

**OSPAR Common Procedure for Identification of
Eutrophication Status:
Application of the Screening Procedure for the Norwegian
coast north of 62°N (Stad – Russian border)**

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0. Summary

The Norwegian coast north of 62°N bordering the Norwegian Sea and the Barents Sea, is effectively flushed by the Norwegian Coastal Current (NCC) that flows northwards along the coast from Skagerrak and into the Barents Sea. The NCC is mixed with Atlantic water and the salinity increases as it flows along the coast. The total Norwegian inputs of nitrogen and phosphorus to this area from anthropogenic sources are about 30.000 tons of N and 3.400 tons of P. The main source of N in the southern part is agriculture whereas aquaculture is the main source for P.

The inputs of N and P for various coastal regions from 62°N to the Russian border make up a very small contribution (0.1-1 %) to the natural flux of N and P in the NCC. The area with the largest and most concentrated inputs is the Trondheimsfjord. Here the anthropogenic inputs of N and P contribute about 5 % increase above background concentrations. Nutrient data show generally low concentrations of nitrate and phosphate in the NCC and fjords, with winter concentrations decreasing with decreasing salinity.

It is concluded that the Norwegian inputs of nutrients have a very low and not detectable effect on nutrient concentrations and budgets in coastal areas and fjords. The coastal areas and fjords of Norway north of 62°N are considered a non-problem area with regard to eutrophication.

1. Background

OSPAR has adopted a Common Procedure for the Identification of Eutrophication Status of the OSPAR Maritime Area (OSPAR 1997). The Common Procedure comprises two different procedures: (1) the Screening Procedure, and (2) the Comprehensive Procedure. The Screening Procedure is intended as a “broad-brush” approach to identify obvious non-problem areas with regard to eutrophication. Areas that are not identified as obvious non-problem areas in the Screening Procedure are to be subjected to the Comprehensive Procedure to identify whether they are problem areas, potential problem areas, or non-problem areas.

As a contracting party to OSPAR, Norway has previously applied the Comprehensive Procedure to the coastal and inshore waters of the Norwegian Skagerrak coast (Molvær et al., 2003 a), and the Screening Procedure to coastal and inshore waters of the Norwegian west coast bordering the North Sea south of 62°N (Molvær et al. 2003 b). In 1999 Norway finalised the Screening Procedure for the outer coastal area along the Norwegian coast from Lindesnes to the Russian border and the area was classified as an obvious non-problem area (ASMO (1) 99/5/4-E). This report applies the Screening Procedure for the inner coastal areas of the Norwegian coast, north of 62°N and bordering the Norwegian and Barents Seas.

2. The Norwegian Coastal Current

The Norwegian Coastal Current (NCC) is a continuation of the outflow of brackish water from the Baltic Sea flowing northwards in Kattegat and inner Skagerrak. This flow is joined by water from the Jutland Current coming up along the west and northwest coasts of

Denmark. The NCC in eastern Skagerrak has low salinity (about 25) due to the high amount of freshwater from the Baltic Sea (about $500 \text{ km}^3 \text{ year}^{-1}$) and rivers discharging into the coastal waters of the southeastern North Sea (about $150 \text{ km}^3 \text{ year}^{-1}$).

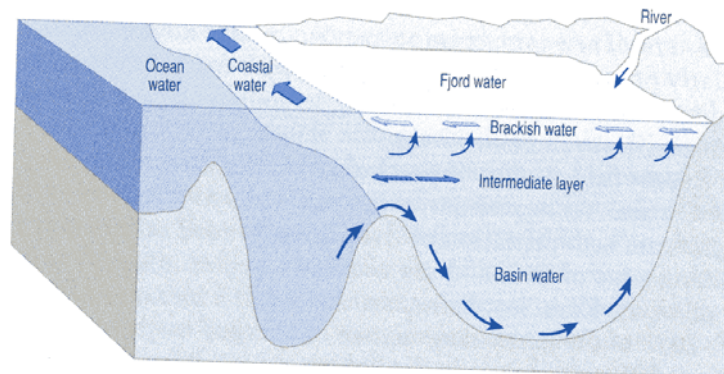


Fig. 1. Schematic representation of a cross-section trough the Norwegian Coastal Current (NCC) and the Atlantic (Ocean) water further offshore. The open connection and communication between coastal and Atlantic waters and fjords are also illustrated.

The NCC flows westwards along the Norwegian Skagerrak coast and northwards along the west and north coasts of Norway. It floats like a wedge-shaped buoyant water mass of lower density on top of saltier and heavier Atlantic water below (Fig. 1). This Atlantic water also flows northwards in parallel with the NCC, as outflow of Atlantic water from the North Sea along the coast of western Norway and being joined by the main branch of the Atlantic Current along the continental slope to the Norwegian Sea (Fig. 2). The NCC is kept in place along the coast by the Coriolis force due to the Earth rotation, that makes currents on the northern hemisphere to be deflected to the right.

The bottom topography along the coast and on the shelf steers the currents. The main features of the shelf topography are shown in Fig. 3. Just north of 62°N at the transition between the North Sea and the Norwegian Sea, the shelf is relatively narrow and shallow, with a steep continental slope towards the Norwegian Sea. Further north the shelf is much wider and deeper with some major banks (Haltenbank, Sklinnabank, Trænabank) separated by deeper areas. The Lofoten Islands sit on a topographic feature that separates the deep Vestfjord on the inner side from the relatively shallow shelf on the outside. In the Vesterålen area just to the north of Lofoten, the shelf is particularly narrow and the slope steep down to the Lofoten Basin of the northern Norwegian Sea. North of this area the shelf again widens as part of the Barents Sea. At the entrance to the Barents Sea, the Tromsøflak extends northwards from the coast as a more shallow area with deeper water closer to the coast east of this.

The less dense water of the NCC tends to extend out from the coast and cover shallow bank areas, whereas the denser Atlantic water flows in onto the shelf in deeper parts between banks. The Atlantic water also flows into the fjords and constitute the basin water of most fjords except those with shallow sills. More detailed features of the NCC and the circulation on the shelf are described by Sætre (1999).

The NCC is dynamic and changes as it flows northwards along the coast of Norway. On its way it receives freshwater discharge from Norwegian rivers, in total about $400 \text{ km}^3 \text{ year}^{-1}$. This tends to lower the salinity of the NCC. However, there is also considerable mixture with

Atlantic water from below or on the outer side of the NCC that tends to increase the salinity. This mixing with Atlantic water causes dilution of the water mass of the NCC originating from Skagerrak as it flows northwards along the coast.

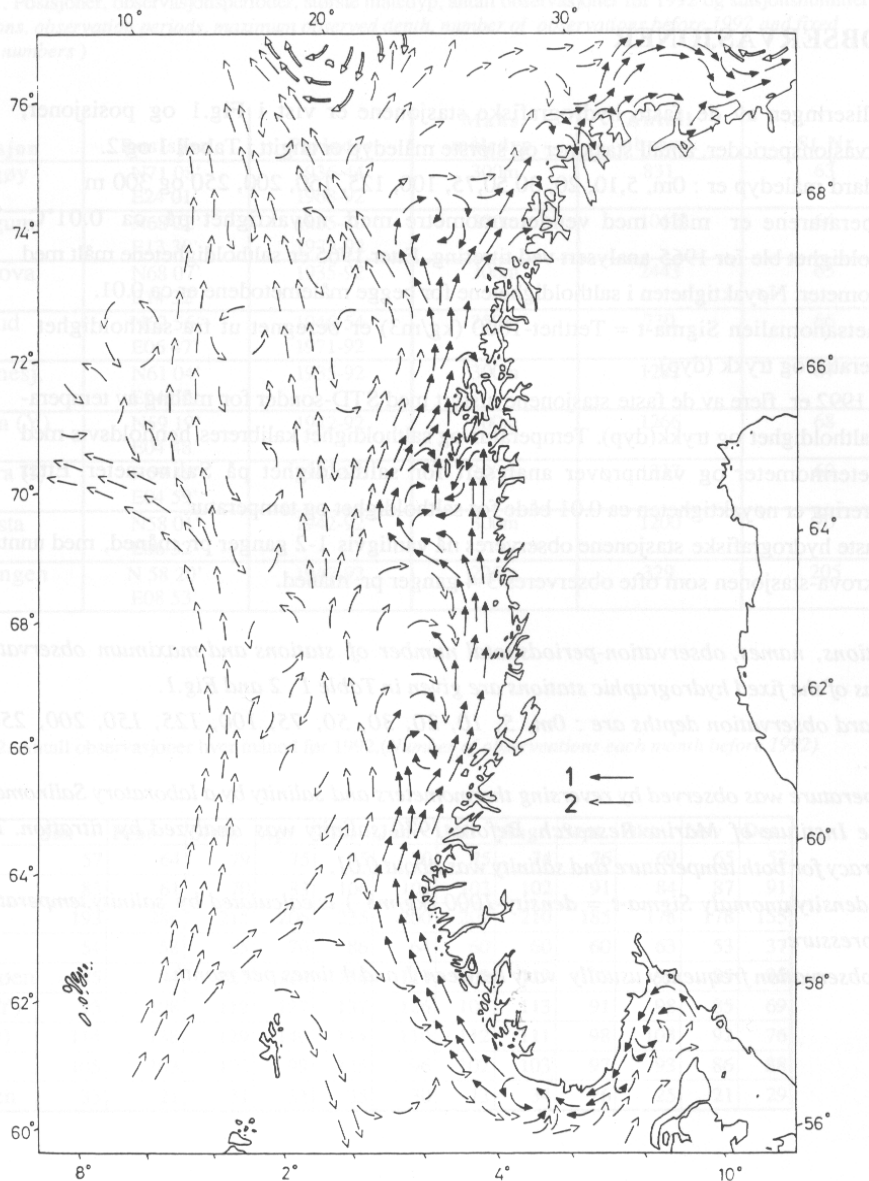


Fig. 2. Map showing the Norwegian Coastal Current (NCC, 1) and the Atlantic Current (2) flowing northwards along the Norwegian coast and shelf.

The current speed of the NCC can exceed 50 cm s⁻¹. The mean transport speed calculated from oceanographic drift buoys, is about 10-15 cm s⁻¹ northwards along the coast (Sætre 1999). This transport can be seen in distribution of herring larvae that drift with the currents. Herring larvae that hatch on the shelf just north of 62°N in April are found in the Lofoten area in June. Two months later they are found distributed into the Barents Sea.

The water mass of the NCC communicates openly with the water in the fjords. Fjords in Norway are structures excavated by glaciers during former ice ages. They have typically a deep basin separated from the deeper shelf by a sill. The deepest fjord (Sognefjord, south of

62°N) is 1303 m deep, while the deepest fjords north of 62°N are about 700 m. Most fjords are 300-500 m deep.

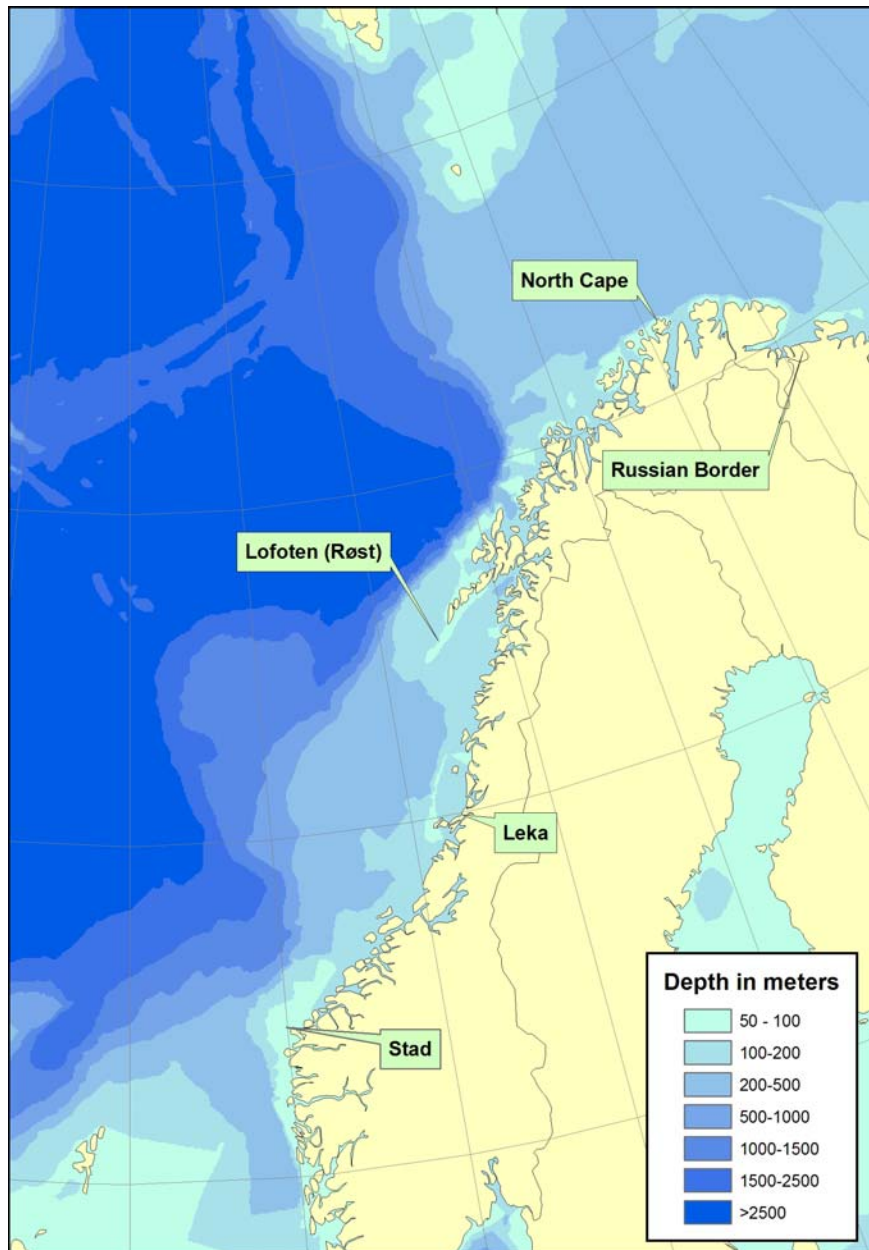


Fig. 3. Map of Norway with main features of bottom topography on the shelf and adjacent sea areas. The locations of Stad, Leka, Røst (Lofoten), North Cape, and Russian border are shown. These locations are used to divide the coast north of 62°N into four regions: Stad-Leka, Leka-Lofoten, Lofoten-North Cape, and North Cape-Russian border.

The water mass structure in fjords can be separated into three main layers: a surface layer, an intermediate layer down to the sill depth, and a basin layer below sill depth (Fig. 4). The fjords receive input of freshwater from rivers and runoff. This forms a thin brackish upper water layer that flows out of the fjord. It is gradually mixed with underlying seawater and this leads to increases in the volume and salinity of the outflowing surface layer. To compensate for this outflow there is a net inflow of water in the intermediate layer. This is

called the estuarine circulation. In addition, there is considerable exchange of the intermediate water layer driven by changes in density of the water outside the fjords due to wind-driven up- and down-welling at the coast. This density-driven exchange is typically 10 or more times greater than the exchange due to the estuarine circulation. The basin water below sill depth is more stagnant and exchanged less frequent. Usually there is renewal of this water at least once a year, typically in winter or spring when the density of the water outside the fjord is at its seasonal maximum.

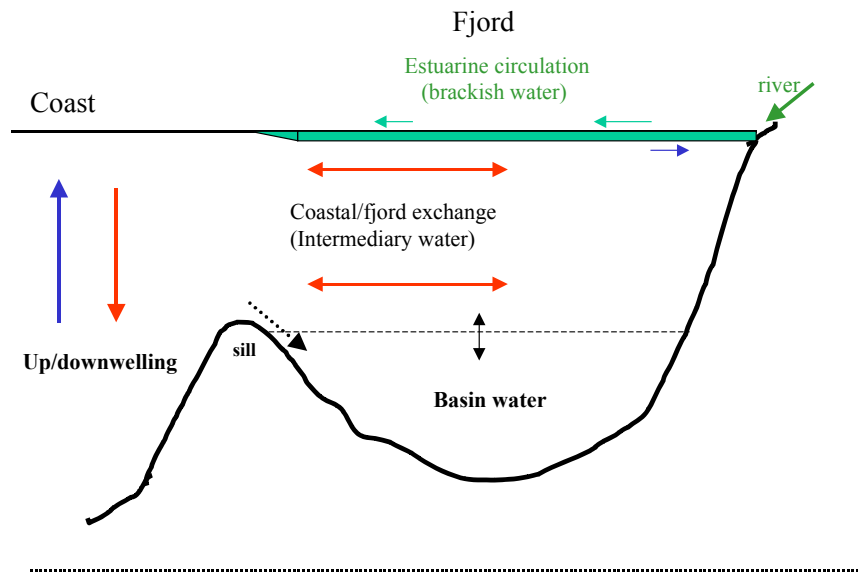


Fig. 4. Schematic transect through a fjord showing the surface brackish water layer, the intermediate water layer above sill depth, and the basin water layer below sill depth.

The rates of exchange and residence times of the various water layers can be calculated by use of a model based on theoretical and empirical relationships (“Fjordmiljø”; Aure and Stigebrandt 1990, Stigebrandt 2001). Parameters of fjord morphology that are used in the calculations are sill depth, sectional area of fjord mouth opening at the location of the sill, basin depth, and basin volume. In general the exchange rate is high and the residence time is low for short fjords with deep sill, wide opening, and low volume. In contrast, the exchange rate is lower and the residence time longer for long fjords with shallow sills, narrow mouth opening, and large volume. The residence time of the water layers are for most fjords typically days to weeks for the surface layer and the intermediate layer, and months to a year for the basin water.

3. Approach, methods, and data sources

3.1 Approach

The main approach we have taken is to scale the Norwegian input of nutrients to the natural fluxes of nutrients in the receiving marine water body. This is done at two different scales, for different parts of the NCC and for selected fjords and fjord areas. Due to the dynamic nature of the NCC, with mixing of freshwater and fjordwater into the NCC and flushing of coastal

and fjord areas by the NCC as it flows along the coast, this is considered to be a realistic scaling. The degree of mixing and dilution of the NCC is assessed by using mean salinity data from long-term monitoring stations along the coast.

As a further approach we have examined nutrient concentration data from the NCC from winter, spring and summer to reveal if there are any sign of elevated concentrations. We have also examined data on nutrient and oxygen concentrations from long-term monitoring of selected fjords in the area.

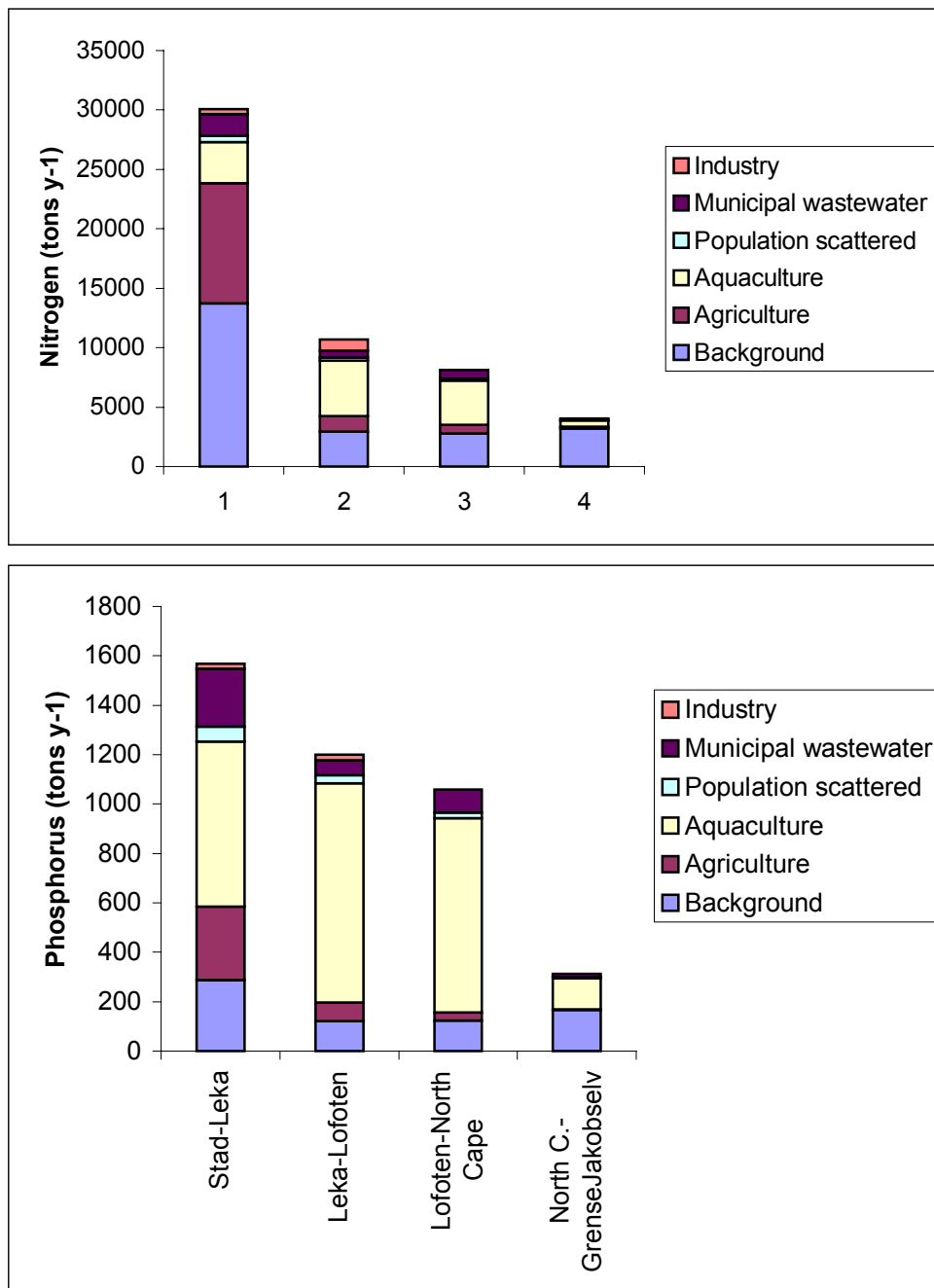


Fig. 5. Total Norwegian annual inputs of nitrogen (upper panel) and phosphorus (lower panel) from different sources for four coastal regions between 62°N and the Russian border. The inputs are based on data from 2001 and estimated by use of the model TEOTIL.

The results from the scaling of nutrient input and the nutrient concentration data did not indicate any significant eutrophication effects in the area. We have therefore not included any detailed examination of biological data.

3.2 Nutrient sources and input

Nutrient inputs were calculated by running the input model TEOTIL (Bratli and Tjomsland 1996). The data were from 2001 and are based on the measurement program for main and tributary rivers that form the basis for the Norwegian reporting to OSPAR (Aquateam 2002). The model calculation takes account of data from industrial sources, municipal wastewater, scattered dwellings, agriculture, and aquaculture.

The total calculated inputs of nitrogen and phosphorus for 4 regions of the coast north of 62°N are shown in Fig. 5. The region Stad-Leka corresponds to the counties Møre and Romsdal, Sør-Trøndelag and Nord-Trøndelag (Fig. 3). The region Leka-Lofoten corresponds to the main part of the county Nordland. The region Lofoten-North Cape comprises the northern part of Nordland county, Troms county, and the western part of Finmark county. The region North Cape-Grensejakobselv is the eastern part of Finmark county to the border with Russia.

The total annual (2001) nutrient input to the coastal areas north of 62°N are 53.000 tons of nitrogen and 4100 tons of phosphorus. These values include the estimated natural background values that constitute 23.000 tons of nitrogen and 700 tons of phosphorus. The total nutrient inputs from anthropogenic sources are about 30.000 tons of nitrogen and 3.400 tons of phosphorus.

Agriculture is the largest source of nitrogen for the southernmost region (Stad-Leka), whereas aquaculture is the main source of phosphorus for all regions (Fig. 5). Input from the human population is generally low.

The input of nutrients north of 62°N occurs over a long coastal area that stretches more than 1.500 km in straight line. With fjords, and large and small islands the total coastline is more than 40.000 km. The nutrient inputs occur distributed over this large area with no marked hot spots. Fig. 6 shows the inputs of total nitrogen and phosphorus (including natural background) for 156 statistical areas from south (62°N) to the Russian border in north.

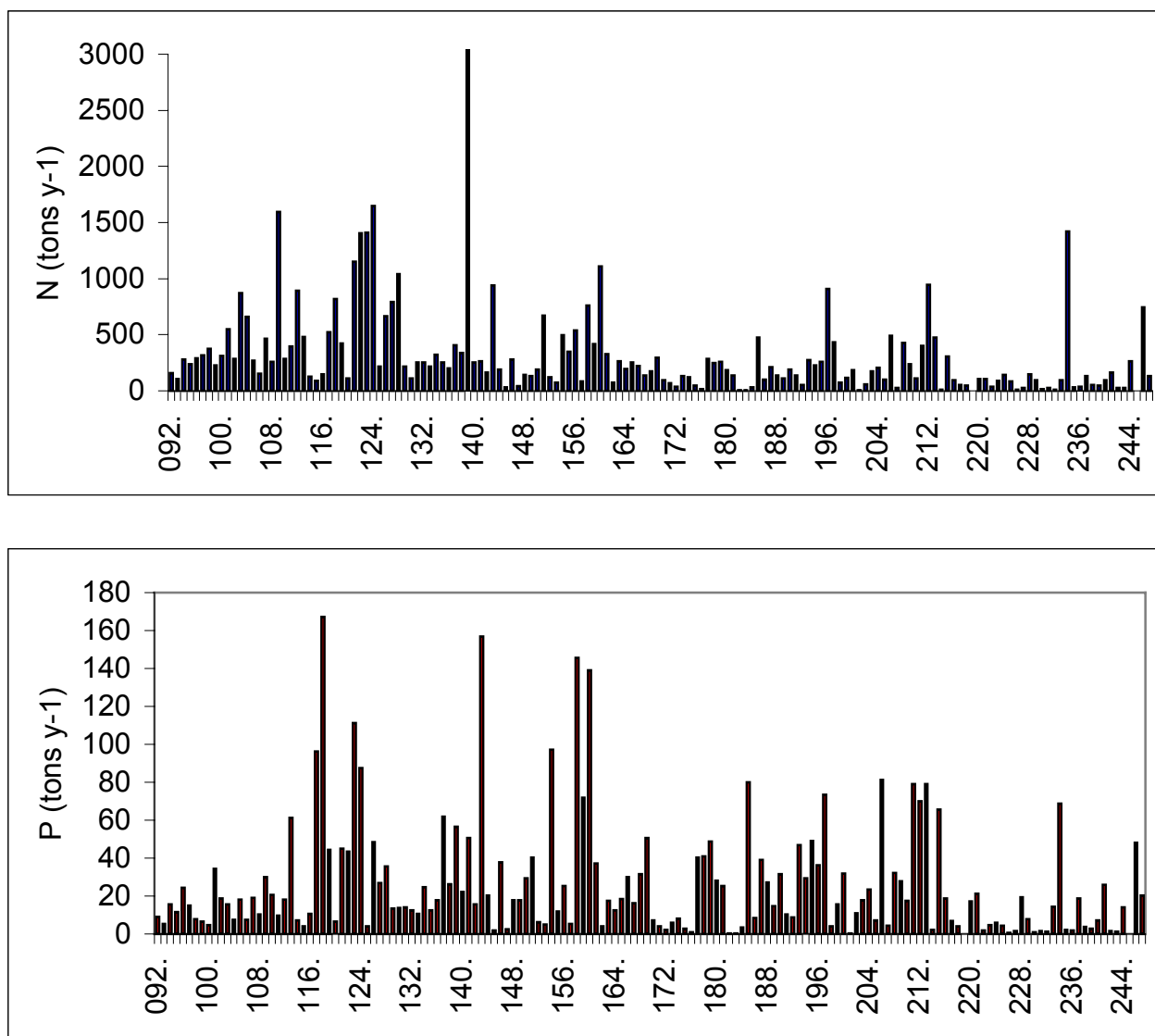


Fig. 6. Total annual Norwegian inputs of nitrogen (upper panel) and phosphorus (lower panel) for statistical areas from 62°N in south (area 92) to the Russian border in north (area 247). The coastal regions shown in Fig. 5 comprise the following areas: Stad – Leka , 92-144; Leka – Lofoten, 145-183; Lofoten – North Cape, 184-219; North Cape – Russian border, 220-247. Note that Area 139 has a N input of 5.699 tons y-1 which exceeds the scale in the figure.

3.3 Dilution and transport in the NCC

Hydrographic observations have been made since 1936 from the coastal liners that sail between Bergen and Kirkenes close to the Russian border. Monthly means of salinity have been calculated for this long time series for the period 1936-1989. Fig. 7 shows the maximum (winter) and minimum (summer) monthly mean salinities for 21 stations located between Sognesjøen (No. 1) south of 62°N and Vardø (No. 21) in eastern Finmark. Station Nos 3 (Breisundet in Møre and Romsdal), 11 (Hestmannøy in Nordland), and 16 (Malangen in Troms) with low salinity values in summer, are located in outer parts of fjords with large input of freshwater in summer.

The salinity increases more or less progressively northwards along the coast in winter when there is low runoff from land. Apart from the fjord areas with intermittent lower salinity, this is also the case in summer (Fig. 7). The increase in salinity shows that admixture of Atlantic

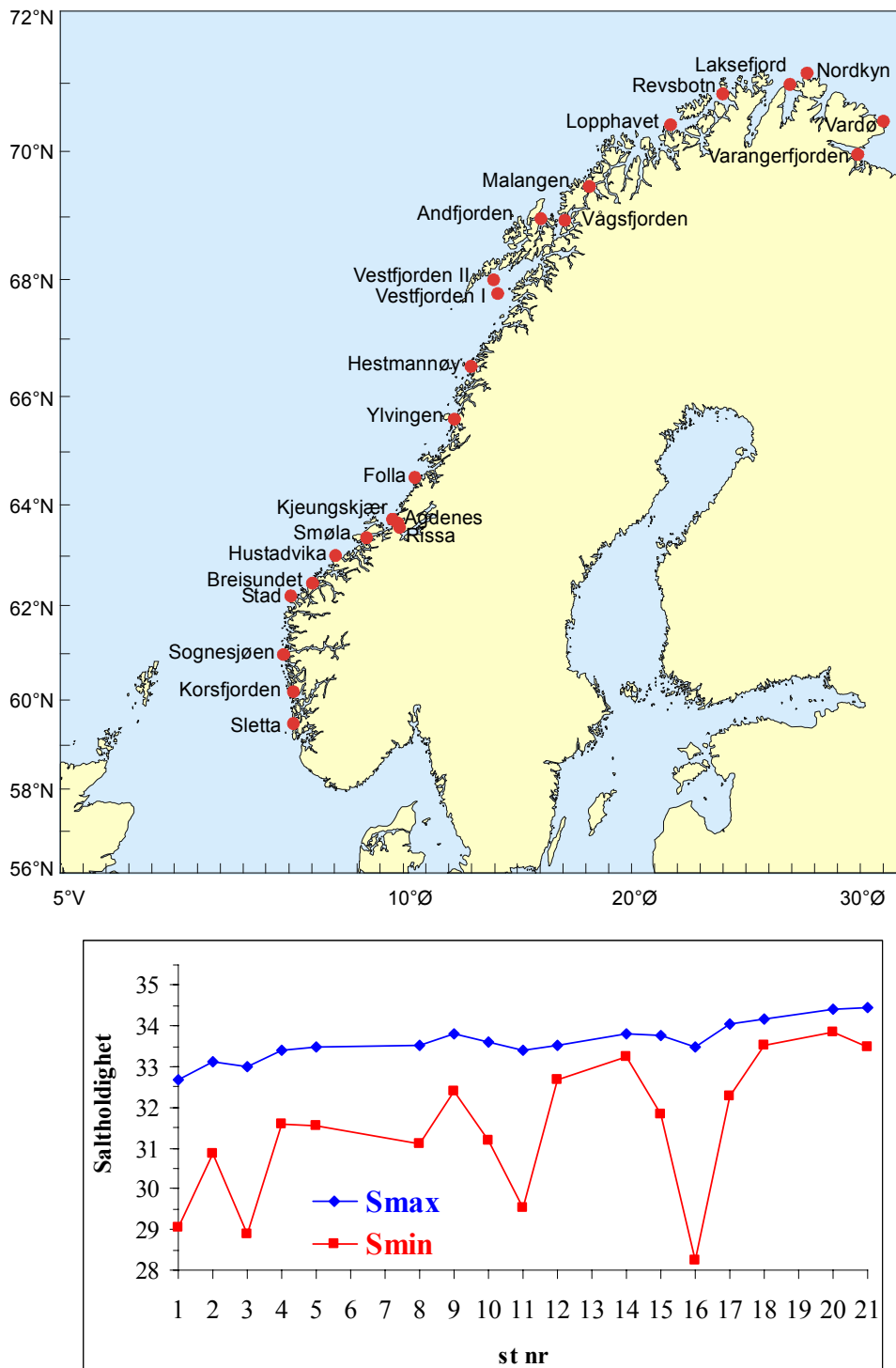
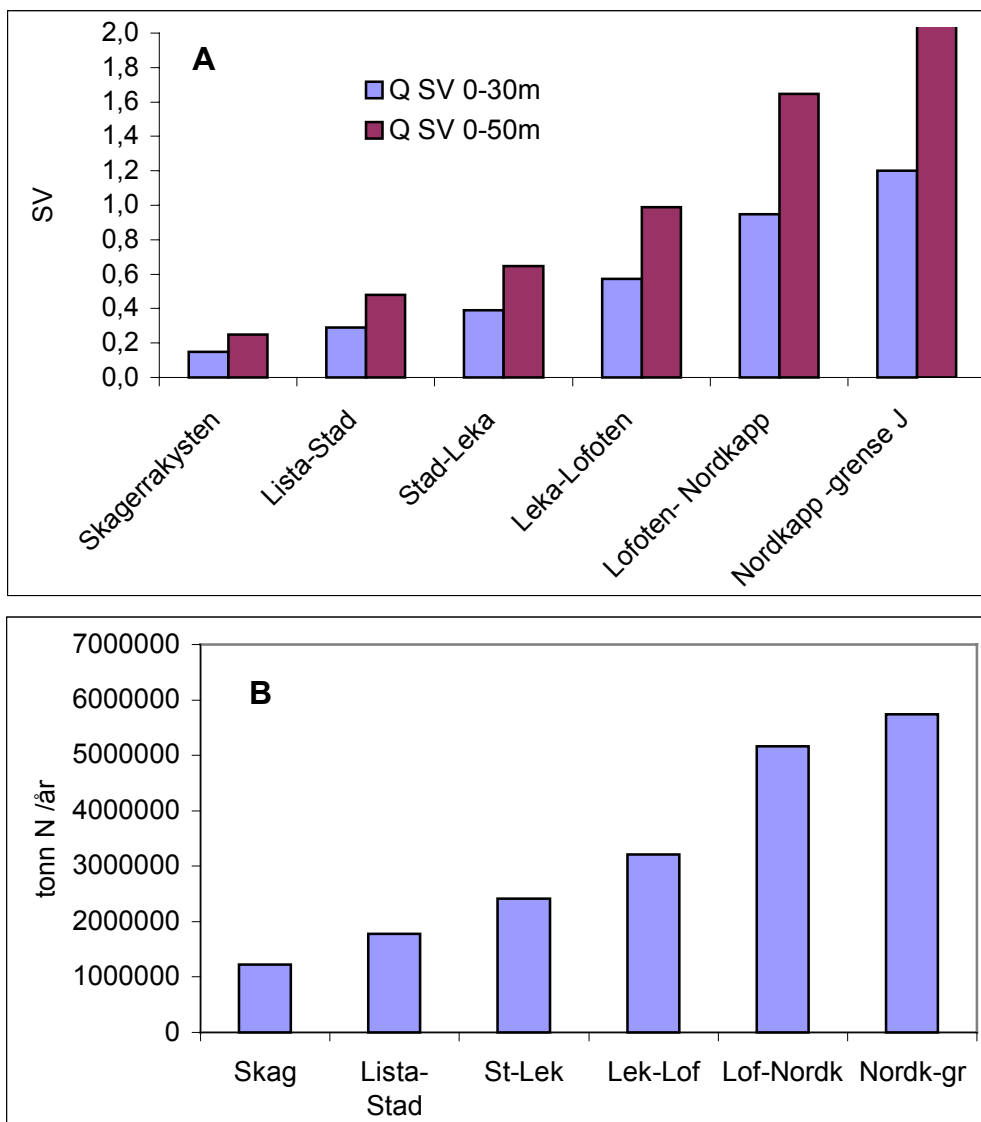


Fig. 7. Lower panel. Maximum (winter) and minimum (summer) salinity at coastal stations located from Sognesjøen (St. no. 1) north of Bergen to Vardø (St. no. 21) in eastern Finmark. The stations are long-term (1936-present) monitoring stations taken from the coastal liner that sails between Bergen and Kirkenes close to the Russian border. Upper panel. The location of the stations in the numbered order from south to north.

water dominates over the effect of lowered salinity due to freshwater runoff from Norway. The mixing of Atlantic water has two main effects: it dilutes the NCC and results in an increase in the total volume transport.

Using the increase in salinity (Fig. 7), we have calculated the increase in flow of the NCC. In doing this we have extended the calculation upstreams into Skagerrak using salinity data for this coastal region (Anon. 1997). The volume transport in the upper 30 m of the NCC in Skagerrak outside Arendal has been estimated to 0.15 Sv (1 Sv (Sverdrup) = $10^6 \text{ m}^3 \text{ s}^{-1}$). This flow has more than doubled at Stad and increased by almost an order of magnitude in eastern Finnmark (Fig. 8 A). Part of this increase in flow represents water that leave the NCC and are being mixed into the Atlantic water that are flowing northwards in the Norwegian Sea and into the Greenland Sea.



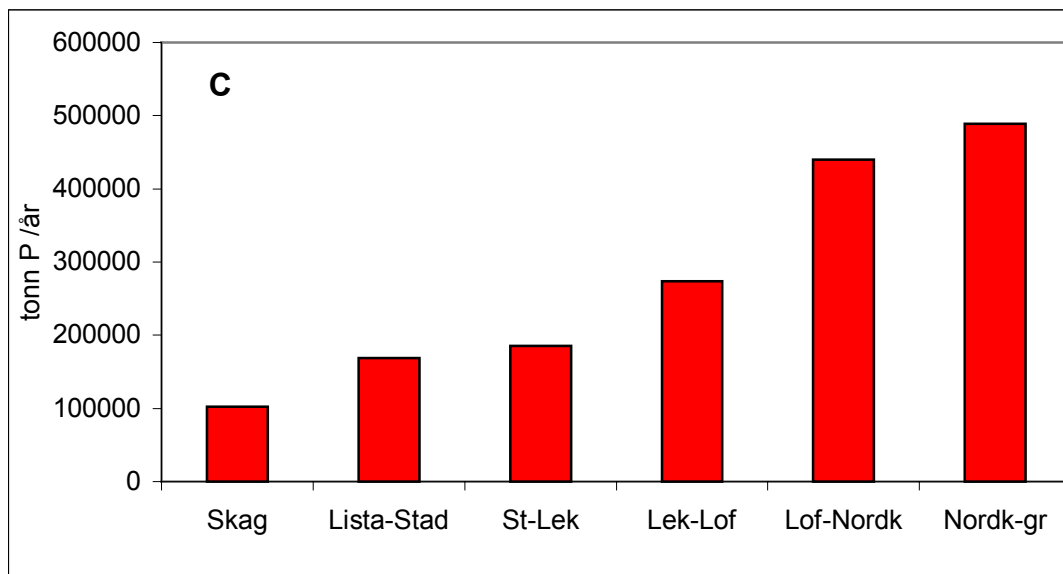


Fig. 8. A) Estimated volume flow (in units of Sverdrup, which equals $1 \text{ million m}^3 \text{ s}^{-1}$) for the Norwegian Coastal Current (NCC) for coastal areas from Skagerrak in south to North Cape – Russian border in north for the upper 30 and 50 m. Estimated annual transport of nitrogen (B) and phosphorus (C) in the NCC (0-30 m) based on the volume transport and typical N and P concentrations .

The flow of water in the NCC brings with it the natural content of nitrogen and phosphorus. Using typical concentrations of total nitrogen (about $12 \text{ }\mu\text{M}$) and total phosphorus (about $0.5 \text{ }\mu\text{M}$), the annual transports of nitrogen and phosphorus has been calculated (Fig. 8 B and C). The annual transports at Stad are about 1.8 million tons of total nitrogen and 0.17 million tons of total phosphorus.

3.4 Nutrient load and budget for fjords

The model “Fjordmiljø” (Fjord-Environment) (Aure and Stigebrandt 1990, Stigebrandt 2001) has been used to calculate the nutrient load to selected fjords, in particular the Trondheimsfjord. The model calculates the water exchange between the fjord and the coastal water mass outside the fjord using changes in water density outside the fjord, tides, and freshwater discharge to the fjord as the driving forces for exchange. Morphometric parameters for the fjord that are used as input to the model calculations, are sill depth, cross-sectional area above the sill, area of the fjord, and volume of the fjord. The model calculates residence times of water for various depth layers. The nutrient input to the fjord is being diluted and partly transported out of the fjord with the water exchange. The model calculates the increase in nutrient flux and concentration due to the local nutrient input.

The model also includes sedimentation of organic material from the upper euphotic zone and calculates the oxygen consumption and oxygen concentration in the basin water.

3.5 Nutrient concentration data

The Institute of Marine Research has monitored nutrients and oxygen concentrations in 30 selected fjords north of Stavanger since 1980 (Fig. 9). We have used data from some of these fjords located north of 62°N to examine nutrient concentration levels and trends over the recent decades.



Fig. 9. Selected fjords where long-term monitoring of hydrography, nutrients and oxygen are carried out by Institute of Marine Research.

We have used data on nutrients (nitrate and inorganic phosphate) for the NCC between 62 and 64°N for the winter and spring periods in 1990-95. These data have been analysed in relation to salinity to examine if there are any signs of elevated nutrient concentrations.

4. Results from the Screening Procedure

4.1 Scaling of nutrient input to the transport in the NCC

The Norwegian nutrient inputs to the 4 coastal regions shown in Fig. 5 have been scaled relative to the flux of nutrients in the NCC. Fig. 10 shows the nutrient inputs as percentage of the flux in the NCC. For comparison we have included the nutrient inputs to the coastal regions south of 62°N, the Skagerrak region and the coast of western Norway between Lista and Stad.

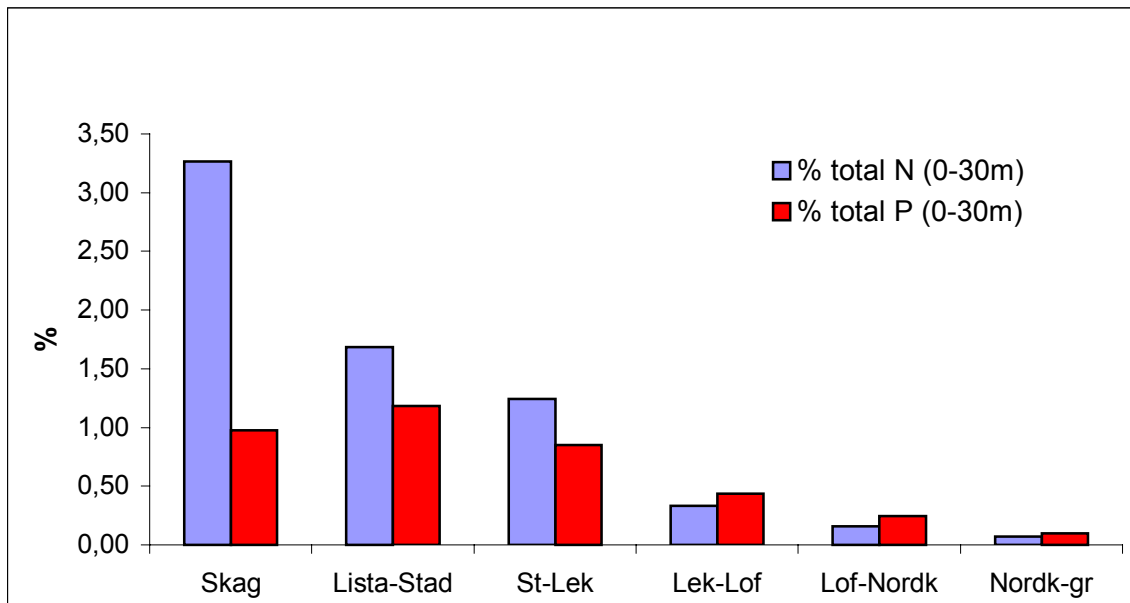


Fig. 10. Norwegian annual inputs of total nitrogen and phosphorus (including natural background runoff) expressed as percentage of the natural flux of these nutrients in the upper 30 m of the Norwegian Coastal Current for coastal areas from Skagerrak to the Russian border. The four areas north of 62°N are Stad-Leka, Leka-Lofoten, Lofoten-North Cape, and North Cape-Russian border.

The nutrient input to the region Stad-Leka is about 1 % of the natural transport in the NCC. This decreases to about 0.4, 0.2 and <0.1 % for the three regions further north (Fig. 10). The relative nutrient input for the region Stad-Leka is comparable to that for the region Lista-Stad and, for phosphorus, also to that for Skagerrak. The N input to Skagerrak is somewhat higher at about 3 %, and this is mainly input to the outer Oslofjord area (Anon. 1999). For comparison the nutrient input to the coastal regions of the southeastern North Sea is much higher (25-50 %) when scaled to flux (NSTF 1993).

The gradual increase in salinity northwards along the coast (Fig. 7) demonstrates the effective mixing and dilution of the NCC and of the Norwegian freshwater discharges and nutrient input from land. The scaling shows that the Norwegian nutrient input (including the natural background) does not have the potential to have a significant influence on nutrient levels and budgets in the coastal areas.

4.2 Scaling of nutrient input to the Trondheimsfjord

The Trondheimsfjord is a large fjord in mid Norway (Fig. 11). It receives proportionally a large fraction of the nutrient input to the coastal region Stad - Leka, with 36 % for nitrogen and 25 % for phosphorus (Fig. 12). The land surrounding the Trondheimsfjord is an important agricultural area, and the population density is by Norwegian standards fairly high with Trondheim as the third largest city in Norway (about ¼ million). Thus 46-47 % of the estimated nutrient input from agriculture for the Stad - Leka region comes to this fjord. The corresponding figures for input from human population (municipal wastewater and scattered population) are 43-49 % (for N and P, respectively). There is virtually no aquaculture in this fjord.

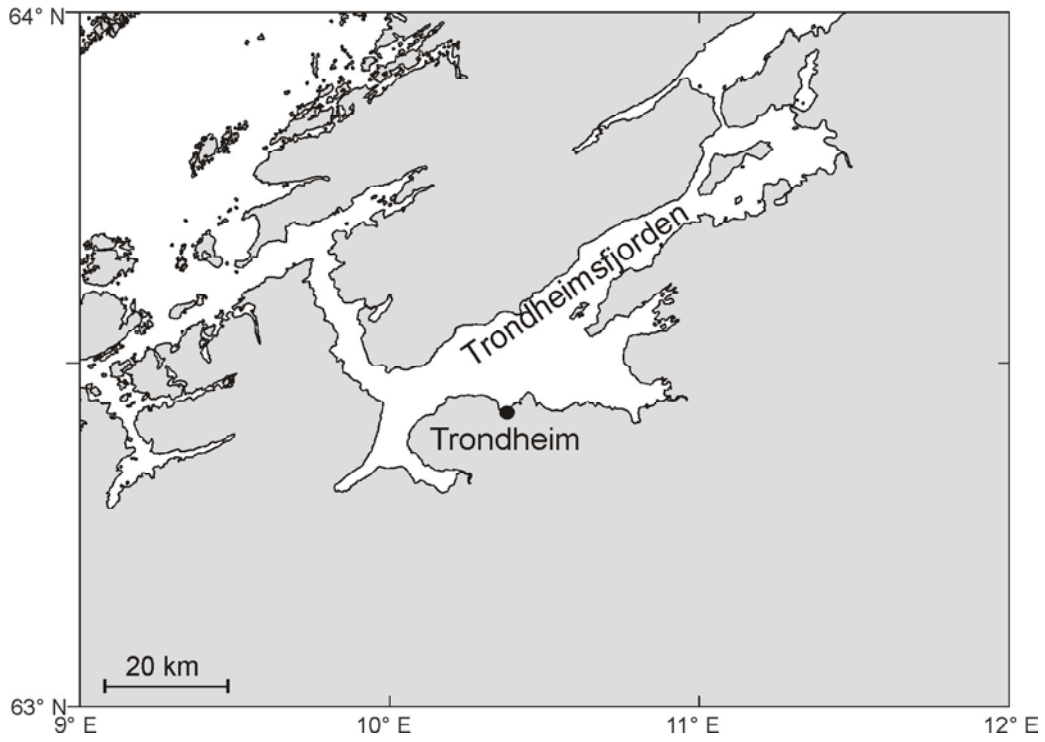


Fig. 11. Map of the Trondheimsfjord.

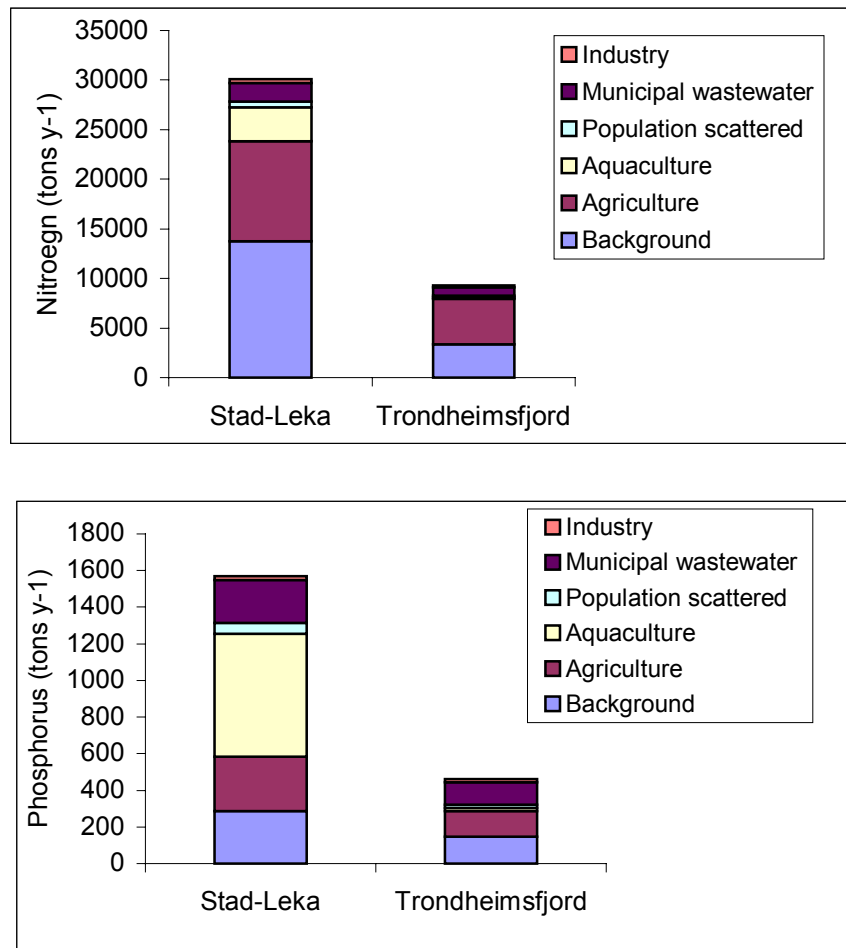


Fig. 12. Total annual input of nitrogen (upper panel) and phosphorus (lower panel) from different sources to the coastal region Stad-Leka and to the Trondheimsfjord contained in that region.

Results from application of the model “Fjordmiljø” to the Trondheimsfjord is summarised in Table 1. The fjord has a sill depth of 190 m and a total area of 1260 km². The mean residence time for water in the upper 30 m is estimated to be 25 days, whereas the basin water is fairly stagnant with an estimated residence time of about 5 years. The input of nutrients from anthropogenic sources results in an increase in concentration of 6 % for nitrogen and 4 % for phosphorus, above their natural background concentrations (assumed to be 12 and 0.45 µmoles l⁻¹ for N and P, respectively).

Table 1. Results from the model “Fjordmiljø” applied to the Trondheimsfjord.

INPUT	Value	% change
Fjord parameters		
Sill depth	190 m	
Width at sill	3 km	
Cross-sectional area at sill	4.6 10 ⁵ m ²	
Length	125 km	
Area	1260 km ²	
Volume 0-30 m	3.8 km ³	
Physical driving forces		
Tidal amplitude	0.9 m	
Fresh water discharge	600 m ³ s ⁻¹	
Density variation parameter M	55 kg m ⁻²	
Anthropogenic nutrient input		
Nitrogen	5.932 tons y ⁻¹	
Phosphorus	317 tons y ⁻¹	
OUTPUT		
Residence time for water in 0-30 m	25 d	
Increase in nitrogen concentration	0,76 µmol l ⁻¹	6 %
Increase in phosphorus concentration	0.02 µmol l ⁻¹	4 %

If there were no water exchange, the total annual input of nitrogen from anthropogenic sources would result in an increase in concentration in the upper 30 m of about 11 µmoles l⁻¹, or an approximate doubling of the natural background. Due to the relatively short residence time, however, most of the nutrients do not remain but is exported from the fjord, either as inorganic nutrient or as bound into organic compounds after having been taken up and used by phytoplankton. Due to the slow sinking rates of phytoplankton (usually less than a few m per day), most of the nutrients used in production do not sink fast enough to reach the sill depth before they are advected out of the fjord. Therefore local input of nutrients will have insignificant influence on the oxygen conditions in the deep water.

4.3 Consideration of nutrient input to other local areas

The case of the Trondheimsfjord considered in the previous section, is the area with the concentrated largest input of nutrients to any coastal or fjord area north of 62°N. The model “Fjordmiljø” has been applied to several fjords that span from small to large fjords. In general, the water exchange tends to be greater in small fjords reflecting a larger ratio of cross-sectional area of the fjord mouth opening to the total fjord area. The large fjords in northern Norway, such as Ofotfjord and Tysfjord in Nordland, Malangen and Lyngenfjord in

Troms, and Altafjord, Laksefjord, Porsangerfjord, and Tanafjord in Finnmark, all have wide openings and deep sills. The low nutrient input and the generally good water exchange for both large and small fjords, make the relative nutrient loading smaller than estimated for the Trondheimsfjord. In the following we provide some commentary on other areas that appear to have relatively high input of N and/or P as shown in Fig. 6 for the separate statistical areas.

Statistical area 109 comprises the Sunndalsfjord. The relatively high N input to this region (1600 tons y^{-1}) is due to the river Driva and about 2/3 is estimated to be natural background runoff. The Sundalsfjord is a relatively long and contained fjord. Nevertheless the water exchange is good due to a deep sill (about 140 m) and two entrances each about 1 km wide.

Areas 117 and 118 have relatively high input of P (95-107 tons y^{-1}). These areas comprise the islands Hitra and Frøya and the main source of input is aquaculture. Hitra and Frøya are in the outer coastal region and the water exchange is very high.

Area 139 has the single highest input of N (5.700 tons y^{-1} ; see Fig. 6). This area contains the River Namsen and the input of N contains mainly natural background runoff (about 85 %).

Area 143 has an input of about 160 tons y^{-1} of P. This area contains the island Leka in the outer coast and the input is mainly due to aquaculture. The water exchange is very good.

Areas 158-160 comprise islands (Træna a.o.) and fjords (Melfjord, Glomfjord a.o.) in Nordland. The input of P is mainly from aquaculture. In Glomfjord there is also some input of N from industry (fertiliser (ammonium) production). The fjords are openly connected with the outer coast and the water exchange is very good.

Areas 177-181 are located in the Svolvær-Lødingen area in Lofoten. Area 185 comprises Sortland and areas 193-197 comprise Finnsnes and Malangen in Troms. The input of P to these area is mainly from aquaculture. The N input in area 196 is mainly natural background runoff in the River Målselv. Area 197 comprises the city Tromsø. The water exchange is generally very good in all these areas.

Area 206 comprises Skjervøy in Troms and areas 211-215 comprise coastal areas and fjords (Altafjord a.o) in western Finnmark. The input of P to these areas is mainly from aquaculture. The N input to area 212 is mainly background runoff in the River Alta. The water exchange is generally very good in these areas.

Area 234 comprises the River Tana. The inputs of N and P are mainly background runoff.

There are no large point sources of input of nutrients to any coastal area north of 62°N. Instead the input is from many small sources scattered over the long coastal stretch and the large coastal area from outer skerries and islands to inner fjords. The inputs are also more or less protracted over time without very pronounced seasonality. The many and scattered small sources of input combined with good water exchange make it very unlikely that the nutrient input can cause detectable local elevated nutrient concentrations. As we have seen, the magnitude of all sources summed are so small in relation to the receiving water body that is also can not lead to elevated nutrient concentration at the regional scale (Fig. 10).

There are some local areas with restricted water exchange, e.g. polls. These are very special environments often with naturally anoxic conditions in the deeper water. The tidal difference

increases from south to north in Norway. At 62°N it is about 1.0-1.5 m and in Finmark about 2-3 m. The high tidal difference causes considerable water exchange across even shallow sills. This makes these environments less sensitive to nutrients and organic loading than similar polls in southern Norway where there is less tidal amplitude. The local and restricted nature of polls are such that we do not consider them problem areas per se, but rather as special environments that receive special attention by local management authorities. Aquaculture is generally excluded and wastewater is either treated or diverted from such areas.

4.4 Nutrient concentration data from NCC and fjords

Nutrient concentration data from the NCC between 62 and 64°N from January to June 1991 are summarized in Fig. 13. Nitrate concentrations in the upper 30 m have been plotted against salinity for 5 different time periods from winter to summer (January, February/March, April, May, and June). In January and February/March there is fairly strict inverse relationship between nitrate and salinity. This is before the initiation of the spring bloom, and physical mixing is mainly controlling the nitrate concentration. The decreasing concentration of nitrate with decreasing salinity reflects the low nitrate concentration in Norwegian freshwater and in the resulting brackish surface layers in fjords.

In April the spring bloom is progressing in the inner coastal areas with low salinity but not in the offshore area with high salinity. The biological consumption causes more variation in the plots of nitrate versus salinity.

The data in Fig. 13 from the NCC just north of 62°N show no signs of elevated nutrient concentrations from local runoff, but rather in contrast, show the effect of nutrient poor water from the fjords on the nutrient levels in the inner (low salinity) parts of the NCC.

Fig. 14 shows nutrient concentration data for nitrate and inorganic phosphate from four selected fjord areas, Glomfjord and Sørfolda in Nordland, Malangen in Troms, and Altafjord in Finmark. The data are from 30 m depth in November from 1981 onwards. The nitrate concentrations were typically 6 $\mu\text{mol l}^{-1}$ or less, whereas the phosphate concentrations were

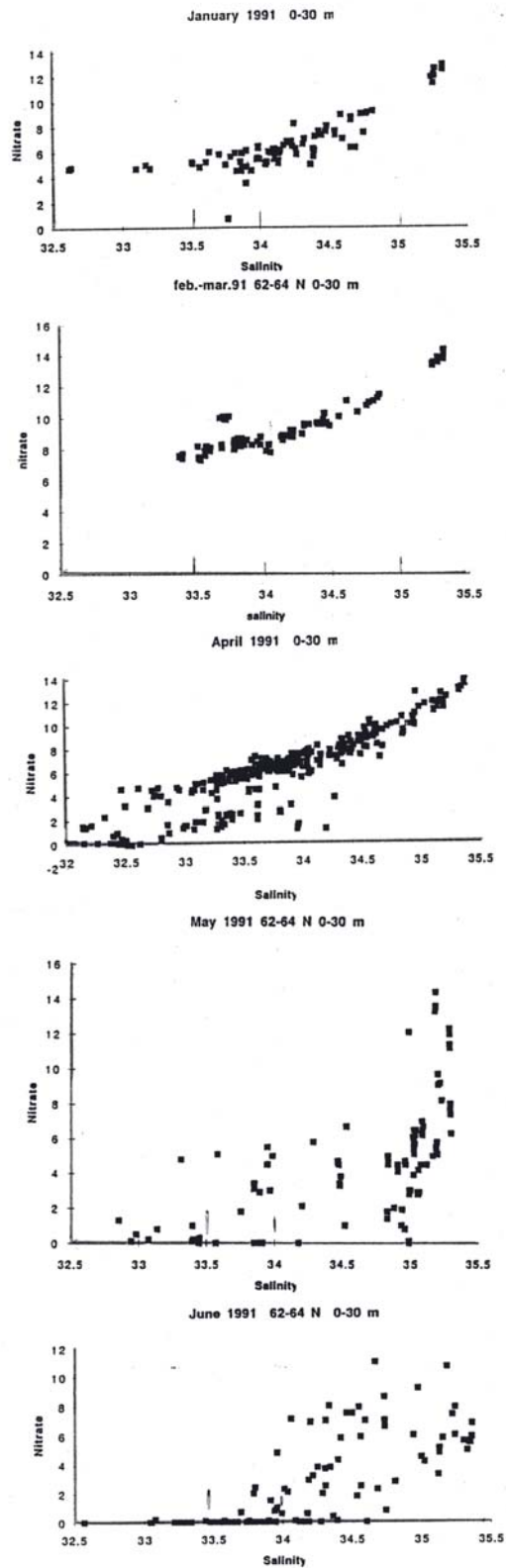


Fig. 13. Plots of nitrate concentration ($\mu\text{mol l}^{-1}$) versus salinity for samples from the upper 30 m from the Norwegian Coastal Current between 62 and 64°N for January, February/March, April, May, and June 1991.

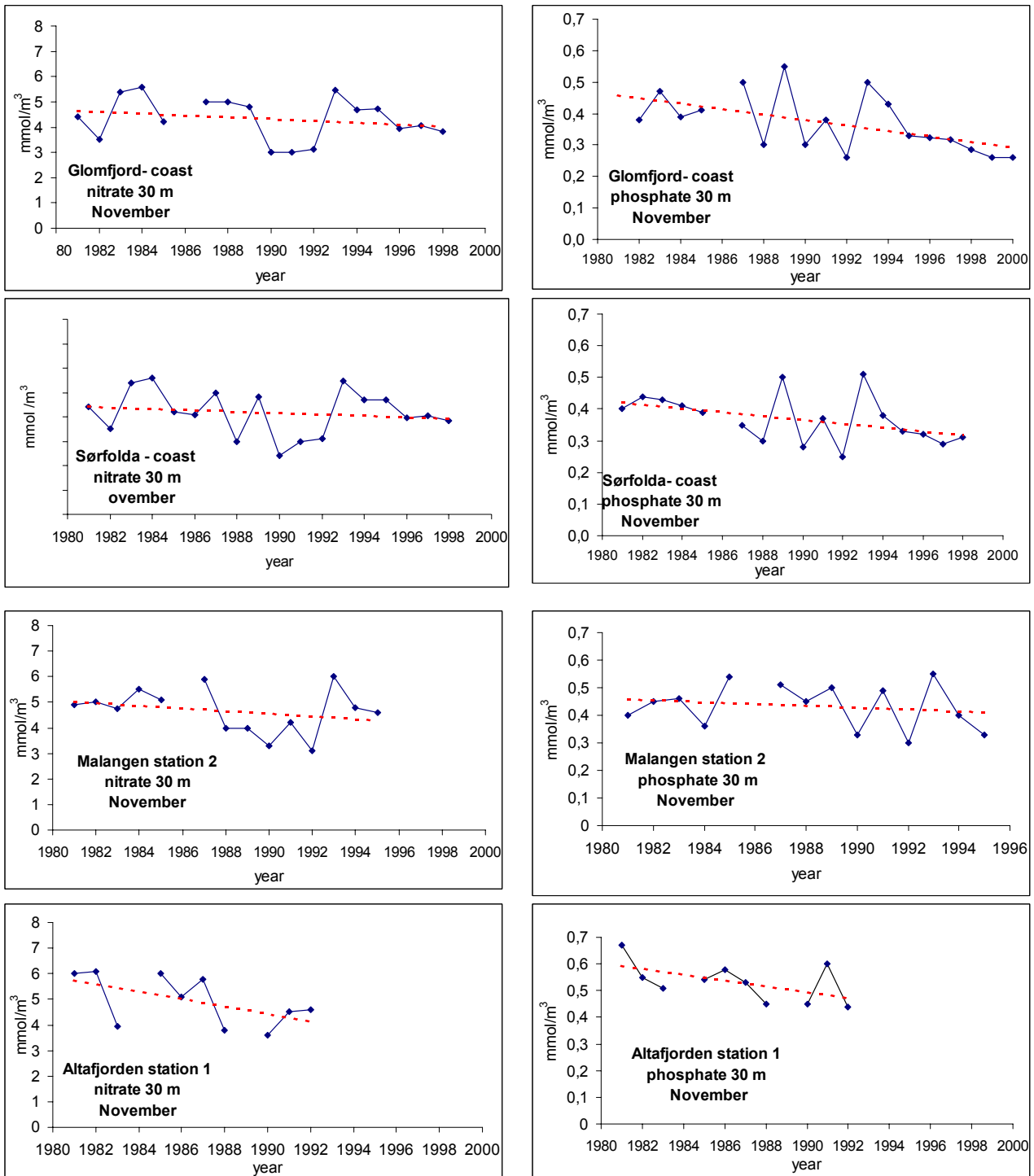


Fig. 14. Time series from 1981 of nitrate (left panels) and inorganic phosphate (right panels) from monitoring stations in four fjords: Glomfjord, Sørfolda, Malangen, and Altafjord. See Fig. 9 for location of these fjords.

usually around $0.5 \mu\text{mol l}^{-1}$ or less. The nutrient concentrations tend to show decreasing trends. The reason for this could be related to changes in hydrographical and climatic conditions as a reduction in salinity in the coastal water has been observed in recent decades (Sætre et al. 2003).

5. Discussion

The overall nutrient loading from Norwegian sources to the coastal areas north of 62°N is low, in total about 30.000 tons of nitrogen and 3.400 tons of phosphorus from anthropogenic sources. The inputs are from many small sources scattered over a very long coastline (1.500 km) and a very large coastal area. The coast is flushed by the Norwegian Coastal Current, and the residence time of water in any coastal area and fjords is generally low. The NCC is effectively diluted through mixing with Atlantic water as it flows northwards, as shown by progressively increasing salinity. Scaled to the nutrient flux in the receiving marine water of the NCC, the Norwegian nutrient inputs from anthropogenic sources contribute 1 % or less to the nutrient budget. The inputs are therefore too small to have a material effect on nutrient concentrations.

The largest and most concentrated input of nutrients occurs to the Trondheimsfjord. This fjord receives an annual input of about 5.900 tons of nitrogen and 320 tons of phosphorus, or about 20 % of the input of nitrogen and 10 % of the input of phosphorus for the whole area north of 62°N. These inputs are estimated to lead to increases of 6 % and 4 % in the concentrations of total N and total P, respectively, in the upper 30 m of the fjord. The calculation is based on a mean, steady state consideration. In reality there could be shorter periods where the local nutrient input could have an effect above the mean condition. However, this is not likely to lead to any detectable eutrophication effects. It would in reality be very difficult to measure any increase in nutrient level of the order of 5 %. The marginal magnitude of nutrient enrichment for the Trondheimsfjord is well below the criteria used to assess lowered water quality in Norway (SFT), and is an order of magnitude lower than what is considered to be elevated nutrient concentrations (50 % above some background reference) in the OSPAR comprehensive procedure.

The nutrient inputs from anthropogenic sources are widely distributed and there are no single small areas that receive a very high relative load (Fig. 7). The inputs to the different statistical areas are generally low when compared to the surface area of the receiving marine water body in the area. In addition to the wide geographical spread of the inputs, there is also a temporal spread in that the inputs are continuous over time. With the generally good water exchange, the many small and widely distributed inputs are very unlikely to cause any elevated nutrient levels even at the local scale.

There are some small areas with restricted water exchange, such as polls. Some of these are located at the transition between fresh water and the marine environment. These may be meromictic lakes or being in the process of becoming meromictic lakes. A meromictic lake is a lake with freshwater in the upper layer but old and relict saltwater in the deeper layer. Some polls have a shallow sill above mean sea level, but with saltwater inflow at high tide. An example is the Rossfjordvatn in Malangen in Troms. Due to the still rising land after the last ice age in this part of Scandinavia, this will gradually change over the next century and the Rossfjordvatn will turn into a true meromictic lake shut off from the sea (unless sea level rise due to global warming overrides the effect of land rise, or the channel are kept open by human intervention). Ordinary polls with sill depth below sea level have fairly good water exchange due to the high tidal amplitude in this part of Norway. While polls are sensitive to organic enrichment, their small extent and sheltered location make them very special environments that receive much attention from local authorities.

With the generally very low nutrient load to coastal areas and fjords north of 62°N, it is very unlikely that there are any eutrophication effects. There are a number of studies that have addressed phytoplankton production, benthos, fish communities etc. from this part of Norway. The University of Trondheim has studied areas in the Trondheimsfjord, The University of Tromsø has investigated fjords and coastal areas around Tromsø, and the College in Bodø (Distriktshøyskolen) has investigated fjords around Bodø. The Institute of Marine Research has regular and long-term monitoring of fjords and coastal waters over the whole area. There has been a large number of investigations of environmental conditions and recipient capacity in relation to consideration of wastewater discharge and treatment from local communities and localisation of aquaculture plants. From this large amount of studies there are no indications that there are eutrophication effects.

6. Conclusion

The nutrient loading to the coastal areas and fjords north of 62°N is overall very low and contributes very little to the natural budgets of nutrients both regionally and locally. We therefore conclude that this area is a non-problem area with regard to eutrophication.

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