There are several methods by which lakes may be restored. Removal of roach and bream followed by stocking with predators, removal of sediment and planting of benthic vegetation are examples of such measures.

Bio-manipulation by means fish populations

Many counties have manipulated fish populations in nutrient-rich lakes. Thus, 15 such interventions have been made since 1986 (Jensen et al., 1997a). Stocking with predators is one manipulation method to be used where nutrient input to a lake has been reduced and where the number and thus also the biomass of fish such as roach need to be reduced. The biological consequence of stocking is eventually clear water and increased spread of benthic flora.

Experiments in Lyng Lake have shown that introducing pike fry at densities of up to 2,000 per hectare can affect the biological structure (Søndergaard et al., 1996). A positive correlation was established between the stocking with pike and reduced phosphorus concentration in the water and an increase in the zooplankton biomass, which will in the long term improve environmental conditions in the lake. Provisional results indicate that the phosphorus level should be lower than 0.05-0.1 mg/l in the future equilibrium in order to make the changed conditions stable and thereby permanent (Jensen et al., 1997a). Studies over the coming years will attempt to elucidate whether the alterations and thus the improved environmental conditions in bio-manipulated lakes are permanent.

But as the pike stocked mainly eat smaller roach, the method is not directly suited to remove larger, older fish, which despite stocking with pike are still free to produce large numbers of fry again. For this reason, many counties remove roach or bream before stocking with predators. In nutrient-rich lakes where the predator population is assessed to be good, bio-manipulation often consists only in removal of unwanted fish.

Lake restoration by dredging of

There is often a large reservoir of phosphorus in the benthic sediment of nutrient-rich lakes, which is continually released to the water resulting in algal blooms. A reduction in phosphorus *sediment*

inputs from cultivated areas, waste water outfalls, etc. will often not have the desired effects in lakes. The internal reservoir of phosphorus can be removed by dredging and removal of the sediment.

Attempts to reduce the reservoir of phosphorus by dredging have unfortunately not produced the desired reductions in impact on the environment by the internal phosphorus load (Jørgensen & Skovgård, 1997). One explanation could be that sediment not previously accessible may, as a result of the dredging, liberate phosphorus from the new sediment surface.

Conclusions on the environmental condition of the monitored lakes

Summing up, it can be concluded that the environmental condition of the lakes monitored is strongly affected by nutrient loading. In the period 1989-96 there has been a small reduction in phosphorus loading (especially in the most polluted lakes), a small reduction in concentrations of total phosphorus, chlorophyll-a, and phytoplankton, and a small increase in Secchi depth. The amount and occurrence of zooplankton and aquatic plants has remained unchanged during the same period.

The results show a slight tendency towards improved environmental conditions in the lakes.

5.5.2 Objectives for Danish lakes

Targets for quality and utilisation of lakes are set by county councils in their regional plans.

Many high targets for lakes

A national survey of the use of target setting shows that the B target is the commonest (Table 5.6). 95% of the lakes have either basic or strict targets, showing that the counties wish to preserve the lake environment.

Table 5.6

Distribution of strict, basic and modified targets for the Danish lakes in 1996.

	Targets		
	A (strict)	B (basic)	C (modified)
Number	259	402	37
Percent	37	58	5

The counties’ monitoring includes checks on whether objectives are being met.

28% targets met in 1996

In 1996, the counties carried out monitoring to a varying degree in a total of 225 lakes with a view to assessing target compliance which could only be assessed in 209 of these, out of which only 28% met their targets in 1996.

34% targets met in 1994-96

Between 1994 and 1996, the counties assessed whether all the 698 Danish lakes with targets set actually met their targets. The proportion found was 34% (Jensen et al., 1997a).

Compliance rises from target C to A (Table 5.7), i.e. it is highest in A-targeted lakes, nearly half of which comply. Despite the fact that in the case of modified targets it is acceptable that the ecological condition of a lake is affected by outfalls, only 16% of such lakes met the objective.

Table 5.7

Distribution (%) of target compliance for A, B and C targeted lakes 1994-96.

	Target		
	A (strict)	B (basic)	C (modified)
Number	259	402	37
Target met (%)	46	26	16

High target compliance in

Degree of compliance is also related to lake size. It has been found that target compliance coincides with decreasing lake size. In the case of lakes less than 3 ha in area, 48% meet their *small lakes*

objectives, while in the case of lakes over 3 km² only 8.3% do (Jensen et al., 1997a). This difference probably arises because it is easier to implement sufficient measures in small lakes to bring it to its target level. For example, it would take far greater efforts to combat the diffuse nutrient loading from a large catchment of a large lake compared with a smaller one.

The counties' regional monitoring does not indicate any development in target compliance between 1990 and 1996 (Figure 5.8).

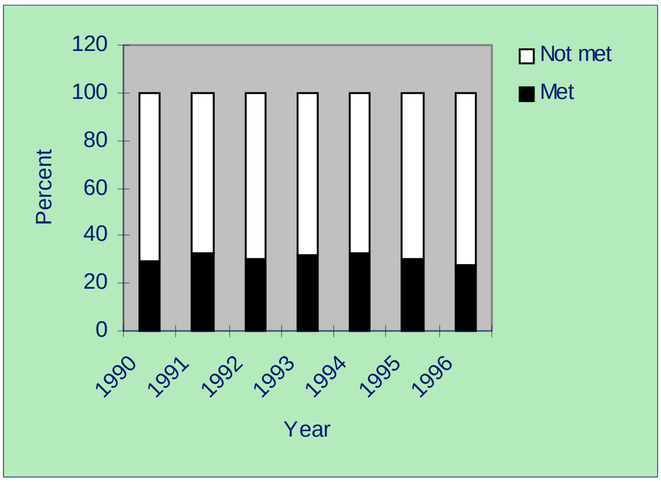

Figure 5.10
Development of meeting lake targets determined by regional monitoring in 1990-96.

Reasons for lack of improvement in target compliance

The reductions achieved in nutrient loading of lakes, with little resulting improvement in environmental condition of the lakes, have often not been sufficient for the lakes to meet the objectives set in the regional plans. Current nutrient inputs from cultivated areas and point source outfalls together with the internal phosphorus loading from nutrient-rich lakes are considered to be the reasons for this lack of improvement of the environmental condition of the lakes.

Further measures against nutrient sources

Several counties point out a need for further measures against nutrient inputs, and that many lakes need restoration to be able to meet their objectives. Marked improvements can presumably only be achieved by further reductions in phosphorus loading from open land such as cultivated areas and sparsely populated areas.

Phosphorus loading can be reduced at source and by re-establishment of water meadows along lakes and watercourses.

The revised Rural Waste Water Treatment Act (1997) has provided a basis for further reducing phosphorus discharges from sparsely populated areas over the coming years.

Standardisation of lake monitoring programmes

Today, the monitoring of lakes is differing from county to county. Thus, there are great variations in choice of methods, selection of stations, sampling times, etc. in the regional supervision. For example, about 200 lakes out of the more than 600 lakes with targets set are checked for target compliance every year. This means that any national overview of developments in the environmental condition in lakes and target compliance registered by the regional supervisory authority is to be treated with great caution, if indeed such a data processing is possible at all.

For this reason, there is a need to standardise the regional monitoring programme for lakes including differentiated supervision of a larger number of lakes in a fixed network of stations, so that in future it will be possible to provide a true nation-wide picture of the development of the environmental conditions in Danish lakes.

Supervision of small ponds

The counties' supervision does not today, unfortunately, cover small lakes and ponds, which is regrettable because they are vital habitats for a great range of protected flora and fauna such as amphibians. This lack of supervision means that there is not enough information available to describe the environmental condition of bodies of water of less than 1 ha. With the increasing interest in restoring polluted, small ponds and establishing new ones, a standard classification system needs to be developed over the coming years to record and describe the condition of small lakes and ponds so that development trends resulting from various environmental improvement measures can be tracked.

5.6 Scenarios

Further measures are needed to address nutrient inputs from cultivated areas and from sparsely populated areas to enable more lakes to achieve their target conditions in the coming years.

By, for example, halving phosphorus inputs from the open land, the majority of lakes in the monitoring programme would achieve Secchi depths of about 4 metres (Jensen et al., 1997a).

A 50% reduction in phosphorus input from waste water alone would be enough to improve visibility in about half of the lakes to over 2 m.

The conclusion is therefore that satisfactory meeting of lake quality objectives in the lakes monitored depends on efforts to reduce phosphorus inputs from cultivated areas and sparsely populated areas.

6. The state of the environment in Danish fjords

The fjords are one of the most characteristic Danish natural features. As so many other notable elements of the appearance of the country, they are chiefly a result of the impact of the Glacial Age. The eastern Danish fjords were created by melt waters which, during the retreat of the ice, eroded deep valleys in the landscape. The lower reaches of the valleys now lie beneath the surface of water and form the fjords. Such a fjord is in most cases more or less wedge-shaped with a wide opening towards the open waters and a watercourse at the upstream end. Some of the fjords and bights discussed in this report were, however, created in another way, for example by material transport along a length of shoreline cutting off a bight or cove. Figure 6.1 shows the fjord areas discussed in this report.

Figure 6.1
Map of selected fjords

The chapter begins with a short review of the public interests and activities associated with the fjords and the resultant impact. Then comes an account of the administration of the state of the fjord environment. The following section contains a description of the physical conditions which form the basis of the environmental conditions in the fjords. The chapter concludes with a description of the status and development of the fjords' environmental conditions.

6.1 Utilisation and impact on Danish fjords

The Danish fjords are important from both recreational and occupational viewpoints. They function as breeding and nursing grounds for many species of fish and birds, and as transport routes to coastal towns. The activities associated with the fjords and their consequences are described below.

6.1.1 Fisheries and fish farming

A great deal of the Danish fishing previously took place in the fjords. The importance of herring-fishing to the development of the towns along Limfjorden is well known. These days, only a small proportion of commercial fishing takes place in the fjords, whereas recreational fishing is very intense.

Intensive fishing for common mussels takes place in Limfjorden, the Wadden Sea and some of the fjords of East Jutland. Fishing is by means of bottom-scraping devices, which can affect or damage bed conditions in the areas worked. Damage to eelgrass in Limfjorden has been noted in several places (The Limfjorden monitoring, 1996)

A great deal of the marine and salt-water fish farms are located in the fjords. Table 6.1 lists the location of fish farms in Danish fjords.

Table 6.1
Summary of the number of marine fish farms, salt-water fish farms and other aquaculture in the theme fjords studied in 1995.

Fjord	Marine	Salt-water	Other
Vejle fjord	1	0	0
Horsens fjord	4	0	1 1)
Kolding fjord	2	0	0
Ringkøbing fjord	0	8	1 2)
Limfjorden	0	0	3 3)
Kalundborg fjord	0	1	0
Isefjord	0	0	1 4)
Åbenrå fjord	0	1	0
Total	7	10	6

1) Breeding of Pacific oysters. 2) Illuminated breeding plants 3) Illuminated breeding plants and breeding of oysters and mussels. 4) Oyster breeding.

The environmental effects of marine and salt-water fish farms are associated with emissions of nutrient salts and especially the local effects of organic matter.

6.1.2 Utilisation of raw materials

Extraction of raw materials (sand, gravel, stone, shells) in Danish waters is regulated by the Raw Materials Act. Between 4 and 8 million m^3 per year are extracted. The large variations are primarily due to periodical supplies of sand fill for large construction projects.

In 1996, the Raw Materials Act was amended on a number of points. The changes mean, among other things, that as from January 1997, raw materials extraction may only occur in designated areas where an environmental impact assessment has been undertaken. To ensure compliance with the Constitution and a smooth changeover from the previous practice, whereby extraction could in principle take place anywhere, a ten-year transitional period has been decided on for pebble and sand suction dredging in those areas where extraction has taken place over many years. These transitional arrangements will cover approx. 110 areas in the North Sea and the inner Danish territorial waters.

Most of the transitional areas will be in the open sea and only a few individual areas, mainly for local supplies, will be in fjord areas.

About 30 areas will be allocated to boulder fishing. None of these will be near fjord areas.

Raw materials extraction in EU bird sanctuaries and Ramsar sites was prohibited in 1994, although a phasing-out arrangement has been made for pebble and sand suction dredging in a small number of areas, primarily in Nissum Bredning. Shell extraction in Roskilde fjord will be phased out at the end of 1997.

Effects of raw materials extraction in fjords

Extraction of sand, gravel and boulders is carried out by sucking up material from the sea bed using a hydraulic pump. Point suction forms a hole, the size of which depends mainly on the amount of material won and the depth of the deposit. When drag suction is used, elongated grooves about 1.5 m wide and 30-50 cm deep are formed. Intensive extraction causes a general sinking of the sea bed over large areas.

During the extraction process, the finest grained material is usually returned to the sea with the wash water. The process causes a certain liberation of nutrients from the sediments.

Extraction mainly takes place in unpolluted sea bed sediments, where liberation of e.g. nitrogen is usually of the order of 0.5-10 g N/m^3 of materials dredged. Liberation of heavy metals is insignificant.

Apart from areas in the western part of Limfjorden, Grønsund and Roskilde fjord, no significant raw materials extraction occurs in the actual fjord areas, and the total environmental impact on the aquatic environment will therefore be insignificant.

6.1.3 **Disposal of dredging materials**

Of the 83 disposals of dredging materials which took place in Danish waters in 1995, only 15 were in fjords. This involved less than 10% by weight of the amounts disposed of.

Vejle Fjord: Two small volumes of dredging materials were disposed of in the outer part of the fjord. The material was unpolluted.

Ringkøbing Fjord: Three small volumes of dredging materials were disposed of in the fjord. Most of the dredging materials from the area are disposed of in the North Sea. The material was unpolluted.

The Jutland Wadding Sea: About 263,800 tonnes of dredging materials were disposed of in three places in Grådyb tidal zone. Most of it originated from Esbjerg and was disposed of immediately outside the harbour. Totally this material consisted of 17 kg of mercury, 37 kg of cadmium, 3.4 tonnes of chromium, 1.9 tonnes of copper, 13 tonnes of zinc and 3.4 tonnes of lead.

Isefjord: Only one minor disposal of dredging materials took place in 1995.

Aabenraa Fjord: In 1995 there were 150,000 tonnes in the fjord. As the material was deemed to be unpolluted, no analyses are available.

Limfjorden: Six disposals of dredging materials took place in the whole of the fjord, totalling about 215,000 tonnes. A large part of the material originates from annual dredging of shipping fairways and of harbour mouths. The dredged sea bed materials consists of coastally transported sediments, which according to experience are unpolluted.

A temporary physical covering over of plant and animal life will, of course, occur at a disposal site, but migration of animals will quickly begin after the disposal has ceased. On permanently used disposal sites, the animal life will at short intervals be wiped out/covered over.

No increased levels of heavy metals or contaminants have been demonstrated in Danish fjords as a result of disposal of dredging materials. This may be attributed in part to scant monitoring of the disposal grounds and their surroundings, but reflects to a higher degree that material is only permitted to be disposed of when they are judged to be unproblematic in relation to the marine environment. Similarly, no oxygen depletion in Danish fjord areas has been directly associated with disposal of dredging materials.

6.1.4 **Archaeology**

The Danish sea and fjord beds are a repository to a great many cultural relics, partly from the period in the Stone Age when the areas were dry land (settlements) and partly from the exploitation of the sea over many years (prehistoric fishing equipment, harbour and defence constructions as well as wrecks). All such finds, provided they are more than 100 years old, are protected under section 14 of the Danish Protection of Nature Act. Finds may neither be removed nor destroyed without the permission of the Minister for the Environment.

The National Forest and Nature Agency estimates that there are about 20,000 historical wrecks, a similar number of Stone Age settlements and approx. 5,000 harbour and defence constructions on the Danish sea bed. A great many of these will be found in the fjords, which in the Stone Age as well as in historical times were attractive areas to settle in, easy to protect with relatively simple defence systems and hard to navigate.

No systematic recording has taken place in the fjords and so no table has been prepared, since the number of finds would differ significantly from the actual number of items.

The archaeological finds made in the Danish fjords are often of significant historical interest because the sedimentation that occurs in the fjords and the calm settlement conditions preserve the items. Understanding the cultural environment of the fjords through time and the changing usage of the fjords will often depend on the knowledge provided by marine archaeological finds.

Generally, the archaeological remains are well protected on the beds of the Danish fjords, but increasing intensity of exploitation of the fjords in recent years may under certain circumstances mean that historic monuments are at risk of destruction. Deepening or straightening of shipping fairways and actual construction work often affect a historic monument, but it is very rare for the monument to be of such a nature that the work must be moved or abandoned. Archaeological documentation of the find before it is removed will most often be sufficient.

6.1.5 **Waste water outfalls**

The number of waste water outfalls is described in the chapters on point source discharges and inputs to marine areas.

6.1.6 **Bathing**

Of Denmark’s approximately 7,000 km of coastline, about 5,000 are suited for bathing. The quality of bathing waters is monitored at some 1,300 monitoring stations spread along the sea coast, in fjords and in lakes. Bathing waters are regularly examined to protect bathers from illness and to check whether pollution of the waters occurs, and in the event of pollution to identify the source and stop the pollution.

6.2 **Administrative matters**

6.2.2 **Setting of quality objectives**

Under the Planning Act, counties are responsible for establishing through the regional plans the environmental quality and usage of coastal waters. One aim of the Act is to ensure that community development can occur in a sustainable manner. This means that determination of the environmental quality in a given water body is very much a political issue.

Water area plans

Water area plans form the basis of the regional plans and often contain the following parts:

- A description of the natural state of the area.
- A description of the current state.
- An account of the community exploitation of the area e.g. for waste water outfalls, bathing waters, etc.
- Establishment of the desired environmental quality (objectives) based on weighing of the various exploitation interests.
- An evaluation of the initiatives necessary to achieve the desired environmental quality.
- A description how achievement of the objectives can be monitored.

The target-setting system operates with three possible target levels:

1. A general target implies that the area is unaffected or only mildly affected by human activities. There must be a varied flora and fauna, good hygienic water quality, good light conditions, good oxygen conditions and little or no trace of toxic matter in water sediments and organisms. It is assumed that the general target is used unless particular circumstances apply.

2. In areas where particular community interests in the usage of the water area mean that general objectives cannot be met, a modified objective may be set. This may for example be the case in the immediate vicinity of a waste water discharge point or in a harbour. The activity which means that the general target level cannot be achieved must be stated along with the degree and manner in which a lowering of the environmental quality is acceptable.

3. A stricter target may be set for certain areas which are particularly vulnerable, either because of their special environmental importance or because the usage of the area demands a particular environmental quality. For bathing beaches, for example, a stricter target will often be set. This does not mean that the environmental quality in such an area need be higher than in a general target area, but that stricter monitoring shall be applied to check compliance.

6.2.3 **Bathing water requirements**

Bathing water areas are regulated by the Statutory Order on bathing waters and beaches (No. 292 of July 23, 1983), which implements the EU bathing waters Directive of 1976. Local authorities are responsible for checking bathing waters and for ensuring that samples of bathing waters are drawn for microbiological testing. Locations and numbers of sampling stations are decided by the local authority councils in conjunction with the counties. Should a deterioration in water quality be ascertained, the local authorities are required to undertake further tests and, should it prove possible to identify the source of deterioration, to undertake preventive measures. Should it not be possible to alleviate a confirmed pollution to acceptable levels, the local authority, in consultation with the medical officer of health and the county, will prohibit bathing. Such a prohibition will only be rescinded when it can be documented that the pollution has ceased and that it is safe to bathe in the water.

On average 10 samples per bathing water station have to be drawn during the bathing season running from May to October. The marine stations are examined for E. coli and freshwater stations for E. coli and total coliform bacteria. In addition, visual inspections have to be made to assess whether the bathing waters have been polluted by the presence of surface-active substances, algae or suchlike. Should there be any suspicion of the presence of other micro-organisms than those routinely tested for, the testing programme is widened to cover the relevant organisms. For example, where the waste water outlet from an abattoir is concerned, tests might be undertaken for salmonella/camphylobacter at the bathing water stations adjoining the outlet. Vibrio parahaemolyticus might similarly be tested for at a bathing water station near a fish farm.

There was a total of 1,300 bathing water stations in 1995, of which 110 are freshwater sites (in lakes), and about 16,000 tests were made. 19 areas were subject to bathing prohibitions compared with 22 the previous year.

In general, it can be said that bathing water quality has improved and that by national and international standards compliance of the bathing water with the values set is high.

6.2.4 Ramsar sites, bird sanctuaries and habitats

In 1979, on accession to the Ramsar convention, Denmark designated 27 Ramsar sites, followed in 1983 by 111 bird sanctuaries under the EU bird protection Directive. All Ramsar sites are wholly contained within the bird sanctuaries, and their boundaries coincide.

Designation of EU bird sanctuaries aims at preventing pollution or deterioration of the areas as habitats for and disturbance of the birds, to the extent that such pollution, deterioration or disturbance has significant effects on the protected species. Since adoption of the EU habitat Directive Denmark has proposed the designation of a number of habitats. The EU habitats are expected to be covered by the protection requirements applying to the EU bird sanctuaries, but on a different basis as to the species or aspects of nature motivating the designation.

Ramsar sites

25 of Denmark’s 27 Ramsar sites are more or less marine and 15 of these lie wholly or partly in the fjord areas covered by this report. Approx. 1,500 km^2 or 25% of the approx. 6,000 km^2 of marine Ramsar sites are in fjords, covering about 32% of the water area of about 4,750 km^2 (Limfjorden, Isefjord and Roskilde fjord are included in their entireties).

Bird sanctuaries

51 of Denmark’s 111 EU bird sanctuaries are more or less marine and 32 of these lie wholly or partly in the fjord areas mentioned. Approx. 2,100 km^2 or 29% of the approx. 7,175 km^2 of EU bird sanctuaries are in fjords, covering about 44% of the water area.

Habitat areas

30 of the above-mentioned 32 EU bird sanctuaries have also been proposed as EU habitat sites and cover approx. 2,075 km^2 of the fjord areas. It is a question of 21 of a total of 175 areas, of which 50 are marine and cover approx. 7,412 km^2 and 35 are also EU bird sanctuaries. The extent of Ramsar sites, bird sanctuaries, and habitat areas is specified in Table 6.2.

Table 6.2

Survey of Ramsar areas, bird sanctuaries, and habitats

	Number	of which marine	of which in fjords	Area (marine)	of which in fjords
	number			km^2	
Ramsar	27	25	15	5,996	1,519
EU bird protection area	111	51	32	7,176	2,109
EU habitat area	175	50	21	7,412	2,075

6.2.5 Marine nature and wildlife reserves

Wildlife reserves are established in accordance with the Hunting and Wildlife Management Act. The aim is to protect and encourage populations of wild birds and mammals.

Nature reserves are set up in accordance with the Protection of Nature Act. Under section 51 of this Act, conservation may be granted to state-owned areas and in Danish territorial waters (the fisheries territory). One is to protect nature with its populations of wild animals and plants and their habitats.

On September 1, 1996, there were 91 protected areas (nature and wildlife) with a total area of 278,756 ha, of which 247,804 ha or more than 80% are marine. Protected areas vary in size, some being quite small. The Jutland Wadding sea, which has the status of both nature and wildlife protected area, covers 90,000 ha and is thus the largest protected area in Denmark.

In connection with the passing of the Hunting and Wildlife Management Act, which came into force in 1994, it was decided that the protection of migratory waterfowl in the coastal EU bird sanctuaries should be enhanced by the establishment of new protected areas or expansion of existing ones.

The National Forest and Nature Agency is about halfway through its task of expanding the network of protected nature areas. The total area classified as reserves has grown by 45,000 ha in three years. A similar or slightly lower growth can be expected over the coming years.

6.3 Physical conditions in the fjords

The Danish fjords cover a wide spectrum in terms of topography, hinterland, freshwater inputs, etc. The topography is the foundation of the meteorological, hydrographic and man-made variations which affect the state of the environment. In other words, it is impossible to give a meaningful description of the environmental state without a thorough knowledge of e.g. depth and weather conditions, etc. Table 6.3 outlines the physical characteristics of a large number of Danish fjords.

Table 6.3
Mean depth, maximum depth, area, volume, mean freshwater run-off in the period 1989 to 1995 plus catchment areas for a number of Danish fjords.

Fjord No. and name	Mean depth	Max. depth	Area	Volume	Run-off	Catchment area
	m	m	km^2	km^3	mill.m^3/ year	km^2
1 Roskilde Fjord	3	31	123	0.360	476.2	1176
2 Karrebæk Fjord	3	6	14.8	0.044	1308.7	1110
3 Vejle Fjord	8.3	21	62	0.515	1223.6	732
4 Horsens Fjord	2.9	22	46	0.132	526.7	449
5 Kolding Fjord	5.2	15	14.7	0.077	633.9	367
6 Dybsø Fjord	1	2	17.5	0.018	52.3	44.6
7 Guldborg Sound	3	11	81.7	0.245	445.0	437
8 Guldborg Sound B	2.5	4	30.3	0.076		196
9 Nakskov Fjord	2.5	7	42.7	0.107	355.7	236
10 Sønder Cove	1	2	8.9	0.009	2.0	1.3
11 Stege Bight	2.4	18	42	0.101	33.1	31.6
12 Stege Cove	1.4	4	5.2	0.007	19.9	18.8
13 Nysted Cove	1.5	3.5	0.9	0.001		15.5
14 Sakskøbing Fjord	2.5	4	21.1	0.084	224.9	247
15 Avnø Fjord	5	11	41.1	0.206	122.7	138
16 Vålse Inlet	1.5	3	7.1	0.011		32.3
17 Præstø Fjord	2.7	6	21.8	0.059	170.9	148
18 Nissum Fjord	1	2.5	75	0.084	2986.1	1666
19 Ringkøbing Fjord	1.9	5	294	0.557	6508.7	3442
20 Grådyb tidal zone	2.6	14	138	0.235	3096.5	1798
21 Ebeltoft Inlet		16	84.4			60.5
22 Randers Fjord	1.6	7	21.6	0.034	2317.9	3260
23 Aarhus Bight	12	22	315	3.8	357.0	659.3
24 Norsminde	0.6	2	1.86	0.0011	32.2	101
25 Mariager Fjord	4.9	29	47.7	0.234	302.7	587
26 Stavns Fjord	1.8	8.7	15.6	0.0293		25.3
27 Odense Fjord	2.3	7	60.3	0.136	690.6	1057
28 Kerteminde Fjord / Kertinge Cove	1.9	7.7	8.34	0.0162	20.8	53.5
29 South Funen Archipelago	8.5	38	415	3.52	321.7	436
30 Holckenhavn Fjord	1.1	3.8	0.69	0.0008	145.1	221
31 Lindelse Cove	2.1	6.2	6.7	0.014	19.2	31.5
32 Nakkebølle Fjord	3.2	10	7.3	0.023	78.8	103
33 Helnæs Bight	5.4	15	65.6	0.353	107.2	183
34 Bredningen (the Broad)	0.5	1	0.28	0.0001	75.7	111
35 Gamborg Fjord	2.4	14	10.4	0.025	34.7	53
36 Faaborg Fjord	4.8	11.3	11.8	0.057	15.6	27.8
37 Gamborg Cove	0.8	0.8	0.208	0.0002	18.9	32.4
39 Tryggelev Cove	1.78	4.7	0.0644	0.00007	5.4	10.04
40 Nærå Beach	0.31	1	4.82	0.0015	22.1	74.6
41 Kelds Cove	0.4	1.1	1.03	0.0004	1.3	2.23
42 Tybrind Inlet	6.1	12.2	10	0.062	24.1	39.5
43 Emtekær Cove	0.5	1	0.81	0.0004	6.6	10.9
44 Skårupøre Sound	1.2	7	2.58	0.0032	5.8	9.5
45 Thurø Head	2.6	10	1.32	0.0034	1.3	2.1
46 Lunke Bight	3.8	8.4	11.1	0.04	10.7	17.6
47 Nyborg Fjord	5.29	11.6	8.37	0.0044	160.5	243.5
48 Tempelkrog	1.5	5.6	4	0.006	87.5	57.09
49 Holsteinborg Cove	0.8	4.4	7	0.0056	13.8	16.04
50 Basnæs Cove	0.8	2.5	9	0.0072	28.1	39.89

51 Skælskør Fjord	1.5	4	1.8	0.0025	14.3	17.88
52 Korsør Cove	1.8	2.5	8	0.014	23.5	29.49
53 Kalundborg Fjord	9.5	17.9	79	0.75	41.0	65.06
54 Isefjord	5.1	15.2	307	1.56	719.3	734
55 Isefjord outer Broad	6	15.2	212.6	1.214	74.5	64.52
56 Nykøbing Bight	3	6.2	12.4	0.036	26.6	36.48
57 Lammefjord	5	12.9	20	0.1	283.5	296.25
58 Isefjord inner Broad	4	11.6	42	0.168	83.5	93.38
59 Holbæk Fjord	2.6	11	14	0.036	163.5	176
60 Hjarbæk Fjord	1.9	5	25	0.047	372.8	1180
61 Halkær Broad	1	1.5	6.1	0.0081		271
62 Skælskør Cove	3	5.8	2.3	0.0067	6.3	7.91
63 Skive Fjord Lovns Broad etc.	4.9	19	151	0.748	849.2	2420
64 Flensborg Fjord	14.5	40	272	4.11	44.7	214.7
65 Haderslev Fjord	1.8	10	3.9	0.009	45.5	184.8
66 Aabenraa Fjord	23	35	31.2	0.622	21.8	82.2
67 Genner Fjord	14	23	4.48	0.054	7.4	39
68 Augustenborg Fjord	4.4	14	13.7	0.07	15.5	94.7
76 Limfjorden	4.9	28	1500	7.4	11037.6	7590

Depth of water

Depth conditions in the selected fjords vary from the very shallow fjords with depths of 1-2 m, such as Ringkøbing fjord and Norsminde Fjord south of Aarhus to the very deep ones such as Mariager Fjord (30 m) and Flensborg Fjord. Even though depths of more than 10 m are found in many fjords, such areas are often small so that the mean depths are usually significantly less.

6.3.1 **Hydrographic conditions**

Water is not just water. There can be great variations in salinity, temperature, turbidity, etc. These conditions are of great significance to the organisms which live in a specific body of water.

Salinity

In Danish waters salinity is generally least in the southern part near the Baltic and higher nearer the North Sea and the Atlantic Ocean. Salt-water is denser than freshwater and cold water is denser than warm water. Bodies of water with different salinities and temperatures will therefore have different densities. In the absence of strong winds or currents to mix them, the two bodies will tend to separate themselves so that the water nearer the bottom has no contact with the air above. The water area is said to be stratified..

In comparison with water in the open sea, the fjords are generally less saline due to the input of water from watercourses. In all fjords receiving freshwater input, there will naturally be a surplus of water which will flow towards the open sea. However, in most fjords, this volume of water is very small compared with the volumes of water flowing in and out due to tides or winds.

Temperature

As a fjord comprises a relatively small water mass, the water temperature is more a function of the air temperature than is the case with the open sea. This means that, other things being equal, the fjord waters will be colder in winter and warmer in summer.

Circulation

In a fjord the hydrography, i.e. the current patterns and physical composition of the water, is determined by three conditions in particular: the topography of the fjord, freshwater inputs and variations in water level.

It has turned out in practice that fjords and estuaries can be divided into three types depending on the relationship between freshwater run-off and water level variations due to either tide or wind.

If freshwater inputs are large and there is little variation in water level, the freshwater will be found to flow out above the salt-water, the two bodies hardly mixing. Seen as a vertical section along the fjord, the salt-water will form a wedge along the bottom. The inner part of Randers Fjord is an example of this type of fjord. In areas where the level variations are greater, the greater turbulence will lead to more mixing of the layers. As a result of this mixing with bottom water, the outflow at the surface may greatly exceed the original inflow of freshwater. To compensate for this, a mass of water equivalent to the "shortfall" must flow in along the bottom. Such a current pattern is called "estuarine circulation". Hydrographic conditions of this type can be found, for example, in the inner part of Vejle fjord.

If water level differences become relatively even greater, total mixing of the bodies of water can occur and no vertical variation will be seen. Due to the earth's rotation, the outflowing freshwater will tend to "keep right", leading to a difference in salinity between the sides of the fjord. An example of this type is Haderslev fjord. The same fjord may also change type depending on where in the fjord and at what time the classification is made.

Sill fjords

To meet the scientific definition of a fjord, a shallow sill should be found in the outer part. However, this applies only to a few Danish fjords. The effect of such a threshold is that salt-water can be trapped in the deep water inside the sill, leading to a greater tendency towards stratification than in other types of fjord. In Denmark, only Mariager, Flensborg, and Kerteminde Fjords and to a certain degree Isefjorden are sill fjords.

Shipping fairways and locks

Man-made conditions may also be of significance to the hydrographic conditions in a fjord. Shipping fairways have been dug through shallow waters in many fjords, as for example in Odense Fjord. In such a fjord, a great part of the water movements will take place in the fairways. There is also the special case where the mouth of the fjord is completely closed by a lock, as in Ringkøbing and Nissum Fjords. Here, lock practice completely determines the hydrography.

Sedimentation

The sediment in the fjords originally consists of the materials, which the rivers cut through in times past when the rivers formed the fjords. Subsequently, a superposition of material has taken place either coming from the watercourses or from contiguous sea areas or created in the fjord. Water movements determine where the different materials settle out. The mechanism at work is that only materials coarse enough not to be carried away by currents or waves are deposited in a given spot. This means that in shallow water or narrow channels, subject to wave action or strong currents, the sediment will be coarser than in deeper, calmer waters. Thus it is often only in the deeper sedimentation basins that the bed actually consists of mud, and permanent sedimentation takes place. It is possible to determine how long ago the material at a given depth was deposited. In this way it is also possible to calculate the effect on sedimentation. The annual growth rate in sedimentation areas is often between 1 and 5 mm.

6.4 Conditions and developments in the fjords

This section describes the environmental conditions in the Danish fjords and their development. It is based in particular on the fjord report of the National Environmental Research Institute (Kaas et al., 1996) and on county reports on their respective fjords. This section is broken down into individual parameters: nutrients, phytoplankton, benthic vegetation, oxygen conditions, benthic fauna, and heavy metals and contaminants are dealt with separately. The section concludes with a comparison between the planned condition of the fjords and the condition actually measured. Each parameter is introduced by a brief summary of its environmental significance, followed by a description based on county reports of the current situation in comparative table format. Finally, the different trends are discussed.

6.4.1 **Nutrients**

The Danish fjords show great variation in their nutrient contents. The current nutrient richness is a result of the balance between addition and removal of the nutrients.

As additions and removals are often out of step, characteristic annual variations in levels of the various substances will be observed. Nutrients are input from land via watercourses or through waste water outfalls, from the atmosphere or from contiguous sea areas. Inputs from earlier times can be stored in the fjord bed and participate in the turnover under certain conditions. Nutrients are removed from the fjords by permanent storing in the bed; nitrogen also by denitrification and by water exchange with contiguous sea areas. The most important nutrients, nitrogen and phosphorus, occur in two main forms. The inorganic form dissolved in water is directly available to plants, whereas the organic compounds, which are often found as particles, first need to be broken down into inorganic compounds before they can again contribute to plant growth.

Exchanges between sediment and water

Materials are constantly exchanged between sediment and the overlying body of water. Processes in the sediment are thus very significant to both the nitrogen and phosphorus budgets in a water area. The phosphorus which enters a closed body of water can only be “removed” (made biologically unavailable) by being bound in the sediment. In this manner a large phosphorus pool can develop over a number of years, which, if liberated, provides nutrition for the growth of algae. This liberation depends on temperature and oxygen content, the highest rate occurring in warm periods with low oxygen content. This is exactly the reason for the frequently observed increase in the inorganic phosphorus content in summertime. Nitrogen is not accumulated in sediment in the same manner. Nevertheless, it is a process in the sediment which is decisive for converting nitrogenous nutrients into inactive nitrogen. This process is called denitrification meaning that nitrate, which is an important plant nutrient, is converted by bacteria to free nitrogen which can only be used by a small number of organisms. Denitrification is one of the most important “self-cleansing” processes in the environment.

Nutrient inputs

The percentage distribution of types of sources of nutrient input to the fjords in 1995 is shown in Table 6.4, which also shows total inputs of phosphorus and nitrogen.

Table 6.4
Percentage distribution of types of sources of nutrient input and total inputs of phosphorus and nitrogen to selected fjords in 1995.

Fjord No. and name	Atmospheric precipitation		Diffuse sources		Point sources		Total inputs	
	%		%		%		t	t
	N	P	N	P	N	P	N	P
1 Roskilde Fjord	15	1	69	31	17	67	1935	88
2 Karrebæk Fjord	1	0	87	29	12	70	2207	57
3 Vejle Fjord	4	1	81	46	15	53	1911	75
4 Horsens Fjord	4	2	82	57	14	42	1656	30
5 Kolding Fjord	2	1	91	75	8	24	965	27
6 Dybsø Fjord	20	20	76	9	3	71	62	1
7 Guldborg Sound	11	2	75	50	14	47	926	35
8 Guldborg Sound B	12	3	83	70	5	28	324	11
9 Nakskov Fjord	8	4	87	59	5	37	594	11
11 Stege Bight	26	16	63	-8	12	91	184	3
17 Præstø Fjord	9	3	84	40	7	56	286	7
18 Nissum Fjord	2	1	88	60	10	39	2994	61
19 Ringkøbing Fjord	4	2	86	62	9	36	6710	158
20 Grådyb tidal zone	2	1	80	49	18	49	4918	115
21 Ebeltoft Inlet	44	29	54	39	2	32	211	3
22 Randers Fjord	1	0	87	58	12	42	5338	152
23 Aarhus Bight	21	5	63	29	16	66	1682	66
24 Norsminde Fjord	1	1	97	87	2	12	172	4
25 Mariager Fjord	4	2	88	64	8	34	1693	29
26 Stavns Fjord	56	48	43	37	1	16	28	0
27 Odense Fjord	3	1	84	61	13	38	2492	67
28 Kerteminde Fjord / Kertinge Cove	12	7	86	60	2	32	75	1
29 South Funen Archipelago	31	13	66	59	3	28	1297	30
30 Holckenhavn Fjord	0	0	96	87	4	13	472	10
32 Nakkebølle Fjord	4	2	95	94	2	4	215	4
33 Helnæs Bight	18	8	80	76	2	16	400	8
34 Bredningen (the Broad)	0	0	95	70	5	30	226	5
35 Gamborg Fjord	9	4	88	89	3	7	129	2
49 Holsteinborg Cove	17	4	72	18	10	78	51	2
52 Korsør Cove	13	6	84	41	3	53	80	1
53 Kalundborg Fjord	29	11	52	18	19	72	284	7
55 Isefjord outer Broad	19	9	75	42	6	49	1296	23
57 Lammefjord	3	2	93	58	4	41	806	13
58 Isefjord inner Broad	7	2	86	41	8	57	774	19
59 Holbæk Fjord	5	2	89	45	6	53	402	8
61 Halkær Broad	1	0	94	76	5	23	698	13
63 Skive Fjord, Lovns Broad etc.	15	6	170	140	14	54	2107	58
64 Flensborg Fjord	22	5	67	63	12	32	622	26
65 Haderslev Fjord	1	0	90	67	8	32	391	22
66 Aabenraa Fjord	12	2	71	35	17	36	285	13
67 Genner Bight	5	1	90	63	5	35	99	3
68 Augustenborg Fjord	5	1	89	66	6	32	316	9
73 Risgårde Broad	31	13	69	82	0	5	219	4
76 Limfjorden	8	3	86	65	6	31	19458	439

Status 1995

The nutrient enrichment status in the fjord areas is based on the county reports and shown in Table 6.5

Condition and development

Figures 6.2 and 6.3 illustrate the average time-weighted summer and winter values in the period 1989-1994. In general, nutrient enrichment is greatest and most variable in the shallow fjords. In the nutrient-enriched areas, a large proportion of the nutrients are found all year round in inorganic form immediately available to plants. In the nutrient-poor areas, the nutrients are mostly bound in organic matter in summer. The greatest nutrient enrichment, especially with respect to nitrogen, is found in Holckenhavn Fjord and Bredningen (the broad) in the Little Belt. Aarhus Bight and Kalundborg Fjord are the least nutrient-rich fjords. All the fjords are more or less nutrient-rich in comparison with the open seas.

Table 6.5
Overall review of the state of hydrochemical conditions in the theme fjords in 1995. The review is regionalised for practical reasons – for detailed information refer to the county theme reports (see Appendix 5).

West Jutland fjords	Ringkøbing and Nissum Fjords are strongly affected by nutrient inputs from land. Nitrogen input is especially high, with resultant high nitrogen concentrations. Grådyb Tidal Zone also has high concentrations of nitrogenous and phosphorous nutrient salts.
Limfjorden	There was a high nitrogen content (about 1 mg/l) in Limfjorden in 1995. Phosphorus content was also high. Mean winter values were only slightly higher than the summer values.
East Jutland fjords	In 1995, nitrogen concentrations were generally lower than the averages of 1989 to 1994. The reason is considered to be the low run-off in 1995. Phosphorus concentrations were significantly lower, the reason also being improved waste water treatment. In Aarhus Bight the mean total nitrogen concentration in all months of 1995 was higher than the average for 1983-1994, while for phosphorus it was lower for 11 months. The tendency was the same for inorganic nitrogen and phosphorus. Mariager Fjord also showed generally static or rising nitrogen and falling phosphorus content.
South Jutland fjords	In 1995, nutrient salt content did not differ significantly from the averages for 1989-1994. The phosphorus content of individual fjords was, however, significantly lower towards the end of the year.
Funen fjords and coves	Odense Fjord showed falling concentrations of the annual average of inorganic phosphorus, and of the summer average of inorganic nitrogen due to improved waste water treatment. The levels are, however, still higher than in the surrounding waters. From time to time very high nutrient concentrations are measured in summer as a result of overflows from sewer systems and of liberation from sediments. In the South Funen Archipelago, the inorganic phosphorus concentration has fallen in winter, without any changes in the nitrogen levels. The level here is also higher than in the surrounding waters. This is also the case for Kertinge Cove, where the phosphorus levels have been falling. In all three areas, high run-off resulted in unusually high nitrogen concentrations in the spring of 1995.
North Zealand fjords	Roskilde Fjord had the lowest phosphorus content in the southern part since measurements began in 1972. On the other hand, nitrogen concentrations in the same area were higher than normal, enabling the plants to take up much phosphorus. Isefjorden had a high nitrogen but low phosphorus nutrient salts content in the winter of 1995.
West Zealand fjords and coves	Kalundborg Fjord has high nitrogen and phosphorus contents, while those in Korsør Cove are low. The reason is that all waste water discharges to Korsør Cove ceased at the end of 1994.
South Zealand fjords	The 1995 nitrogen content of Præstø Fjord was slightly higher than before. The phosphorus content does not differ from previous measurements. The nutrient salt concentrations in Stege Bight are of the same order as those in the contiguous open waters and lower than those in the other fjords.

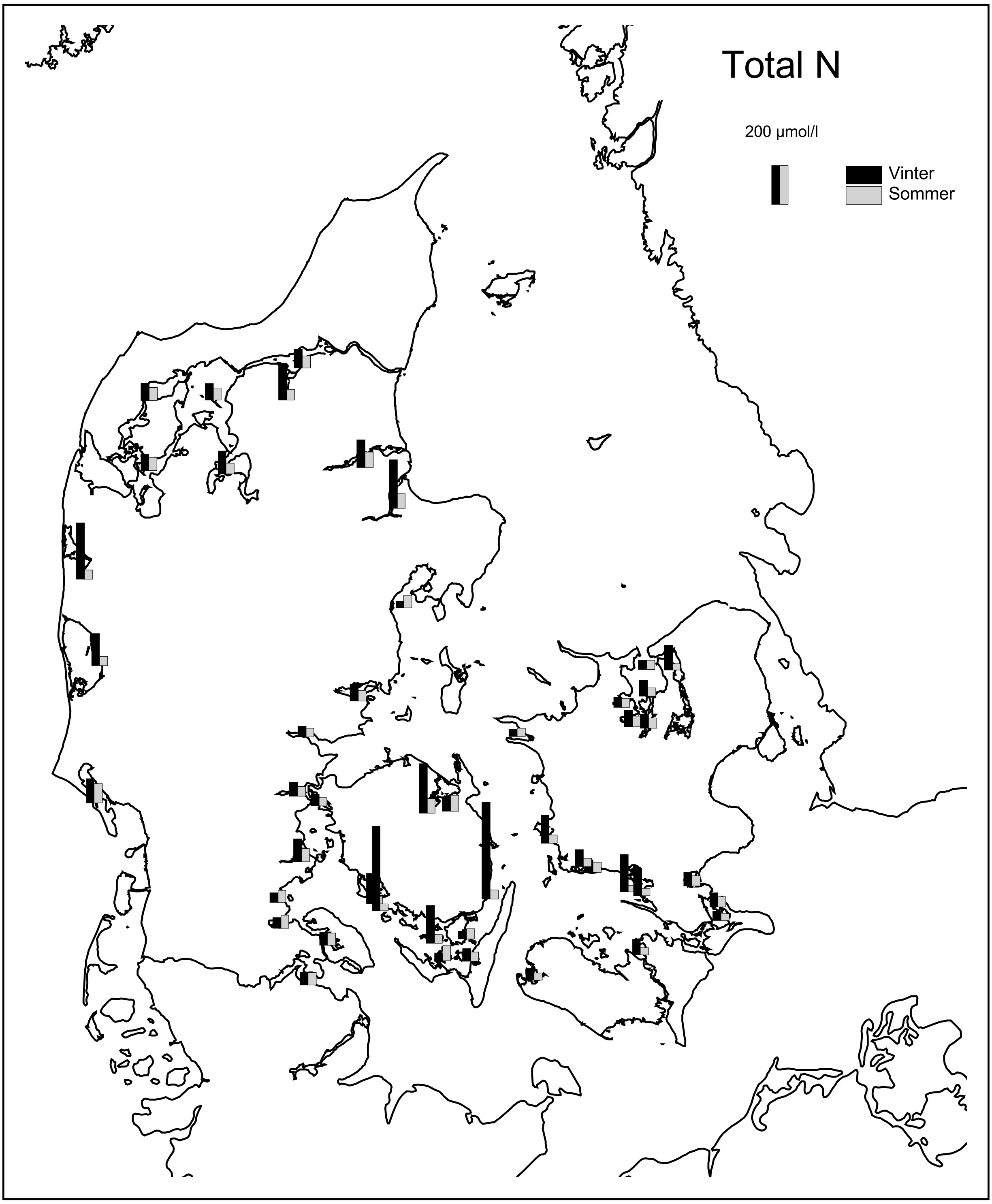

Figure 6.2
Nutrient content of Danish fjords expressed as averages of time-weighted mean values of total nitrogen for summer (May-September incl.) and winter periods (December-February incl.) in the years 1989 to 1994 (from Kaas et al., 1996).

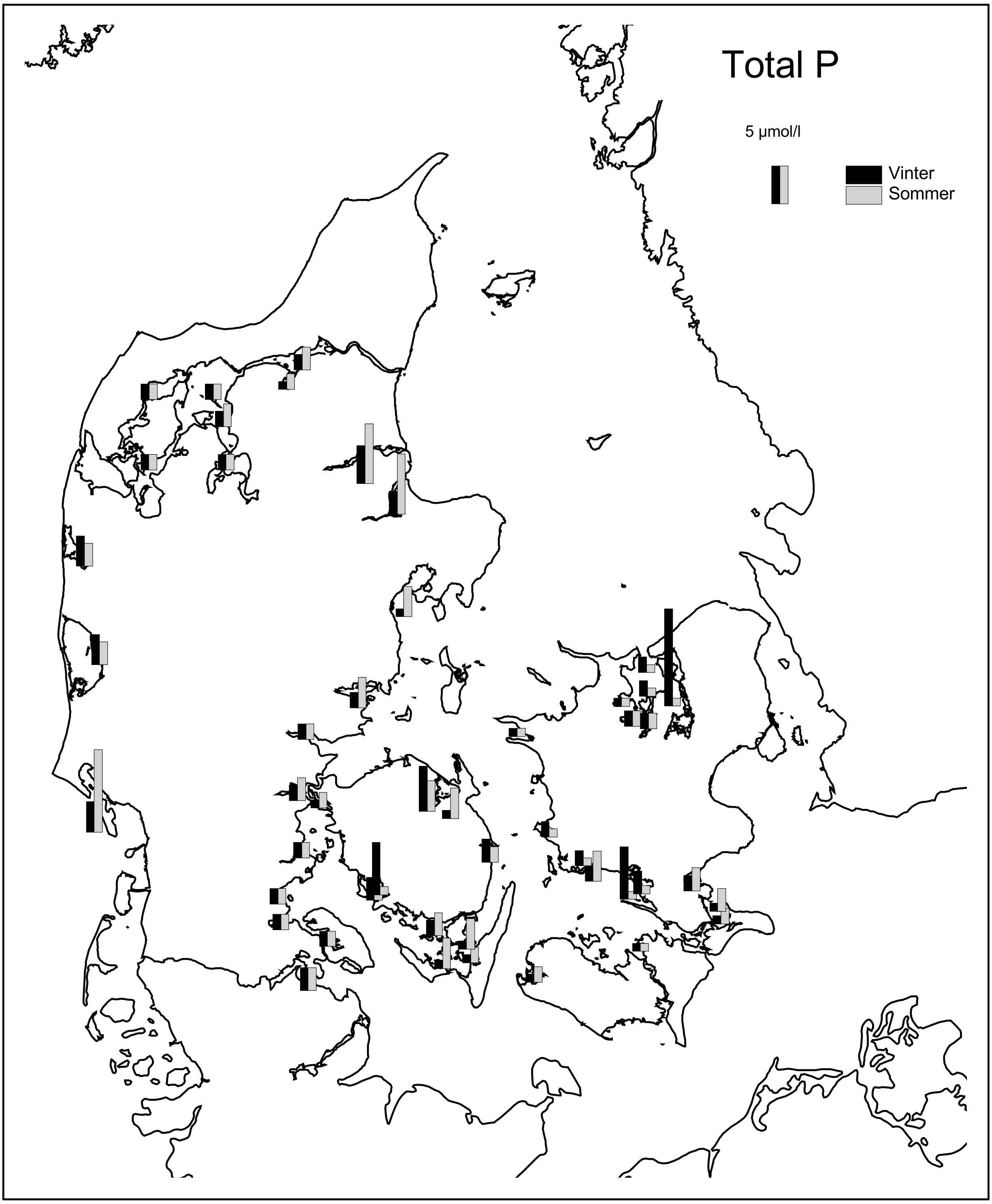

Figure 6.3
Nutrient content of Danish fjords expressed as averages of time-weighted mean values of total phosphorus for summer (May-September incl.) and winter periods (Individual ind-February incl.) in the years 1989 to 1994 (from Kaas et al., 1996).

Annual variations Nutrient concentrations in the water vary during the year. Figure 6.4 illustrates the seasonal variation as the average of 33 fjords. It will be seen that the concentrations of both nitrogen and phosphorus are high in winter because of high freshwater run-off and low consumption. At this time of year, most of the nutrients are in the form of inorganic compounds. Concentrations fall in spring as run-off decreases and nutrients are taken up by plants. Phosphorus levels rise again in summer as inorganic phosphorus is liberated from the fjord bed. As there is no corresponding increase in nitrogen inputs, its concentration falls to the level where the increased phosphorus content cannot be utilised.

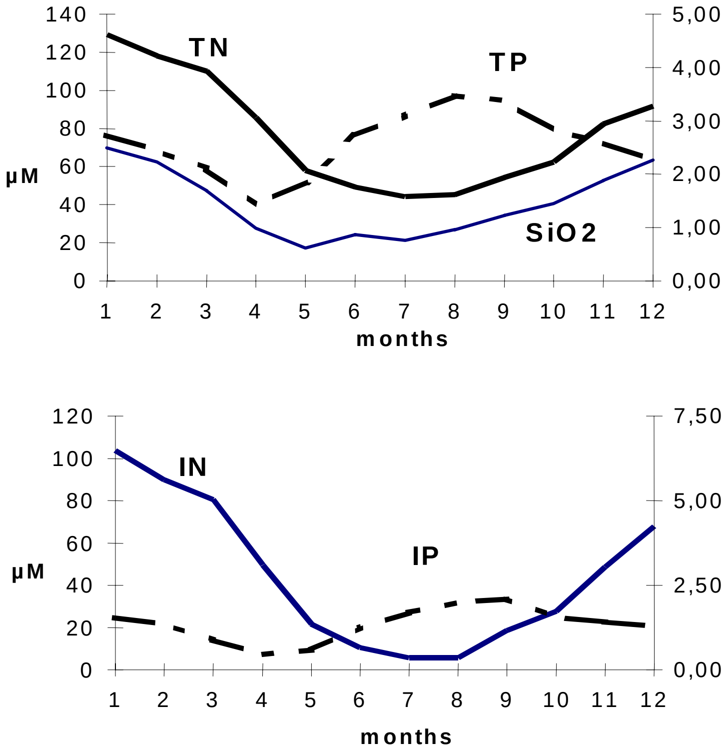

Figure 6.4
Annual variation in nutrient concentrations in Danish fjords. Average values of A: total nitrogen (TN), silicate (SiO2), and total phosphorus (TP) and B: inorganic nitrogen (IN), inorganic phosphorus (IP) in 33 Danish fjords 1989-1994. Right-hand axis gives phosphorus concentrations and left-hand nitrogen and silicate contents (from Kaas et al., 1996).

Phosphorus concentrations have fallen in many fjord areas. This applies to winter concentrations of both total and inorganic phosphorus and to summer concentrations of inorganic phosphorus. The reduced phosphorus discharges as a result of improved waste water treatment has also had a marked effect in many fjord areas.

To examine whether loading from land really is the most significant reason for nutrient enrichment in Danish fjord areas, the National Environmental Research Institute has carried out a statistical analysis. This analysis shows that nitrogen loading can in fact explain a great deal of the variation in nitrogen levels, but that there is not the same degree of correlation between phosphorus loads and phosphorus concentrations in the water. If the individual seasons are analysed separately, it appears that the correlation is greatest for nitrogen in winter and least in summer. The reason is, as mentioned before, that in winter the nitrogen concentration is not affected by uptake by plants. The correlation is also shown to be best in shallow fjords.

6.4.2 **Phytoplankton**

Phytoplankton is the most important food source for a range of organisms in marine areas. At the same time, large plankton masses can outshadow other plants or even secrete toxins. Large amounts of oxygen can also be consumed in the decomposition of planktonic algae. The amount and growth of phytoplankton is therefore an important environmental parameter.

Background

In Danish fjords and coastal waters, the biomass of phytoplankton varies between 0.05 and 50 mg/l of carbon. Primary production is typically between 20 and 2,000 mg C/m²/day. The reason that there is not as great a variation as in the production of algae is presumably that the algae begin to shade each other when they occur in very large numbers. The amount of algae can be estimated by measuring the amount of chlorophyll in the water. However, it is the carbon content that is of interest. As a rule of thumb, it can be said that there is 40 times as much carbon as chlorophyll in planktonic algae, which need enough light and nutrients to grow. If even one growth factor is missing, the growth will stagnate. As a rough estimate, it is often considered that if the combined concentration of nitrite and nitrate is under 14 µg/l or the concentration of inorganic phosphorus is less than 2 µg/l, then it is the amount of nutrients which limits algal growth. Studies of nutrient concentrations and experiments with enriched nutrient levels have shown that in most areas the amount of nitrogen available is the limiting factor. Planktonic algae growth starts in spring when light levels are sufficient. At this time there are as a rule sufficient nutrients available as a result of winter run-off. Usually the various species of diatoms bloom first. The algal mass often falls again later, partly because all nutrients are consumed and partly because the algae are eaten by bivalves (shellfish) and copepods (water fleas). During the summer, sudden short-lived increases in algal masses to very high levels can often be observed. From time to time, toxic species trigger these massive blooms.

Status 1995

The phytoplankton status of the fjord areas based on county reports is shown in Table 6.6.

Table 6.6

Overall review of the state of phytoplankton conditions in the theme fjords in 1995. The review is regionalised for practical reasons – for detailed information refer to the county theme reports (see Appendix 5).

West Jutland fjords	The amount of planktonic algae is extremely high in Ringkøbing and Nissum Fjords. Blue-green algae predominate in Ringkøbing Fjord, but a bloom of diatoms was also observed in the spring of 1995. In Grådyb tidal zone, the highest chlorophyll concentrations to date were measured in 1995. Nutrient salts are only exceptionally limiting factors.
Limfjorden	1995 was characterised by large masses of phytoplankton, especially the occurrence of dinoflagellates. There were more mass blooms than in the previous 4-5years.
East Jutland fjords	Horsens and Vejle Fjords were characterised in 1995 by unusually few planktonic algae. For this reason the water was also clearer than normally. There were individual very strong algal blooms in Kolding Fjord, which meant that the annual average algal mass was no lower than normally, nevertheless the water was still clearer than previously. The amounts of planktonic algae in Aarhus Bight were less than the averages over previous years for most of the year, but with an extremely large amount measured in spring. The dominant species was a colony-forming flagellate (Phaeocystis). Plankton production is extremely high in Mariager Fjord compared with other Danish marine areas. 1995 was no different from previous years.
South Jutland fjords	Water in the South Jutland fjords was generally much clearer in 1995 than in previous years. By the same token, algal mass and production were low.
Funen fjords and coves	The amounts of planktonic algae measured in Odense fjord were higher than previously, but still lower than in contiguous waters. The rise was due in particular to summer blooms of small green algae. In the South Funen Archipelago, both plankton levels and production were unusually low in 1995, with the greatest Secchi depth to date of 12 metres being measured. The phytoplankton mass in Kertinge Cove was

	also low, while production was at the same level as previously. The plankton mass is thought to have been kept down by filtering bivalves.
North Zealand fjords	Mass occurrences of planktonic algae were registered in Roskilde Fjord and Isefjorden from March to October. Production and biomass were very high, with correspondingly low Secchi depths.
West Zealand fjords and coves	In 1995, both algal mass and production were lower in Korsør Cove than previously. Nitrogen was thought to be the main limiting factor here, as well as in Kalundborg Fjord.
South Zealand fjords	Præstø Fjord only contains minor amounts of phytoplankton, but a single extremely large bloom was seen in August 1995. It is not known which species were involved. There are only occasional limiting nutrient (nitrogen) conditions in Præstø Fjord. There were potential limiting nitrogen conditions in Stege for long periods in 1995. Phosphorus is not a limiting factor in the South Zealand fjords.

Conditions and development

The amounts of phytoplankton in Danish waters are shown in figure 6.5. The figure shows the time-weighted averages of the chlorophyll biomass in spring, summer, autumn and the whole growing season. The highest biomasses are found in Ringkøbing and Nissum Fjords, both of which have water changes controlled by locks so that retention times are very high. This means that, even though loading is not particularly high, there is a high turnover of the input nutrients in the fjord itself. There are also low occurrences of bivalves and other organisms to filter out the algae. The lowest biomasses are found in Lindelse and Holsteinsborg Coves. The reason is partly that there is a relatively low nutrient loading in these areas and partly that the nutrients are utilised by large amounts of benthic flora. Apart from Nissum and Ringkøbing Fjords, the highest summer biomasses are found in the deepest fjords.

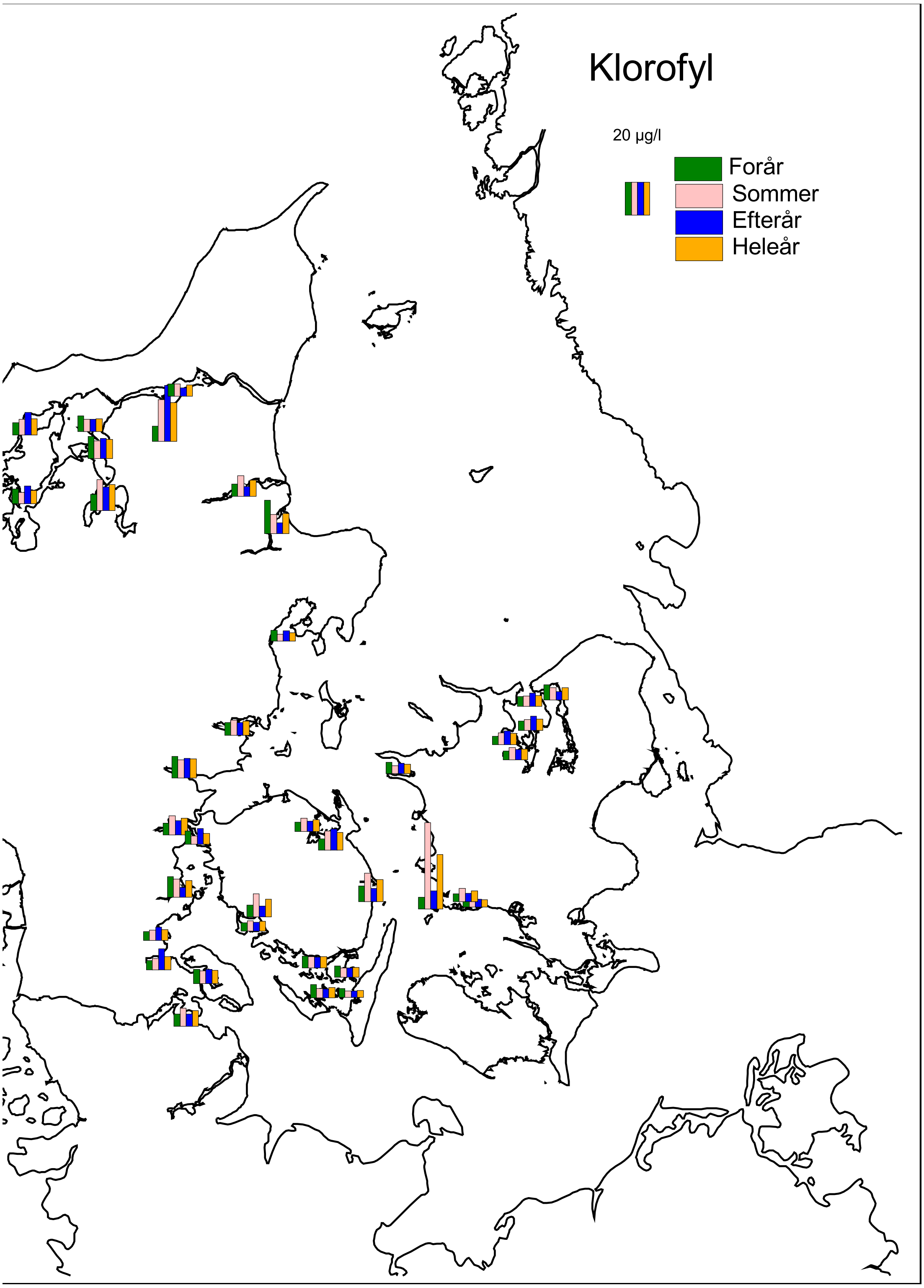

Figure 6.5
Annual (March-October incl.), spring (March and April), summer (May-September incl.) and autumn (October and November) chlorophyll concentrations in Danish fjord waters expressed as time-weighted seasonal averages in the period 1989 to 1994. Data for all years are not available for some fjords (from Kaas et al., 1996).

Primary

While the biomass is a measure of the amount of algae present at a given time, the primary production is *production* an estimate of the instantaneous rate of growth of the algal mass. A situation can easily be imagined where high growth is measured, but because the algae are eaten or disappear by other means, a large biomass is never built up. Mean values of primary production in summertime in Danish fjords are shown on Figure 6.6.

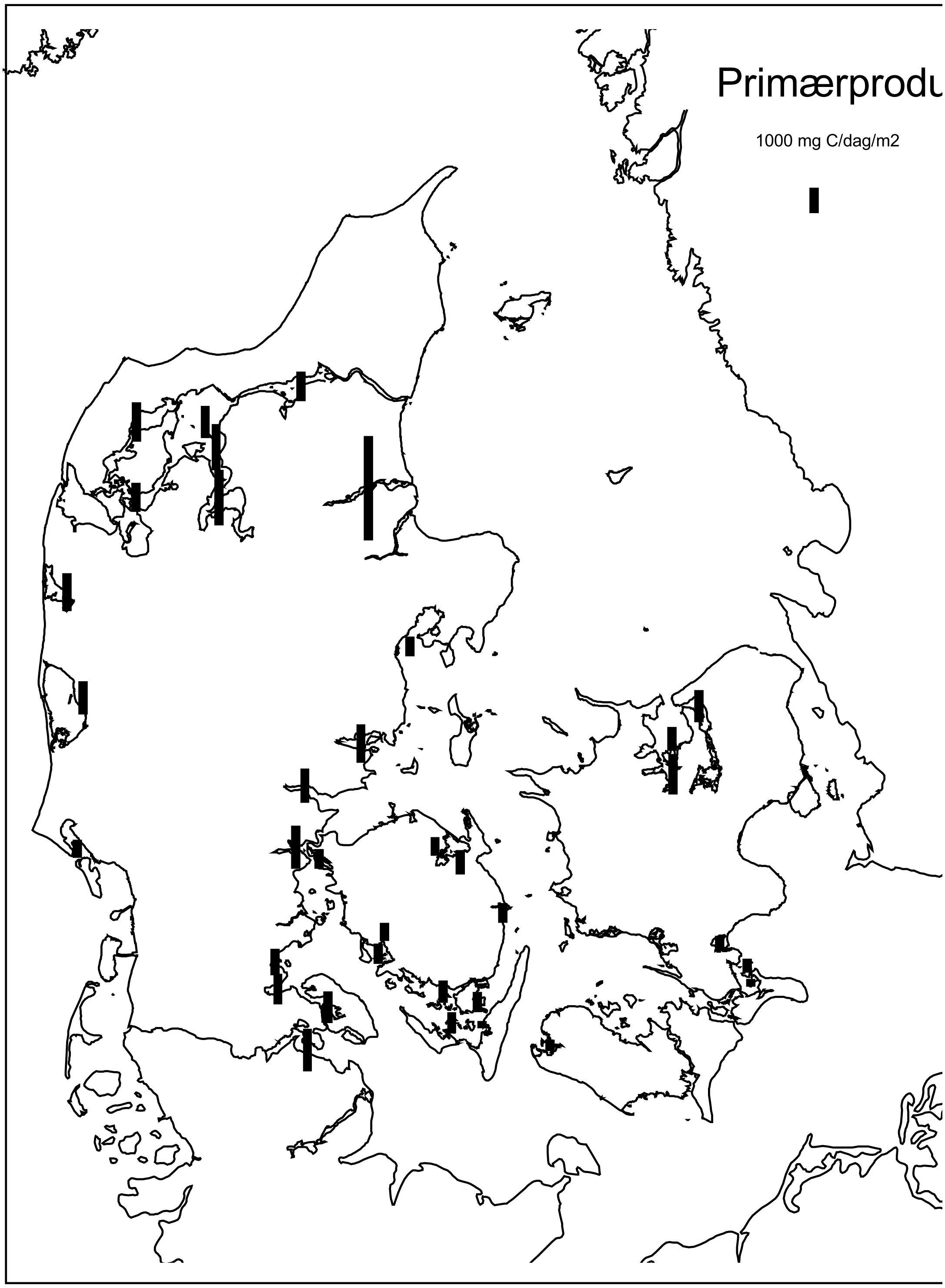

Figure 6.6

Primary summer production in Danish fjords expressed as average of time-weighted mean values for the years 1989 to 1994 (from Kaas et al., 1996).

Composition of species

The different species of algae require different environments. For this reason, they will often occur in a characteristic annual rhythm. Figure 6.7 illustrates the proportions of the different species over the year. In spring, diatoms are usually the first to be able to take advantage of the increasing light intensity. Diatoms and dinoflagellates supplant each other over the summer alternately as the dominant algal groups. In autumn, large dinoflagellates such as various ceratium species often predominate. In Ringkøbing and Nissum Fjords the picture is somewhat different, in that the plankton populations are here dominated in summer and autumn periods by blue-green algae.

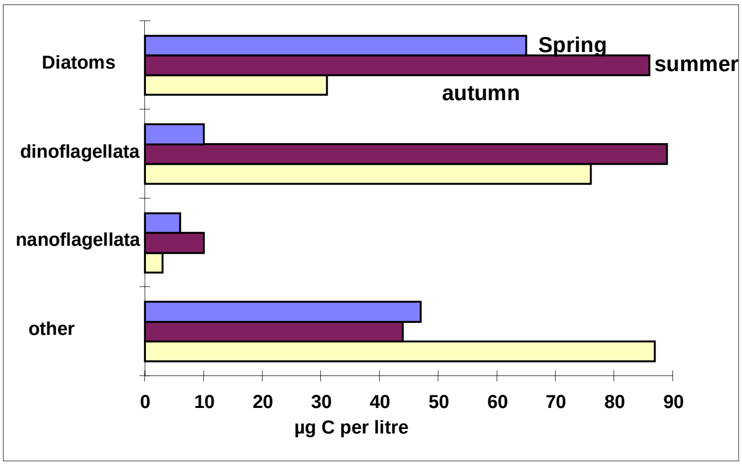

Figure 6.7
Average carbon biomasses of various algal groups in spring, summer and autumn. Data from 32 Danish fjords from 1989 to 1994 are used (from Kaas et al., 1996).

Secchi depth

It has previously been shown that to a high degree the algal mass in the water determines how clear it is. Average Secchi depths in Danish fjords vary from 0.4 to 8.7 metres. The lowest value is found in Ringkøbing Fjord and the highest in Aarhus Bight.

Plankton and nutrient enrichment

The National Environmental Research Institute has undertaken statistical analyses to study which variables are most significant to the growth of planktonic algae and biomass. It was not possible to establish any correlation between algal growth rate and the variables studied. The reason for this is that measurements of growth rates are uncertain compared with the other variables. This was not the case with the biomass studies. Biomass was related to fjord depth, degree of mixing, amounts of algae-eating benthic fauna, nitrogen loading and phosphorus loading. It turned out that algal mass can be explained by the fjord mean depth, amount of algae-eating benthic fauna and nitrogen loading. It is evident that high mean depth has a negative effect on the amount of algae, because the large mass of water “dilutes” the growth which can only take place at the upper levels where there is enough light. The analysis stresses that the nitrogen loading is highly significant to the algal mass in the fjords, but also that algae-eating benthic fauna can check algal growth to some extent.

Based on knowledge of the significance of nitrogen loading to the amount of planktonic algae, the National Environmental Research Institute has calculated what a reduction in nitrogen loading would mean to fjords with various depths and differing populations of plant-eating bivalves. The results are shown in Figure 6.8. It turns out that there is a large effect on the mass of phytoplankton if the amount of nitrogen nutrients is reduced. Thus the algal mass is reduced by approx. 25% for each halving of the nitrogen loading.

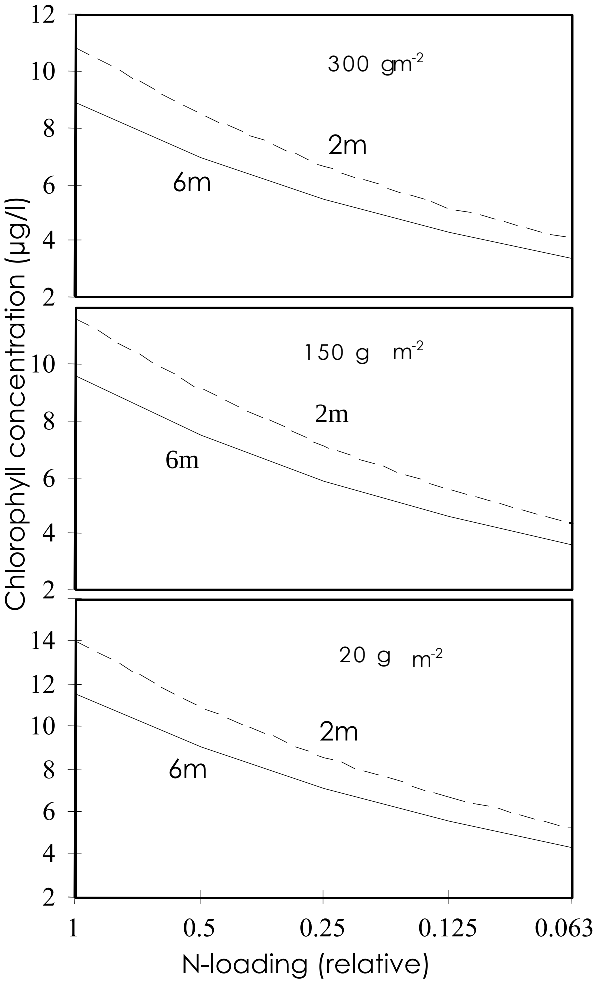

Figure 6.8
Effect of reduced nitrogen loading on summer chlorophyll concentration in two hypothetical fjords with differing mean depths and different populations of filtering bivalves. The horizontal axis represents the relative summer loading averaged for 42 fjords (from Kaas et al., 1996).

6.4.3 **Benthic flora**

The sedentary vegetation of the fjords consists partly of rooted flowering plants such as eelgrass and sea grass, partly of a rich variety of algal vegetation attached to a fixed substrate, e.g. stones. The flora distinguishes itself from a monitoring point of view by being long-lived and therefore able to provide information about environmental conditions over a relatively long period before the investigations.

Background

Eelgrass is the most important benthic plant in Danish fjords, occurring on sand and mud beds in the form of extensive “meadows”. It is an important food for a number of waterfowl and refuge for fish fry. The occurrence of eelgrass depends on a suitable substrate and sufficient light. It is rarely found in waters less than 1 metre deep because of wave action. Its depth range is determined by light, i.e. the greater the turbidity, the lower the maximum extension will be. In Danish fjords the depth limit lies between 2 and 6 metres. Eelgrass can propagate by a side-shoot spreading into new areas. By this means, a colony can spread by about 16 cm in a year. Propagation can also be by seeds spreading and sprouting where no colony existed before, but the seedlings are very sensitive to poor light conditions and are easily pulled up from the bed by waves and currents. If eelgrass disappears from an area due to oxygen depletion or poor light conditions during algal blooms, a vicious circle may initiate as the eelgrass contributes to stabilising the bed so that it is not easily stirred up by currents or waves. Once it has gone, the water can become more turbid and it becomes more difficult for new colonies to become established.

In areas with stone beds, flora is dominated by various algal species. Their depth distribution is also determined by the amount of light. As the different species have different light requirements, a zoning can be observed from shallow to deeper water. Near the coast where the light is stronger, green algae such as enteromorpha are often found. The brown algae bladder wrack and serrated wrack also grow here. Further out, other varieties of brown algae predominate. Finally, the deepest areas are home to various red algae.

In areas with high nutrient inputs, strong blooms of pollution-tolerant algal varieties are often seen, either in the form of small filamentous brown algae, ‘fatty muck’, or various green algae such as sea lettuce or horsehair wrack. These algae can grow while drifting in the water. If they are washed up on the shore or driven together in too thick layers, they may rot and cause odour problems. In other areas the phytoplankton benefits instead from elevated nutrient supplies, leading to greater turbidity and increased risk of oxygen depletion.

The sedentary vegetation as opposed to the planktonic algae is adapted to conditions of relatively low nutrient levels in the water. The benthic flora has a large biomass, is long-lived and breaks down slowly, thereby contributing to removal of nutrients from the water. Even in nutrient-poor areas, the primary production of benthic flora may exceed that of phytoplankton in nutrient-rich waters.

Status

The benthic flora status of fjord areas based on county reports is shown in table 6.7.

Table 6.7

Overall review of the state of benthic flora conditions in the theme fjords in 1995. The review is regionalised for practical reasons – for detailed information refer to the county theme reports (see Appendix 5).

West Jutland fjords	There was great increase in the amount of setaceous-leaved pondweed in Ringkøbing Fjord in 1995. The reason was low salinity in spring. On the other hand, eelgrass has nearly disappeared, partly for the same reason, but also to a high degree because of high turbidity. Eelgrass has completely disappeared from Nissum Fjord as a result of low salinity in spring. The average depth limit of vegetation in Ringkøbing Fjord was approx. 0.8 m and in Nissum Fjord approx. 1 m. Grådyb Tidal Zone is characterised by a rising amount of drifting pollution-tolerant green algae.
Limfjorden	1995 was a bad year for vegetation in Limfjorden. The depth limit for the main growth of eelgrass averaged about 2.5 metres. The biomass is also modest compared with previously. It is thought that especially poor light conditions as a result of large numbers of planktonic algae were to blame. Saragasso weed, first found in Denmark in 1984, has now spread to almost all of Limfjorden, where in some places dense colonies exist.
East Jutland fjords	Large occurrences of pollution-tolerant filamentous algae were found in the inner part of Horsens Fjord in 1995, in some places covering up to 80% of the fjord bed. In the central part of the fjord, the depth limit of the main area of eelgrass was scarcely 2 m. Its spread may be limited by intensive mussel fishing. Filamentous algae also occurred in the inner parts of Vejle and Horsens Fjords, covering up to 50% of the Fjord bed. Eelgrass had depth limits between 1.5 and 5 m. In one part of Kolding Fjord where eelgrass had previously disappeared, sprouting plants were observed. In all fjords, it was presumably the occurrence of suitable substrates that limited the depth limits of the fixed macroalgae. The depth limit of the main growth of eelgrass in Aarhus Bight was 4 – 6 m.
South Jutland fjords	In the South Jutland fjords the depth limit for the main extension of eelgrass was between 3 and 4 metres. There were mass outbreaks of pollution-tolerant filamentous algae, mainly brown filamentous and horsehair wrack in all the fjords in 1996.
Funen fjords and coves	An extensive growth of sea-grass was found in the inner part of Odense Fjord in 1995. A thin spread of sea lettuce was also found at Seden Beach, covering up to 75% of the bed. The depth limit of eelgrass in the inner parts of the fjords was between 1.6 and 2 m. The amount was very sparse, between 0.6 and 1.3 m, possibly because of grazing by swans. In the outer part of the fjord the depth limit for the main growth of eelgrass was 3.6 m. In 1995, the South Funen Archipelago was dominated by a massive spring bloom of filamentous brown algae. Due to oxygen depletion, eelgrass was reduced in extent by 70-80% in the 2-6 m depth range compared with 1994. The depth limit for the main growth of eelgrass was about 6 metres. In Kertinge Cove, the spring brought extensive mats of filamentous algae and benthic microalgae. There was a partial re-establishment of eelgrass during the summer.
North Zealand fjords	Many parts of Roskilde Fjord were 100% covered by pollution-tolerant filamentous algae. The depth limit for the main growth of eelgrass was about 3 m in the outermost parts of the fjord and 1 m in the inner part. Vellerup Inlet in Isefjorden was up to 100% covered by pollution-tolerant filamentous algae in 1995. In the outer reaches the coverage was up to 50%. There was very little eelgrass in the outer reaches of Isefjorden in 1995, while the depth limit for the main growth of eelgrass was about 3 m.
West Zealand fjords and coves	In 1995, there were significant occurrences of drifting mats of pollution-tolerant filamentous algae in Korsør Cove. In the inner part of Kalundborg Fjord the extent of algae is affected by nutrient inputs and elevated temperatures due to warm cooling water from the Asnæs power plant.
South Zealand fjords	Very dense growths of pollution-tolerant filamentous algae were found in Nakskov Fjord in 1995. The depth limit of the main spread of eelgrass was reduced to 3.7 m. Dense growths of pollution-tolerant filamentous algae were found throughout Præstø Fjord. The dominant plant in Karrebæk Fjord was sea lettuce. Stege Bight also suffered massive occurrences of pollution-tolerant species. However, eelgrass was the dominant plant whose depth limit is determined by the depth of water, which only exceeds 3 m in the fairways. In Dybsø Fjord the flora in low waters was

	dominated by pollution-tolerant filamentous algae.

Status and development of eelgrass

The depth limit of eelgrass has been studied in a number of fjords. The results of this study are shown in Figure 6.9. The depth limit varies from 0.8 m in Ringkøbing fjord to approx. 6 m in Aarhus Bight.

Depth limit of the maximum extent of eelgrass 1989-1994

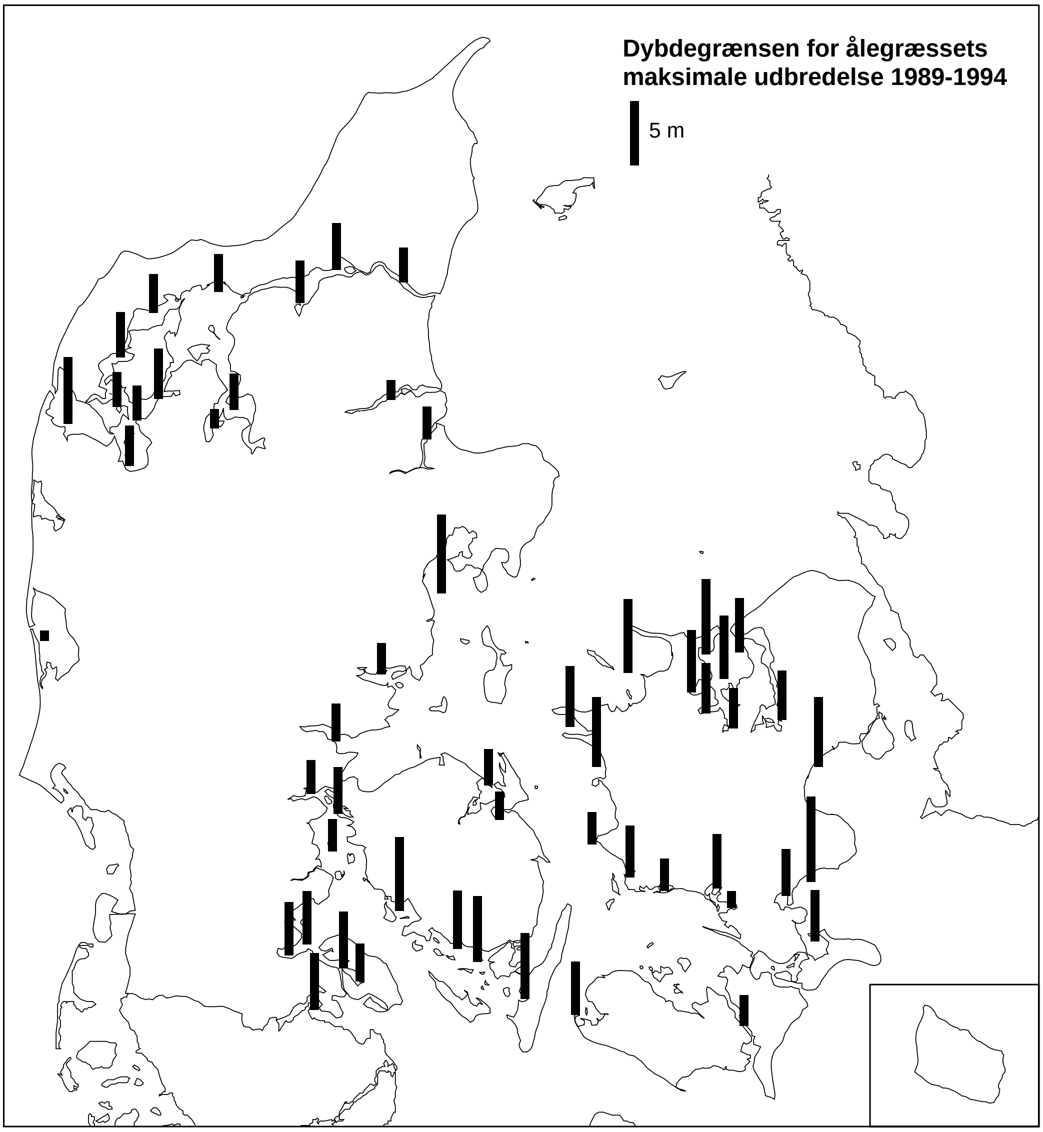

Figure 6.9

Depth limit of the maximum extent of eelgrass in Danish fjords. Averages of data from 1989 to 1994 (from Kaas et al., 1996).

Since the beginning of the century, the extent of eelgrass in Danish waters has dropped sharply. This applies both to the depths at which eelgrass grows and the extent of areas overgrown with eelgrass. There are several reasons for this retrogression. In the 30s eelgrass was hit by a disease and later pollution with nutrient salts caused reduced light conditions. Reductions in depth limits have been greatest in the fjords, which have also been most affected by changes in nutrient inputs. Figure 6.10 shows the reduction in eelgrass depth limits from the beginning of the century to date. In certain areas this depth limit has actually been halved. It is not known when the most rapid retrogression occurred, as regular studies were not made previously. In Randers Fjord, however, it is known that a rapid reduction occurred between 1955 and 1975. In Nissum Fjord it happened between 1966 and 1983.

Reduction in eelgrass depth limits (m)

Figure 6.10
Reduction in eelgrass depth limits from the beginning of the century to date (from Kaas et al., 1996).

From the early 1970s till the mid-1980s, vegetation conditions worsened further in many places. Thereafter, conditions were more stable for a period. 1994 and 1995 have again brought rapid reductions in eelgrass colonies in many places. In the South Funen Archipelago, the area covered with eelgrass was reduced by 70-80% in the 2-6 m depth band. In 1994 the water temperature in the area reached nearly 25 °C, and at the same time the highest oxygen depletion to date was measured. After the oxygen depletion, a powerful algal bloom occurred, leading to the water being extremely turbid for a time. In 1995 an extensive re-establishment of eelgrass was noted in some of the affected areas, while others still only contain dead, black eelgrass remains. Other areas have also been hit by reductions in eelgrass in recent years. Table 6.8 shows the trend in several areas.

Table 6.8
Trend of eelgrass colonies in areas hit by reductions in the 1990s. Key: -- : Elimination in one or more transections, - : Reduction, 0 : Unchanged, + : Growth, ++ : Re-establishment to pre-1992 level, ? : not studied.

Location	1992	1993	1994	1995
Limfjorden generally	+	+	-	-
- South-west of Mors	-	+	-	
- Løgstør Broad	-	-	0	
- Nibe Broad	-	-	-	-
- Langerak	-	-	0	
Randers Fjord	--	0	0	?
Hevring Bight	-	?	-	?
Kolding Fjord, Gudsø Inlet	--	0	0	+
Haderslev Fjord, outer part	-	-	-	+
Genner Fjord, inner part	-	+	+	--
Als Fjord, inner part	--	-	-	
Augustenborg Fjord	--	0	-	+
Flensborg Fjord, Brunsnæs	-	+	-	-
Odense Fjord, north-west	--	+	+	+
Kertinge Cove	-	0	-	+
Gamborg Fjord	--	0	+	+
Helnæs Bight	0	--	0	0
Tetens Ground	--	+	+	++
South Funen Archipelago	0	0	--	-
Køge Bight	-	0	-	-
Roskilde Fjord, inner part	-	+	-	-

The spread of eelgrass can be characterised by how densely it grows and the depths at which it occurs. It appears that the density is in an almost bell-shaped distribution over the depth intervals where it grows. The greatest density is found in the 1-2 m depth band, Figure 6.11. This bell distribution indicates that several factors affect the pattern of spreading of the eelgrass.

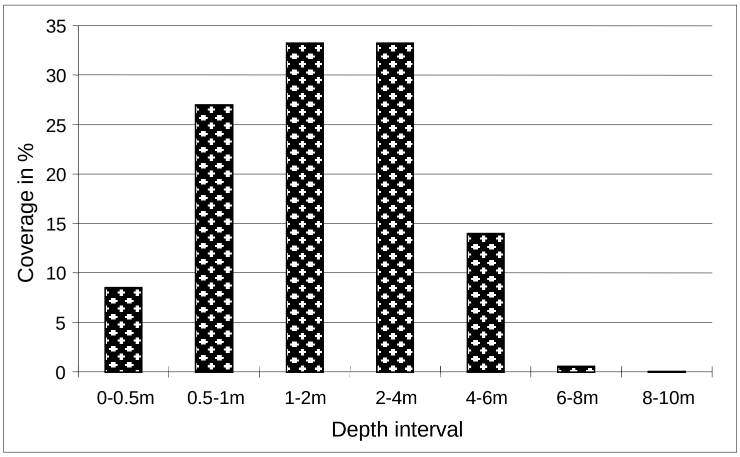

Figure 6.11
Eelgrass density in different depth bands (after Kaas et al., 1996).

There is a well-known inverse correlation between the concentration of nitrogenous nutrients in the water (and hence turbidity) and the eelgrass depth limit, but factors which affect occurrences within the depth bands have not been studied so far. The National Environmental Research Institute has undertaken statistical analyses to show which factors are at work at different depths and over the whole interval. This analysis shows that the light conditions and degree of exposure (wave action) are the most important factors, while the effects of the gradient and composition of the bed are less significant. In shallow water there is always enough light for eelgrass to grow, i.e. the amount of light is not significant here. Moving towards deeper water, light becomes a limiting factor for the growth of eelgrass and thus the most important parameter for regulating the eelgrass. The opposite applies to wave action, which is most significant in shallow water. In very shallow water, the extent is determined by other factors such as ice scouring, drying out at low tide, and grazing by birds.

Status and development – algae

The number of macroalgal species in Danish fjords is shown in Figure 6.12.

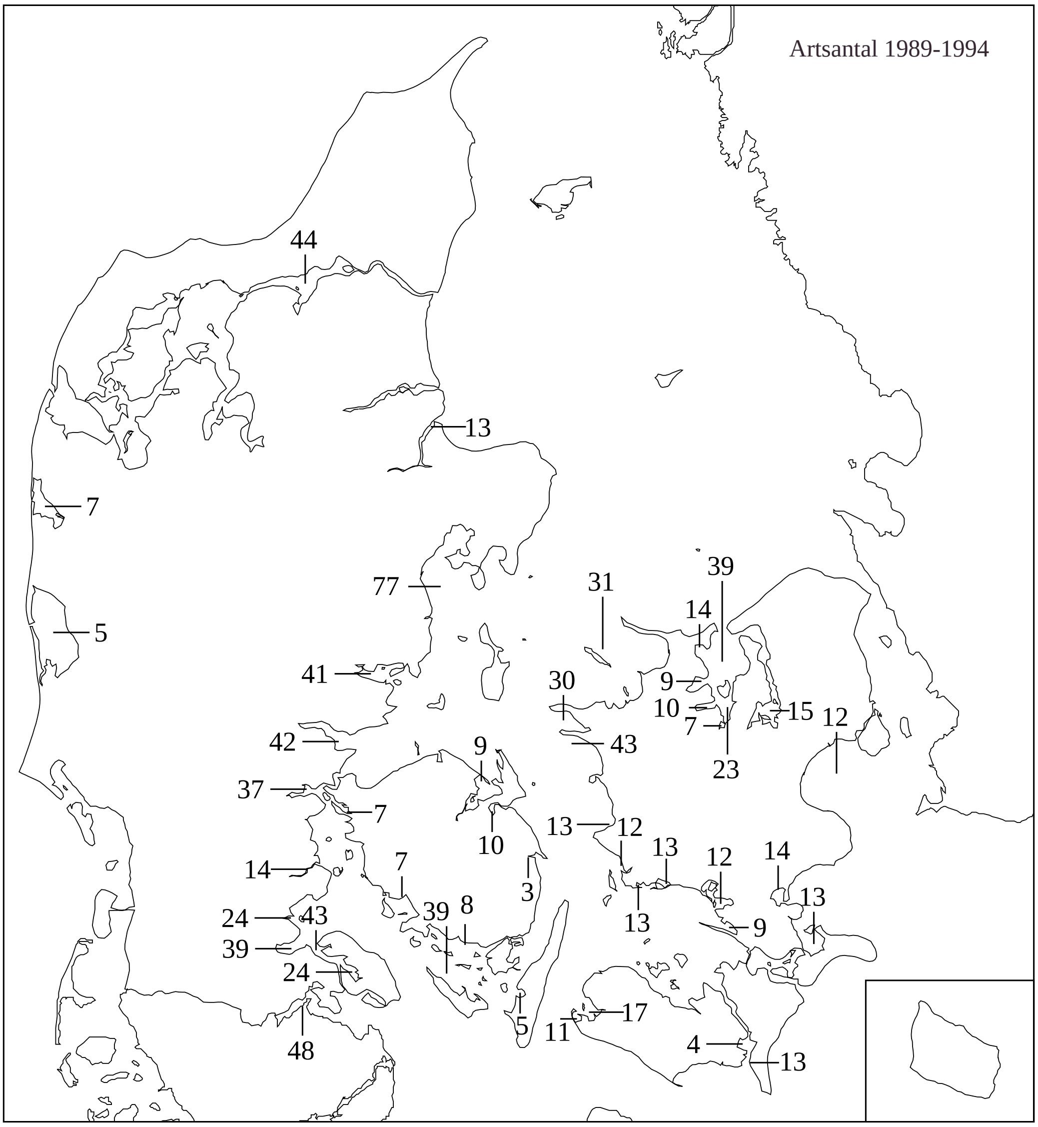

Figure 6.12
Numbers of species of macroalgae (green, brown and red algae) in Danish fjords. Averages of data from 1989 to 1994 (from Kaas et al., 1996).

Numbers of species 1989-1994

Diversity of species

Traditionally, a great diversity of species has often been associated with good environmental conditions. In fjords and fjord mouths it is often the case that the number of macroalgal species and marine organisms generally decreases from the mouth inwards. The reason for this is often given as the decreasing salinity, which then can also explain the difference in numbers of species between Kattegat with approx. 318 species and the waters around Bornholm with about 79. The National Environmental Research Institute has undertaken statistical analyses to examine whether the diversity of macroalgal species in fact correlates with environmental conditions. The analyses were done partly for whole fjords and partly for the individual sampling stations separately. This analysis has shown that the mean depth of the fjord has the greatest positive correlation with the number of species, and that also the volume, salinity, coastal length and area have positive influence on the number of species. On the other hand, there is a negative correlation with the nitrogen and phosphorus loading. The different varieties are known to prefer different light conditions, leading to a zoning from shallower to deeper water. Obviously, the deeper the water, the more depth bands can occur in a fjord. Besides, there is a tendency for salinity to be greatest in the deepest fjords, so it is not surprising that the deeper fjords exhibit more diversity of species. It is similarly known that the greater a given area, the more likely it is that a given species can occur and thrive in the area. Against this background, it is natural that the fjord area, volume and coastline have positive influences on the number of species found. By filtering out the effects of these factors, it can be determined that the number of species falls on average by approx. 2 when the inorganic nitrogen content rises by a factor of 2.7.

Benthic flora and nutrient enrichment

Within the framework of the HAV-90 research programme attempts have been made to assess what effects the implementation of the Action Plan for the Aquatic Environment would have on the flora. The Plan's target of a 50% reduction in nitrogen inputs to the aquatic environment would typically bring about a reduction of 40% in nitrogen concentration in heavily polluted areas and of 20% in less polluted areas. The consequences for the flora are described in Table 6.9.

Table 6.9

Examples of changes in phytoplankton masses and benthic flora depth limits resulting from reductions in nitrogen concentration (Christensen, P. B. (ed.), 1996).

	Heavily polluted area			Lightly polluted area		
	Before	After	% change	Before	After	% change
Total nitrogen (µg/l)	1500	900	-40	400	320	-20
Phytoplankton (µg chlorophyll/l)	17.8	10.3	-42	4.3	3.4	-21
Eelgrass depth limit (metres)	1.7	2.5	+47	4.6	5.4	+17
Brown algae depth limit (metres)	1.0	2.0	+100	5.8	7.8	+34

Calculations by the National Environmental Research Institute show that at a median total nitrogen concentration of 550 µg/l the depth limit will be 3.6 m, and at 275 µg/l about 6 m. Based on these numbers and knowing the bed gradients in the areas examined, it has been estimated that eelgrass could expand its area of growth by approx. 70%. In other words, very large areas could be colonised by eelgrass if nitrogen inputs were reduced.

6.4.4 **Oxygen conditions**

Oxygen depletion with dead fish and benthic fauna are probably the most visible effect of overloading of ecosystems, but less noticeable effects also make oxygen content a key parameter in marine monitoring.

Background

Aquatic oxygen content depends on the relationship between oxygen consumption in the water and bed and the input of fresh oxygen. Consumption is by animal and plant respiration and bacterial metabolism. The amount of organic material present determines the oxygen consumption in a given area of water.

Decomposition of matter in sediments

Part of the organic matter added to sediments functions as food for benthic fauna. The rest decomposes by a complex interplay between a number of microbial processes. Some of these can occur without the presence of free oxygen, sulphates or nitrates being used as oxidising agents instead. Even under normal conditions, anaerobic conditions will occur at a small depth below the sediment surface. During the decomposition processes, the carbon in the organic matter will be broken down to carbon dioxide, which can be taken up again by plants. The nutrient content also becomes available to plants.

Oxygen balances

Oxygen in water originates both from photosynthesis by plants and from the air. In a stratified area, the water beneath the transition stratum will be isolated from atmospheric oxygen. As this stratum is often so deep that it is too dark for plant growth, the fauna below this level depends on the amount of oxygen already in the enclosed mass of water. Other things being equal, there will always be more oxygen available to benthic life the greater the distance between the fjord bed and the transition stratum. The oxygen content varies over the year. In winter when the temperature is lower, the water can contain more oxygen, while at the same time stronger winds cause more surface agitation leading to easier access to atmospheric oxygen. Finally, the lower temperatures mean that processes which consume oxygen proceed at a slower rate. In summer, conditions are quite different: relatively warm and calm. There is also a large amount of easily-decomposed algal material from the spring blooms that can be broken down. It can be seen that oxygen content is high in winter, followed by a fall during the summer until autumn storms and cooler weather again add oxygen to the water. The availability of oxygen to the fauna depends on the oxygen content of the water compared with how much it *can* contain. There are also great differences in the abilities of different fish and benthic fauna to tolerate low oxygen concentrations. A normal rule of thumb is that fish begin to move away at concentrations below about 4 mg/l and most below about 2 mg/l. If concentrations remain below this level for extended periods, the benthic fauna begins to die. In Denmark, oxygen depletion is therefore defined as less than 4 mg oxygen per litre of water. If it falls below 2 mg/l oxygen depletion is serious.

Status The oxygen depletion status in fjord areas is given in Table 6.10, based on the county reports.

Table 6.10

Overall review of oxygen depletion conditions in the theme fjords in 1995. The review is regionalised for practical reasons and does not discriminate between depletion and acute depletion – for detailed information refer to the county theme reports (see Appendix 5).

West Jutland fjords	Oxygen conditions in Ringkøbing Fjord in 1995 were worse than previously. In 1995, oxygen depletion was also measured in Nissum Fjord, which otherwise has good oxygen conditions. Depletion has not yet been measured in Grådyb tidal zone.
Limfjorden	About 25% of the area of Limfjorden was affected by oxygen depletion during 1995, covering largely the same extent as during 1994, but the duration and therefore the effect on benthic fauna was less in 1995.
East Jutland fjords	1995 featured poor oxygen conditions in Vejle and Horsens Fjords. Oxygen depletion was measured in many periods from June to October. In many places, depletions were “imported” by oxygen-depleted waters entering the fjords. Such an event caused extensive fish deaths in the shallow waters of Vejle Fjord. No oxygen deficiencies were measured in Kolding Fjord. In Aarhus Bight, depletion lasted from July 1 to November 1, being very high for five weeks in August/September. This was the most extreme oxygen depletion since 1982.
South Jutland fjords	There was extensive oxygen depletion in the deeper parts of the south Jutland fjords during 1995. In Flensborg inner Fjord, it lasted from June to October, also reaching the outer parts of the fjord from July to September. No depletion was measured in Haderslev Fjord or the inner part of Genner Fjord, though there was oxygen depletion in the outer part of the latter during August. Augustenborg Fjord suffered oxygen depletion in September and October, and Als Fjord in August and September.
Funen fjords and coves	The deep sediment basins of the South Funen Archipelago experienced depletion from July to October. Dead benthic fauna was observed in Nakkebølle Fjord and Lunke Bight in connection with oxygen depletion. No depletion was measured in Odense Fjord or Kertinge Cove during 1995. There are signs in all water areas that there have been poor oxygen conditions caused by mats of drifting algae.
North Zealand fjords	Prolonged oxygen depletion was only measured in two limited holes in the southern part of Roskilde Fjord in 1995. Lammefjord experienced depletion in June and July. The outer broad of Isefjorden, Holbæk Fjord and the outer part of Lammefjord were all hit by oxygen depletion in August.
West Zealand fjords and coves	No depletion was measured in Korsør Cove during 1995. Kalundborg Fjord experienced depletion during July-August and again in September-October.
South Zealand fjords	No depletion was measured here in 1995.

Status and development Large areas of the Danish fjords are frequently affected by deteriorated oxygen conditions, with negative consequences for benthic flora and fauna and for fish. Different forms of depletion occur in the fjords. In deep, delimited holes where a dense mass of water can be trapped for an extended period without mixing with freshwater, depletion may occur even without the addition of extra organic matter. Such areas of natural oxygen depletion are found, for example, in the Ærø Basin in the South Funen Archipelago and in Lejre and Kattinge Inlets in Roskilde Fjord. Other areas experience depletion from time to time as a result of very oxygen-depleted waters flowing in from other areas, the depletion being imported. Such an event was observed in Vejle Fjord in September 1995. During the preceding period there had been poor oxygen conditions in the deepest portion of the outer part of the fjord . At the end of September, a strong westerly wind forced the topmost stratum of water out of the fjord. The water deficient in oxygen forced its way to the innermost part of the fjord causing very poor oxygen conditions throughout the fjord in a very short time. Finally, “normal” oxygen depletion is caused by such heavy growths of organic material that its decomposition consumes all the oxygen dissolved in the water body.

Frequency of oxygen depletion

The mean occurrence of oxygen depletion in fjords from 1989 to 1995 is shown in Figure 6.13. To take into account the different sampling frequencies in different areas and years, the figure shows frequency, i.e. the number of cases of depletion measured, divided by the total number of measurements. Oxygen conditions are generally good in the shallow fjords and areas with great water movement such as Nissum Fjord and Grådyb tidal zone. Oxygen depletion arises every year in deep, enclosed waters such as Mariager and Flensborg Fjords.

Figure 6.13
Average relative frequency from 1989 to 1995 of summertime occurrence of oxygen depletion in Danish fjords. The relative frequency is calculated fjord by fjord by dividing the number of instances of depletion by the total number of measurements during in the same period (from Kaas et al., 1996).

Oxygen depletion and stratification

In many of the medium-depth fjords such as Vejle, Skive, and Roskilde Fjords, the occurrence of oxygen depletion follows a common pattern. It is characteristic that there were poor oxygen conditions in 1991, 1994, and 1995 while occurrences of oxygen depletion were relatively few in 1990 and 1993. This could indicate that the same mechanisms are at work in the different fjords. Figure 6.14 shows the frequency of oxygen depletion in selected fjords and open coastal areas from 1985 to 1995.

Frequency of oxygen measurements <2 mg per litre

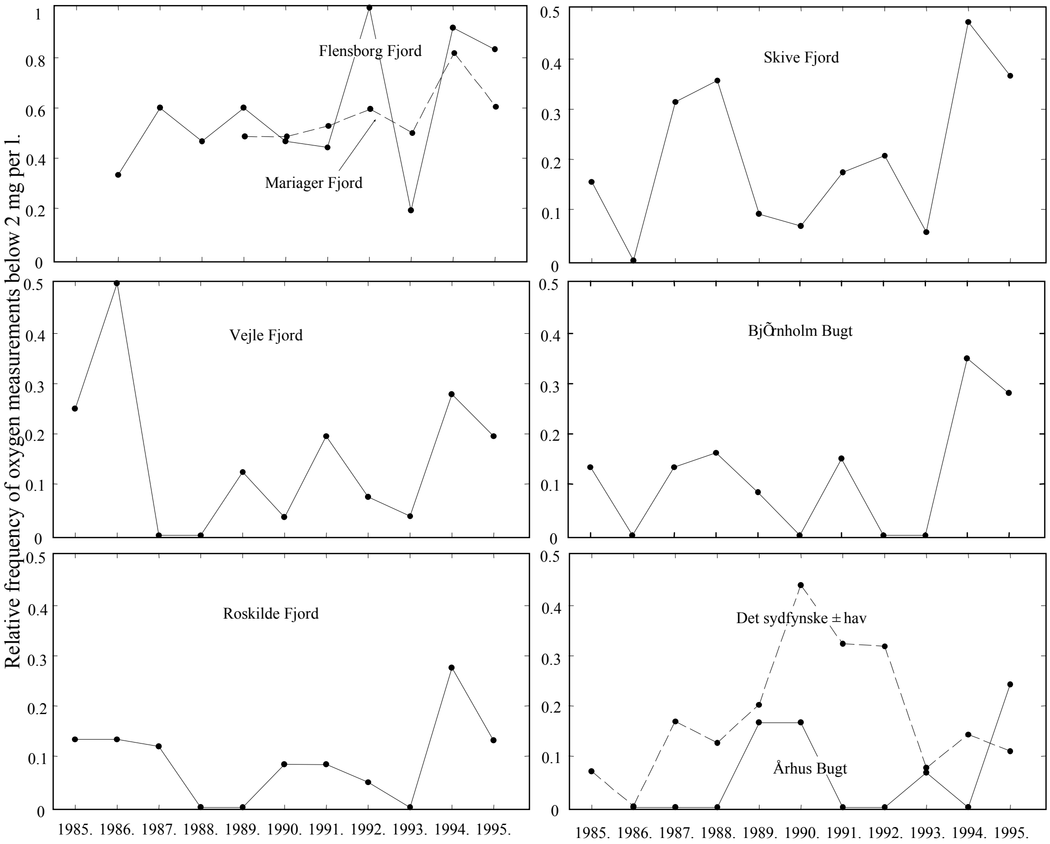

Figure 6.14
Relative frequency of acute oxygen depletion (<2mg O_2/l) from 1985 to 1995 (from Kaas et al., 1996).

The occurrences of oxygen depletion often vary between fjords and open waters. Thus in the summer of 1994, nearly all the Danish fjords were seriously affected while the open waters were not affected, by and large. It is also characteristic that oxygen depletion occurs in fjords earlier in the year than in open waters. Consequently, other mechanisms or local circumstances must be affecting the development of oxygen depletion. In comparison with Kattegat, the fjords are generally shallow and only rarely stratified. The National Environmental Research Institute has carried out statistical analyses to determine which variables are significant to the development of oxygen depletion in fjords. The analysis used data from Roskilde Broad and Skive Fjord. The working hypothesis was that physical and meteorological conditions set the framework, but that within this the availability of nutrients determines the degree of oxygen depletion. The analysis shows that stratification is the most significant parameter, followed by temperature and nitrogen loading. The amounts of light and phosphorus were also influential.

Oxygen depletion and nutrient enrichment

Based on the connection between oxygen depletion and nutrient salt loading, the National Environmental Research Institute has determined what a halving of the nitrogen loading would mean to the development of oxygen depletion. Under current conditions, the oxygen consumption is so high that in Skive and Roskilde Fjords it would take 6 days with stratification for depletion to occur and 14 days for it to become acute. If loading could be halved, it is forecast that depletion would take 12 days to develop and 20 days to become acute. Figure 6.15 shows how stratification typically occurred in the period 1984 to 1995. It can be seen that most periods of stratification are so short that acute depletion would not occur. At an average nitrogen loading, 28 acute cases of depletion would occur with a total duration of 493 days. Under the same conditions, but with a halved nitrogen input, only 11 cases would occur lasting in all only 268 days. A reduction in nitrogen loading would also have a marked effect on the extent of the depletion. As the model shows that there is often a correlation between nitrogen and phosphorus, an accompanying positive effect of a reduction in phosphorus loading cannot be ruled out.

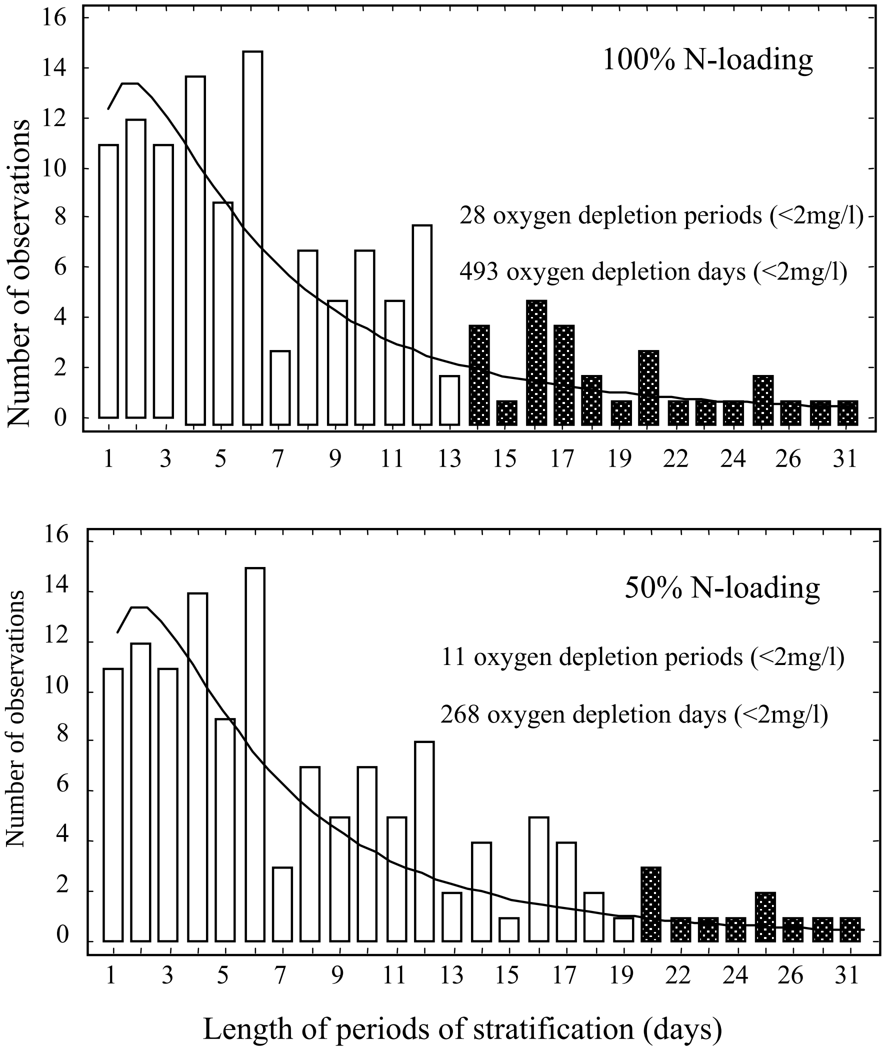

Figure 6.15
Distribution of stratification in summertime and effect of 50% reduction in nitrogen loading on oxygen depletion (from Kaas et al., 1996).

6.4.5 **Benthic fauna**

Background Bivalves are generally the most significant group of benthic fauna in Danish fjords. Among the dominant varieties are common mussels, cockles and soft clams. All these species feed by filtering water. In Nissum and Ringkøbing Fjords, Polychaetopods (bristle worms) rather than bivalves form most of the faunal biomass. Echinoderms such as sea urchins and brittle stars, which are a very significant group in the open waters, are infrequent in the fjords. The reason for this is presumably the relatively low salinity there. The frequent occurrence of creatures that feed by filtering water means that benthic fauna plays a significant part in the fjords' ecosystems.

Thus, it has been calculated that the bivalves on the bed of the outer part of Roskilde Fjord are in theory able to filter algae from the water in the entire fjord between one and ten times daily. The effect of this is that the water becomes clearer and that it becomes harder for copepods and other planktonic fauna to survive. At the same time, the consumption of planktonic algal biomass becomes far more effective when relatively large creatures are feeding as there are fewer links in the food chain. Actually, the filtration by the bivalves is not quite so effective, as often the same water is being filtered time and again. The more current and wave action there is, the more effectively the water can be filtered. The role of the bivalves can also be filled by other fauna such as the chaetopods in the fjords of West Jutland.

Most benthic fauna are long-lived relative to the planktonic organisms. By their nature, the adult fauna, which often lie buried in the fjord bed, is not particularly mobile. This means that examination of the benthic fauna of an area may provide an understanding of conditions over an extended previous period. Benthic fauna propagate by their larvae living free in the water for a longer or shorter time before settling on the bed.

Status The status of benthic fauna in the fjord areas based on county reports is shown in Table 6.11.

Table 6.11

Overall review of the state of benthic fauna in the theme fjords in 1995. The review is regionalised for practical reasons and does not discriminate between depletion and acute depletion – for detailed information refer to the county theme reports.

West Jutland fjords	The benthic fauna biomass in both fjords was the highest measured since 1989. In both fjords the biomass is dominated by pollution-tolerant bristle worms. Grådyb tidal zone has a very high population of benthic fauna.
Limfjorden	Limfjorden features large natural variations in its population of benthic fauna. Bivalves are the most significant group in many areas. Oxygen depletion in 1994 and 1995 had a negative impact and the benthic fauna is generally affected by pollution.
East Jutland fjords	Here shellfish are the dominant fauna. There have been marked improvements in the inner Horsens Fjord and the outer part of Vejle Fjord since the acute oxygen depletion of 1989. Subsequent occurrences have been too short to cause lasting damage to the fauna, although it is generally affected by pollution. Dead creatures were found in the western part of Aarhus Bight associated with oxygen depletion. Studies of bivalve growth have shown that oxygen depletion has a negative effect. It can also be demonstrated that bivalve growth was not optimal in 1995 as a result of oxygen depletion.
South Jutland fjords	Bivalves are also the dominant group here in terms of biomass, but in terms of numbers they have been overtaken by small bristle worms at a number of stations. Oxygen depletion had harmful results in Genner, Aabenraa and Flensborg Fjords, but in general, the number of species rose.
Funen fjords and coves	Bristle worms predominate in the benthic fauna of Odense Fjord, which is shallow and thus not affected by oxygen depletion. The same applies to the shallow part of the South Funen Archipelago. In the other areas the fauna is affected by oxygen depletion. Dead benthic fauna associated with oxygen depletion was observed in Nakkebølle Fjord and Lunke Bight in August 1995. There is no absolutely dominant group in Kertinge Cove.
North Zealand fjords	Oxygen depletion seriously affected the benthic fauna of Roskilde Fjord in 1994, but bivalves are still the dominant group. Bristle worms are dominant in Isefjorden. They are tolerant towards loading. In the areas with many bivalves, only common mussels are older than one year.
West Zealand fjords and	The benthic fauna of Korsør Cove and, to a lesser degree, Kalundborg Fjord is

coves	dominated by small pollution-tolerant species.
South Zealand fjords	No samples of benthic fauna were taken in this area in 1995.

Condition and trend

The benthic fauna biomass in individual fjords is shown in Figure 6.16.

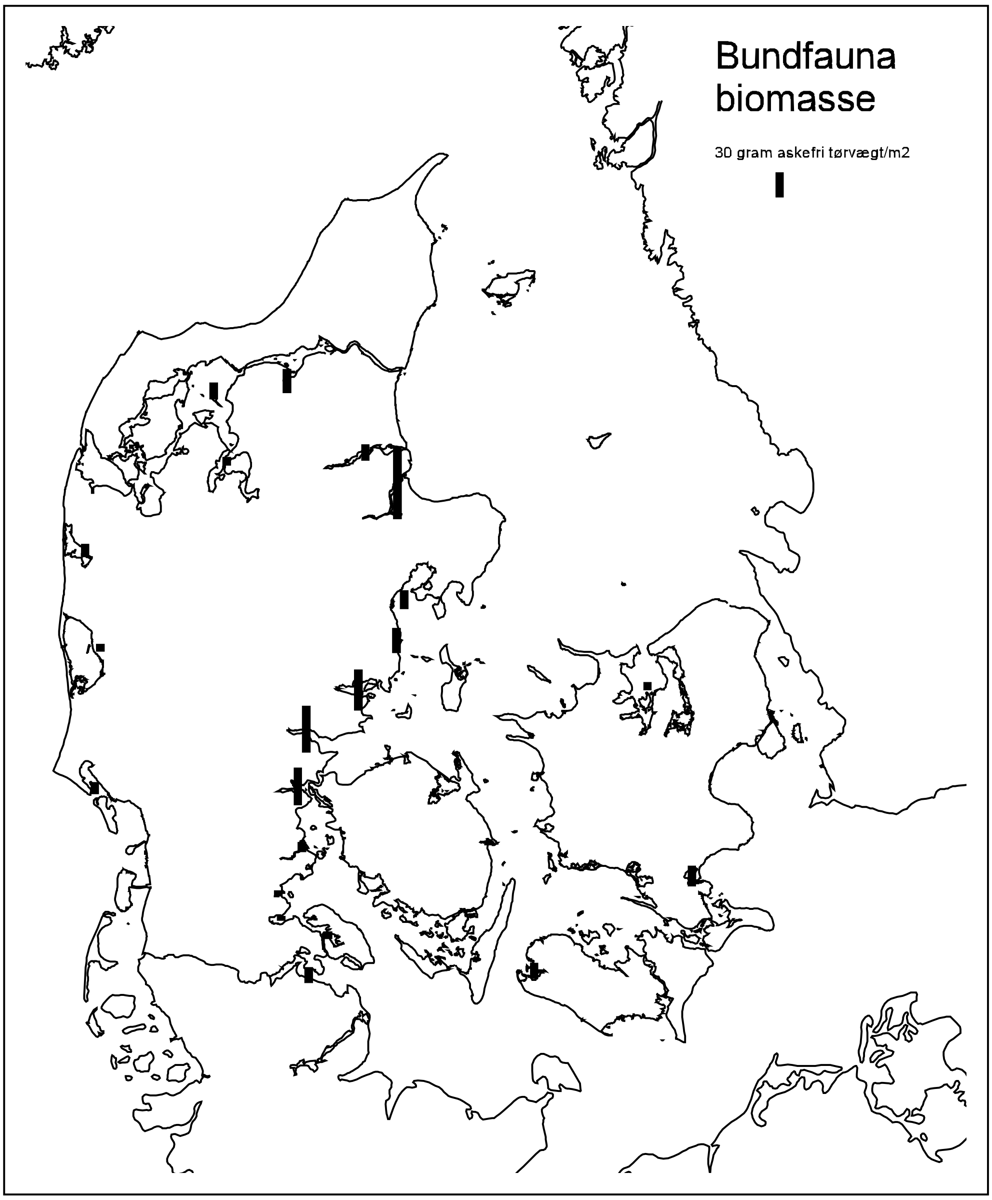

Figure 6.16
Biomass of benthic fauna in Danish fjords. Average values for 1989 to 1994
30 g ash-free dry weight/m^2.

Benthic fauna and nutrient enrichment

The benthic fauna of the Danish fjords has been impoverished and reduced over a long period. For example, some 20-25 species have disappeared from Roskilde Fjord since the turn of the century. A number of these species that are most sensitive to oxygen depletion have also disappeared from the South Funen Archipelago and Limfjorden. Thus, the general picture is that the benthic fauna has been severely affected by pollution, but there have been a number of improvements over recent years, for example in Aarhus Bight, Randers Fjord and Kertinge Cove. Some of these improvements were observed already before the introduction of the Action Plan for the Aquatic Environment. In most places, the improvements are related to improved waste water treatment. However, in most places no improvements have been demonstrated and, in some, conditions have worsened further in recent years. This was the case in the inner part of Roskilde Fjord, which was hard hit by oxygen depletion in 1994.

The National Environmental Research Institute has carried out statistical analyses to determine whether nitrogen and phosphorus loading affect the amount, number and diversity of species of benthic fauna. No correlation was established between nutrient input and numbers of creatures or species, but there was a positive effect on the amount of benthic fauna (biomass).

Benthic fauna and oxygen depletion

It has been attempted to correlate the growth of abra-mussels with the amount of phytoplankton and oxygen depletion. It appeared that bivalves grew larger the greater the sedimentation of planktonic algae, provided there is no oxygen depletion. In periods of depletion the mussel growth came to a standstill. In Aarhus Bight, 1995 featured very high and extended oxygen depletion and the new year's bivalves hardly grew at all and only reached lengths of about 3 mm. In 1990 when conditions were much better, lengths of 10 mm were achieved. It was not possible for the analysis by the National Environmental Research Institute to quantify the effect of oxygen depletion, the reason presumably being that many of the stations where benthic fauna is sampled are located exactly in places which, as experience has shown, are not to be subject to depletion to any particular extent.

6.4.6 Heavy metals and contaminants

Heavy metals in sediments

The Danish EPA (1983) has established guideline limits for a range of heavy metals in diffusely loaded surface sediments. These values are set out in Table 6.12.

Values more than twice those in the table can be an indication that waste water polluted with heavy metals is being discharged into the recipient (The Environmental Protection Agency, 1983).

Table 6.12
Heavy metal content (mg/kg loss by combustion) in diffusely loaded surface sediment (The Environmental Protection Agency, 1983)

Lead (Pb)	*350*
Copper (Cu)	*250*
Chromium (Cr)	*150*
Mercury (Hg)	*2*
Zinc (Zn)	*1300*
Cadmium (Cd)	*10*

Limfjorden: Sediment samples were taken during 1988-1991 in Limfjorden as part of the Limfjorden Partnership's general monitoring programme. The fjord was split up into six parts, samples from which were analysed for the heavy metals As, Pb, Cd, Cr, Cu, Hg, Ni, Sn, Va and Zn.

The general conclusion of the investigation was that the levels of most of the heavy metals were generally lower than the guideline limits in tables 2 and 3 except in localised areas near urban or industrial discharges (Viborg county, 1994).

Mariager Fjord: High levels of a number of metals were found in the inner part of Mariager Fjord in 1981-1983. The Hg content was nine times higher here than in the middle or outer fjord. A follow-up study in 1989 produced similar results. The Hg level of 2.0-9.4 mg/kg exceeded the limits by a factor of 2-5 as compared with diffusely loaded surface sediment (North Jutland County, 1990). The sources of the heavy pollution can presumably be found among present and historical waste water outfalls and illegal, unregistered discharges via the surface water system and even direct discharges into the fjord (North Jutland County, 1990).

Nissum Fjord: The presence of 10 different heavy metals in sediment samples from the brackish area of Nissum Fjord was studied in 1989.

The conclusion was that the Ni content of sediments from Nissum Fjord was about three times as high as of the sediments from a number of other marine sediments. Similarly, the Cr and Zn content was a little higher than the average content of Cr and Zn in marine recipients. Cd, Pb, Cu, and Hg levels were within the fluctuations in content of the same heavy metals in sediment from a number of other marine recipients. (Ringkøbing County Authority, 1989).

The levels of As, Co, and Sn in marine recipients have not previously been routinely checked so it is not possible to compare these with the levels found in Nissum Fjord Ringkøbing County Authority, 1989).

Ringkøbing Fjord: As part of the status description of Ringkøbing Fjord tests were carried out in the autumn of 1987 on sediment from the fjord, including analyses for the heavy metals Cd, Pb, Cr, and Ni. (Ringkøbing County Authority, 1988). This showed that the concentration of these metals varied depending on the type of sediment. The highest content of heavy metals was thus found in samples drawn from surface sediments from deeper waters (Ringkøbing County Authority, 1988). Average values of Cd (6.2 mg/kg loss by combustion), Pb (161 – 204 mg/kg loss by combustion) and Cr (184 mg/kg loss by combustion) were compared with the guideline levels of the Danish EPA (see table 6.12), leading to the conclusion that Pb and Cr levels were generally below these while the Cr content exceeded the value (Ringkøbing County Authority, 1988). The average concentrations in Ringkøbing Fjord expressed on dry matter (DM) basis (Cd: 0.33 mg/kg DM, Pb: 9.1 mg/kg DM, Cr 8.5 mg/kg DM, and Ni; 7.8 mg/kg DM) were comparable with those in non-enriched or only slightly enriched coastal waters. (Ringkøbing County Authority, 1989).

Heavy metals in fauna and flora

Horsens Fjord: Studies were carried out from 1987-1994 of heavy metal content in common mussels from Horsens Fjord which showed that the Hg and Cd content was rising while that of Cu, Ni, Pb, and Cr had generally fallen. The Zn level was relatively high, but did not rise during that period. (Andersen, J.T. & Dall, P., 1995).

The mean concentrations of Hg rose from approx. 0.6 mg/kg DM in 1987 to approx. 0.25 mg/kg DM in 1994. Cadmium concentrations had risen from approx. 0.4 to 1.4 mg/kg DM over the same period. In the later years of the study, the levels of both Hg and Cd were above those found in a number of studies in Western Europe and the USA. It was still less than the threshold limit for shellfish for consumption and therefore does not give rise to health concerns. (Andersen, J.T. & Dall, P., 1995).

Roskilde Fjord: The heavy metal content in common mussels from the various stations in Roskilde Fjord was studied in June 1991 (the Water Quality Institute (WQI, 1992). Unlike Cd and Ni, which were at the same level, higher levels of Cu, Hg, Pb, Cr, and Zn were measured in mussels from near Roskilde than in those harvested further out in the fjord, the Broad (WQI, 1992). The difference in Cr was very high – a factor of 67 – while for other metals the factor varied between 1.5 and 3.7 (WQI). At the station in between, the values for Cd, Cu, Ni, and Cr were at the same levels as in the Broad and at a mean level relative to Roskilde and the Broad for Pb, Hg and Zn (WQI, 1992).

Roskilde Fjord – Frederikssund: Frederiksborg County carried out analyses for selected heavy metals (Hg, Cd, Pb, Cu, Cr, Zn) in mussels collected around the outfall from Frederikssund sewage treatment plant in Roskilde Fjord.

An elevated level of Cu (21 mg/kg DM) in mussels was identified. Concentrations of Hg, Cd, Pb, Cu, and partly Zn in mussels around Frederikssund were at similar levels or lower than those in Roskilde Broad (the 1991 study) whereas Cr content was higher (0.67-1.2 mg/kg DM) (WQI, 1992).

Roskilde Fjord – Frederiksværk: The heavy metal loading in the northern part of Roskilde Fjord around Frederiksværk was studied in 1990. (WQI, 1991). The study encompassed transplantation of common mussels, collection of naturally-occurring mussels on navigation buoys and collection of eelgrass at various distances from Frederiksværk.

In naturally-occurring mussels from buoys a gradient of increased Zn values was found up to a distance of 1.5 km from Frederiksværk, whereas no such gradients could be established for Cd, Cu, or Pb (WQI, 1991). The highest values of Zn measured had been increased by a factor of 2 above the background levels of about 80 mg/kg DM.

Transplanted mussels showed clear gradients and increased levels of Cu, Pb, Zn, and Cd 1-3 km to the west and south-west of Frederiksværk, and for Zn and Cd at a greater distance south of Frederiksværk (WQI, 1992). The highest concentrations were measured in the Steelworks Harbour and Slag Jetty. Pb was higher than background levels by a factor of 4-5 while for Cd, Cu, and Zn the factor was 2.

No gradients could be proven in Cd, Pb, Cu, and Zn concentrations in eelgrass samples. Compared with previous eelgrass studies around the Masnedø power station in Storstrømmen and in Limfjorden, the level of Cu (8.9 mg/kg DM), Pb (2.4 mg/kg DM) and Zn (141 mg/kg DM) was about 2-5 times higher around Frederiksværk.

Biological effects were elucidated by studying the mortality and growth of transplanted mussels (WQI, 1991). There were no indications of acute effects in the form of increased mortality related to heavy metal loading or other factors such as freshwater effects (WQI, 1991). Similarly, the conclusion was that despite negative correlations between soft part growth and the presence of heavy metals, the concentrations were at a level where no growth-inhibiting effects were to be expected (WQI, 1991).

Occurrence and effects of contaminants

A range of contaminants used in large amounts annually in Denmark such as LAS (surface active substances), phthalates (plasticisers), alkyl phenol ethoxylates (detergents) and growth-inhibitors TBT and Irgarol (antifouling paints for ships) all have the potential for ending up in the aquatic environment. As research results have documented aquatic effect concentrations of the relevant substances at very low levels, and as some of them have been shown to have oestrogen-like effects on fish and mammals (Danish EPA, 1995b; TemaNord, 1996), there is a need to survey possible effects in, among other areas, the aquatic environment of these groups of substances.

At present there has been no systematic study of the occurrence and effects of these materials in Danish fjords. For this reason it has not been possible to assess the loading by these substances or their effects on the fjord systems in Denmark.

Various research projects will be initiated over the coming years related to contaminants, one aim of which being to cast light on this problem.

6.4.7 Conditions compared with objectives

The County Councils through their regional plans define the environmental objectives in the fjords. Most have a general objective, meaning that only mild effects of human impact on flora and fauna are acceptable and that the water should be of a good hygienic quality. The properties focused on when requirements are set depend on the character of each individual water body.

Target criteria

To assess whether an area meets its objectives as clearly as possible, parameters are often chosen that are easy to quantify. At the same time, knowledge is needed how the parameter varies in step with changes in the environmental condition. Nevertheless, the assessment will ultimately often depend on an overall estimate, partly because our knowledge of the mechanisms which determine the development of the parameters chosen is incomplete. Mostly, pollution by nutrients and organic matter is of interest. Oxygen depletion is often used to assess such a situation. The reason for this is partly that an unnatural occurrence of oxygen depletion is a good indicator of the fact that nutrients or organic matter are being or have been input, and partly that oxygen depletion is very significant to parts of the ecosystem. Vegetation depth limits, which depend especially on the clarity of the water, also summarise the state of the environment over a longer period of time. The composition and amount of benthic fauna is also used as a criterion. Here the dependency on good oxygen conditions and ample food determines the condition. Areas loaded with large inputs of nutrients will often be characterised in that filamentous algae or annual green algae are favoured at the expense of other types of vegetation. An increased presence of such organisms also offers a useful indicator of unacceptable conditions. Finally, an increased amount or production of planktonic algae is a well-known sign of nutrient input.

Status

Table 6.13 shows the counties’ assessments of the current conditions relative to targets. In the column headed “status”, a minus sign means that the target is not considered met, a plus sign that it has been met. The “criteria” column lists the parameters used to assess the state. The column “action” designates the types of sources where, in the professional opinion of the counties, further action seems most appropriate. The table deals with entire fjords or water areas; local conditions may not be fully taken into consideration.

Table 6.13

Review of the current environmental conditions in fjords relative to their targets.

Fjord	Status	Criteria	Action
Limfjorden	-	Oxygen depletion, eelgrass depth limit, benthic fauna	Limiting of loading from farmland
Ringkøbing Fjord	-	Flora depth limit, Secchi depth, plankton	Water change, limiting of loading from farmland
Nissum Fjord	-	Flora depth limit, Secchi depth, plankton, benthic fauna	Limiting of loading from farmland
Grådyb tidal zone	-	Pollution-tolerant algae, benthic fauna, plankton	Limiting of loading from open land, study of significance of water exchange pending
Horsens Fjord	-	Oxygen depletion, pollution-tolerant algae, nutrient salt concentrations	Limiting of loading from farmland, marine fish farming
Vejle Fjord	-	Oxygen depletion, pollution-tolerant algae, depth limit of vegetation	Limiting of loading from farmland, marine fish farming
Kolding Fjord	-	Oxygen depletion, pollution-tolerant algae, benthic fauna	Limiting of loading from farmland, marine fish farming
Aarhus Bight	-	Oxygen depletion, pollution-tolerant algae, depth limit of vegetation	Limiting of loading from farmland, then waste water and atmospheric loading
Randers Fjord	-	Pollution-tolerant algae, depth limit of vegetation, benthic fauna, plankton	Limiting of loading from farmland
Mariager Fjord	-	Oxygen depletion, poor diversity of phytoplankton species, , pollution-tolerant algae, depth limit of vegetation	Limiting of loading from farmland
Haderslev Fjord	-	Oxygen depletion, pollution-tolerant algae, nutrient salt concentrations	Limiting of loading from open land, establishing wetlands
Aabenraa Fjord	-	Oxygen depletion, pollution-tolerant algae, nutrient salt concentrations	Limiting of loading from open land, establishing wetlands
Augustenborg Fjord	-	Oxygen depletion, pollution-tolerant algae, nutrient salt concentrations	Limiting of loading from open land, establishing wetlands
Flensborg Fjord	-	Oxygen depletion, pollution-tolerant algae, nutrient salt concentrations	Limiting of loading from open land, establishing wetlands
Odense Fjord	-	Pollution-tolerant algae, nutrient salt concentrations, sanitary conditions	Limiting of loading from farmland, waste water outfalls, a disposal site, and the atmosphere, establishing wetlands
South Funen Archipelago	-	Oxygen depletion, pollution-tolerant algae, nutrient salt concentrations	Limiting of loading from farmland, establishing wetlands
Kertinge Cove	-	Pollution-tolerant algae, nutrient salt concentrations	Limiting of loading from farmland, establishing wetlands
Isefjord	-	Oxygen depletion, pollution-tolerant algae, occurrences of sludge	Limiting of loading from farmland and waste water outfalls
Roskilde Fjord	-	Pollution-tolerant algae, flora depth limits, macrofauna	Limiting of loading from farmland and waste water outfalls
Kalundborg Fjord	-	Oxygen depletion, pollution-tolerant algae, flora depth limits, macrofauna	Limiting of loading from farmland
Korsør Cove	-	Pollution-tolerant algae, occurrences of sludge, benthic fauna	Limiting of loading from farmland
The Broad (Guldborg Sound)	-	Pollution-tolerant algae, phytoplankton	Limiting of loading from farmland, establishing wetlands
Stege Bight	+	Conditions of vegetation, benthic fauna	
Karrebæk Fjord	-	Pollution-tolerant algae, phytoplankton	Limiting of loading from farmland, establishing wetlands
Dybsø Fjord	-	Pollution-tolerant algae, phytoplankton	Limiting of loading from farmland, establishing wetlands
Præstø Fjord	-	Pollution-tolerant algae, phytoplankton	Limiting of loading from farmland, establishing wetlands
Nakskov Fjord	-	Pollution-tolerant algae, phytoplankton	Limiting of loading from farmland

The table shows that the environmental condition in nearly all fjord areas is worse than planned and that action on agricultural nutrient inputs is considered necessary to achieve an acceptable quality.