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BOHUSKUSTENS VATTENVÅRDSFÖRBUND

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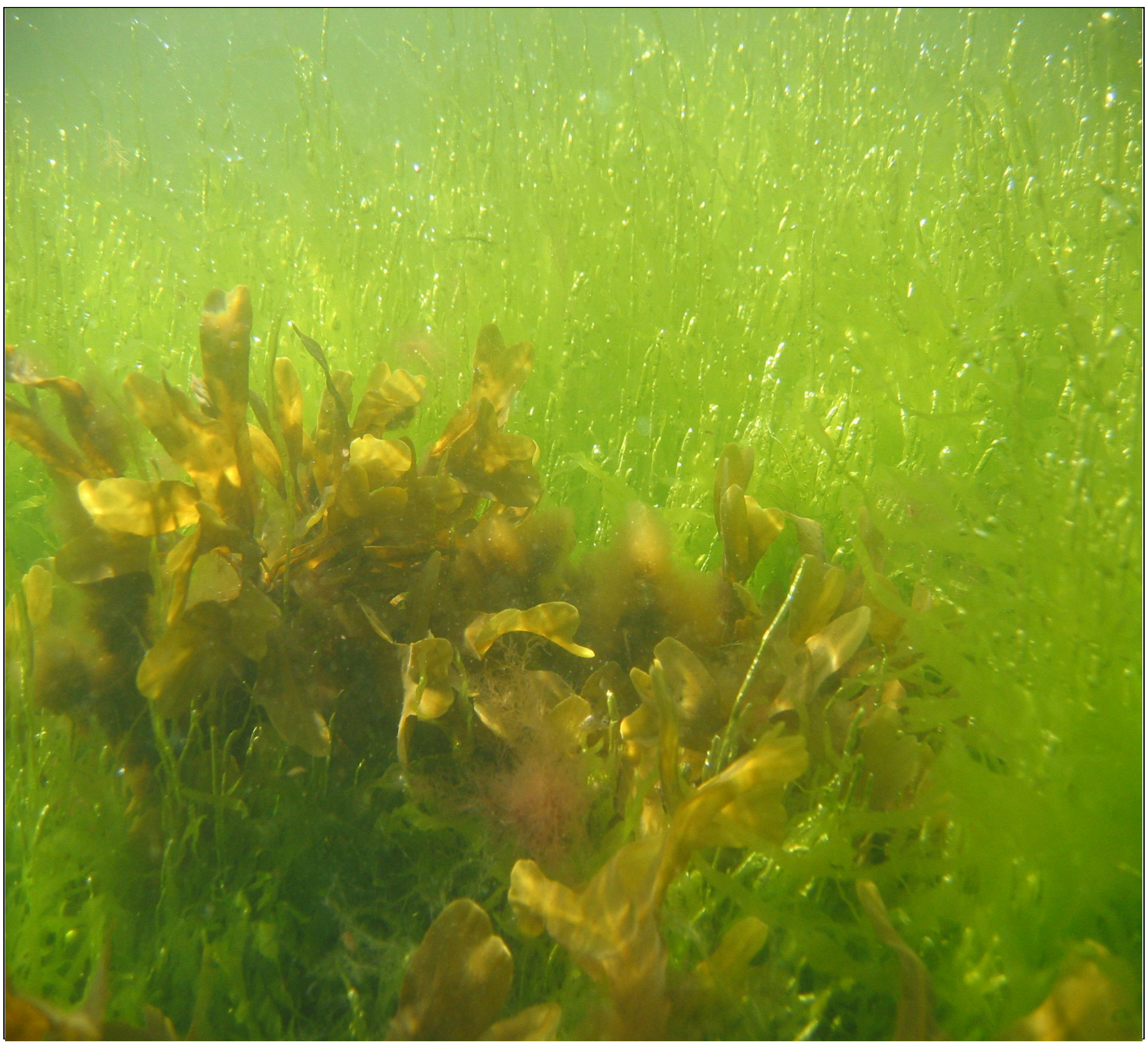
Effects of reduced phosphorous discharge from Ryaverket



Norsk institutt for vannforskning

RAPPORT

Hovedkontor
Postboks 173, Kjelsås
0411 Oslo
Telefon (47) 22 18 51 00
Telefax (47) 22 18 52 00
Internet: www.niva.no

Sørlandsavdelingen
Televeien 3
4879 Grimstad
Telefon (47) 37 29 50 55
Telefax (47) 37 04 45 13

Østlandsavdelingen
Sandvikaveien 41
2312 Ottestad
Telefon (47) 62 57 64 00
Telefax (47) 62 57 66 53

Vestlandsavdelingen
Nordnesboder 5
5005 Bergen
Telefon (47) 55 30 22 50
Telefax (47) 55 30 22 51

Midt-Norge
Postboks 1264 Pirsenteret
7462 Trondheim
Telefon (47) 73 87 10 34 / 44
Telefax (47) 73 87 10 10

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The task has included compilation of literature data and assessing the effects of a further annual reduction of 12 tons of total phosphorous (tot-P) from Ryaverket waste water treatment plant outside Göteborg, Sweden. As a comparison it can be mentioned that the discharge from the plant in 2003 was 44 tons of tot-P. The assessment shall include effects on the phosphorous concentrations in the recipient, as well as the effects on phytoplankton and macrovegetation in the recipient and along the Bohus coast. A compilation of all significant phosphorous supply to the area has been made, including transport by Göta Älv with tributaries, discharges from Ryaverket, and calculations of the transport from the sea by the return current induced by the outflow from Göta Älv. The compilation has been made on a monthly basis in order to sort out seasonal variation in the effects on biota. Hydrological data from stations in the Bohus Coast monitoring program have also been compiled and compared with Norwegian environmental quality criteria. Effects on plankton, measured as chlorophyll a, and on the macroalgal community have been analysed and related to collected data, and have been discussed in relation to general trends along the Bohus coast. The phosphorous discharges from Ryaverket and via the return current from the sea have decreased significantly since 1990. The return current and Göta Älv are now the dominant sources of phosphorous to the recipient, and the Ryaverket contribution is about 20 %. It has not been possible to verify any clear correlation between the supply of phosphorous to the recipient and its vegetation. This is largely due to the recipient characteristics with varying salinity, high water exchange rate and currents. A further annual reduction with 12 tons of phosphorous from Ryaverket will probably not result in any noticeable effects, mainly due to the characteristics of the area and the variations in the large phosphorous transports from Göta Älv and via the return current. There is a general trend of decreasing phosphorous cocentrations in the sea along the Bohus coast, but this has not resulted in decreasing chlorophyll concentrations but rather increasing, in spite of high N:P-ratios. This should be investigated further.

Fire norske emneord	Fire engelske emneord
1. Renseanlegg	1. Waste water treatment plant (WWTP)
2. Fosforutslipp	2. Phosphorous discharge
3. Eutrofiering	3. Eutrophication effects
4. Estuar	4. Estuary

Prosjektleder Martin Isæus

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Report concerning the effects of reduced phosphorous discharge from Ryaverket

A study by NIVA for
Bohuskustens vattenvårdsförbund.

Preface

The discharges from Ryaverket wastewater treatment plant outside Göteborg and the effects of implemented purification has for some time engaged authorities, scientists, media and the public of the Swedish West Coast. Behind this lies the fact that Gryaab, the operator of Ryaverket, has among other things been prescribed by environmental authorities to reduce its total phosphorous discharges by 12 tons annually. The costs of achieving this is about 150 million Swedish crowns and the debate has circled around whether this reduction would be meaningful and if the money will be well spent or not. Gryaab has now initiated another investigation to investigate the effects of the prescribed reduction on the recipient. Pege Schelander of Bohuskustens Vattenvårdsförbund has been entrusted with the ordering of consultations in this matter and with being the project leader.
Norsk Institutt for Vannforskning, NIVA, is one of the four organizations/groups who have accepted this task, the other three being Kristinebergs Marina Forskningsstation, Tjärnö Marinbiologiska Laboratorium and DHI – Danish Hydraulic Institute. Quality controller of the NIVA project has been Torgeir Bakke.

Oslo, 20.02.2005

Martin Isæus
Project Manager, NIVA-project

Contents

Summary

The task has included compilation of literature data and assessing the effects of a further annual reduction of 12 tons of total phosphorous (tot-P) from Ryaverket waste water treatment plant outside Göteborg, Sweden. As a comparison it can be mentioned that the discharge from the plant in 2003 was 44 tons of tot-P. The assessment shall include effects on the phosphorous concentrations in the recipient, as well as the effects on phytoplankton and macrovegetation in the recipient and along the Bohus coast. A compilation of all significant phosphorous supply to the area has been made, including transport by Göta Älv with tributaries, discharges from Ryaverket, and calculations of the transport from the sea by the return current induced by the outflow from Göta Älv. The compilation has been made on a monthly basis in order to sort out seasonal variation in the effects on biota. Hydrological data from stations in the Bohus Coast monitoring program have also been compiled and compared with Norwegian environmental quality criteria. Effects on plankton, measured as chlorophyll *a*, and on the macroalgal community have been analysed and related to collected data, and have been discussed in relation to general trends along the Bohus coast. The phosphorous discharges from Ryaverket and via the return current from the sea have decreased significantly since 1990. The return current and Göta Älv are now the dominant sources of phosphorous to the recipient, and the Ryaverket contribution is about 20 %. It has not been possible to verify any clear correlation between the supply of phosphorous to the recipient and its vegetation. This is largely due to the recipient characteristics with varying salinity, high water exchange rate and currents. A further annual reduction with 12 tons of phosphorous from Ryaverket will probably not result in any noticeable effects, mainly due to the characteristics of the area and the variations in the large phosphorous transports from Göta Älv and via the return current. There is a general trend of decreasing phosphorous cocentrations in the sea along the Bohus coast, but this has not resulted in decreasing chlorophyll concentrations but rather increasing, in spite of high N:P-ratios. This should be investigated further.

1. Task and disposition

The task was to assess the effects of reducing the Ryaverket discharges (12 tons annually) on:

1. The concentrations of PO_4-P and tot-P
2. The production of phytoplankton and macrovegetation

in the local recipient outside Ryaverket and along the Bohus coast. The task has also contained a survey of compiled literature and a list of this literature, with comments, is attached as Appendix 7.1.

The effects of the prescribed phosphorous reduction from Ryaverket (12 tons annually) must be assessed in relation to the concentrations and transports prevailing today in Göta Älv, in the river estuary and in the coastal water along the Bohus coast. The phosphorous concentration is determined on the one hand by discharges to the coast, especially to the Göta Älv estuary, but on the other also strongly by the exchange with salt water from outside the areas of investigation. In particular, the phosphorous from the return current at the Göta Älv mouth can be expected to influence the phosphorous limited production of phytoplankton in the river estuary and in the inner Göteborg archipelago. In the outer archipelago the natural transport of phosphorous is so great that a measurable effect of the prescribed reduction is unlikely. As for phosphorous supply via watercourses, there are often big variations between seasons and between years. To be able to identify the effects of different measures it is important to distinguish between natural (e.g. climate related) variations, and variations that are the effects of discharges from Ryaverket.
The production of phytoplankton and macroalgae can be theoretically computed from the phosphorous supply (given that this is the limiting factor) and known annual production variations but such analyses will suffer from high uncertainty. In the verdict from Svea Hovrätt only discharges of total phosphorous (tot-P) are mentioned, but an assessment of how large a part of bioaccessible phosphorous will be reduced should be made in connection with the survey of literature and other data. The phytoplankton production can be expected to respond quickly to a change of concentration of the limiting nutrient during periods when light and water temperature are not limiting factors, but these patterns have in practice not turned out to be obvious, since the connection between cause and effect is not so simple. Changes in phytoproduction can occur by jumps, so that a small change may not cause any effect on the phytoplankton community, or it may cause a great effect. No studies have been able to show when such jumps occur, but there are lots of studies dealing with the difficulty in predicting the connections between the availability of nutrients and the changes in the plankton community (review Cloern 2001).
Mesocosmic experiments at NIVA have shown that a change from eutrophy favoured species of macroalgae to a more normal composition can occur with a delay of some year after a threshold value has been passed (Hartvig Christie by word of mouth). This makes prediction difficult. Out from these premises and with the help of literature data we should be able to make a qualified guess about longtime changes in the production of phytoplankton and macrovegetation, rather than to make a prediction.

To solve this task we have chosen the following approach:

- Compile and calculate all supplies of total phosphorous (tot-P) and phosphate phosphorous (PO_4-P) from watercourses, the sea and Ryaverket on a monthly basis.
- Assess the Ryaverket contribution of tot-P and PO_4-P to the recipient relative to other sources.
- Search for effects of Ryaverket discharges on plankton and benthic flora by statistical analysis.
- Make a qualified guess regarding the effect of 12 tons further reduction of tot-P

2. Supply of phosphorous

2.1 Supply of phosphorous via watercourses and from Ryaverket

2.1.1 Introduction and description of the region

It is well known that the Ryaverket waste water treatment plant is the greatest single point source of both nitrogen and phosphorous to the coastal water outside Göteborg (downstream the Älvsborg Bridge) and in the Göta Älv drainage area. Equally well known is the fact that the river and its transport of nutrients strongly influence the area. There is, however, a lack of detailed calculation and account of how nutrient transports to the coastal water outside Göteborg develop over time. Consequently, in this chapter the river supply of phosphorous and the direct discharges from treatment plants are calculated and assessed as compared with the planned reduction of 12 tons of P at Ryaverket. The amount of bioavailable phosphorous has also been roughly estimated/ calculated. Apart from phosphorous, calculations of nitrogen transports and N:P ratios have also been made. The calculations are made on a monthly basis over the period 1990-2003. Besides own calculations (based upon data supplied by from the principal) and the reference material mentioned in the offer, results from other sources, such as ”Kväve och fosfor to Vänern och Västerhavet” (Sonesten m.fl. 2004) have also been used.

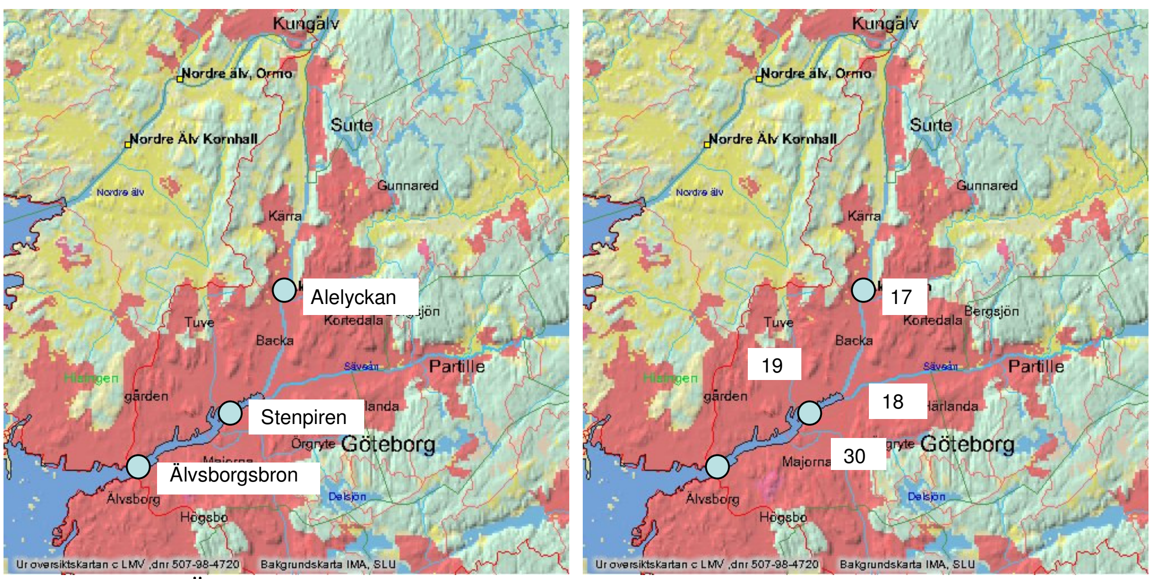

Figure 1. Göta Älv, lower part (the Göteborg branch). Water quality monitoring stations which have been utilized in this report are marked (left). Right, average concentrations of tot-P in Göta Älv (Alelyckan and Stenpiren) and the two tributaries Säveån and Mölndalsån are shown (µg/l).

At Kungälv, Göta Älv forks and about 75 % of the water is diverted (mainly mechanically) to Nordre Älv. In the Göteborg branch downstream Kungälv the water quality is measured at Alelyckan (also called Lärjeholm) and at Stenpiren and the Älvsborg Bridge (**Figure 1**). Three tributaries fall into the Göteborg branch after Alelyckan (Lärjeån, Säveån, Mölndalsån). Göta Älvs Vattenvårdsförbund performs sampling regularly in Göta Älv and in these 3 tributaries. As these tributaries only represent a minor part of the total water flow, they can safely be assumed to be of little importance for the phosphorous concentrations in the discharge of Göta Älv at the Älvsborg Bridge. This is also demonstrated by Axe et al (2004). Furthermore, there is a lack of measurements of PO_4-P in the

tributaries and the sampling frequency of 12 measurements each year in such a small catchment area makes the transport estimates very uncertain.
The sampling at Alelyckan is coordinated by Göta Älvs Vattenvårdsförbund and Naturvårdsverket (with SLU as operative executor). The sampling at the Älvsborg Bridge is done by Bohuskustens Vattenvårdsförbund.

Lärjeån
Lärjeån has, compared to Alelyckan, a small catchment area (112 km^2). At the outfall of Lärjeån (at the bridge on old road 45) water quality is monitored. According to data from Göta Älvs Vattenvårdsförbund (2003), the average concentrations of tot-P are (2001-2003) 66 µg/L. This can be compared with Lärjeholm where the average concentrations are 17 µg/L (**Figure 1**). The higher phosphorous concentrations can be explained by the size of the catchment area, intense farming (especially between Gråbo and Angered), high population density (Angered and further west) and ravine landscapes that hold big quantities of clay.

Säveån
Säveån has a catchment area of 1500 km^2. Lakes, deep ravine landscapes, cultivated valleys and industrial estates (near Göteborg) characterize the catchment area. The phosphorous concentrations (18 µg/l in average 2001-2003, **Figure 1**) are comparable to those measured at Alelyckan (GÄVVF, 2003).

Mölndalsån
Mölndalsån has a catchment area of 268 km^2. Mölndalsån discharges into Säveån downstream the last monitoring station in Säveån. A relatively great part of the catchment area consists of lakes (10 %). Mölndalsån is a reserve raw water supply for Göteborg. The phosphorous concentrations today are clearly lower than the levels monitored from the middle of the seventies to the middle of the eighties. Two important events have made water quality change radically; Stora Mölndal (Papyrus) installed better treatment of their process water and Härryda municipality connected its sewage system to Ryaverket. The phosphorous concentrations in the period 2001-2003 amounted to 30 µg/l (**Figure 1**)(GÄVVF, 2003). According to Sonesten et al (2004) the phosphorous transport has between 1995 and 1999 increased by 22 % in Mölndalsån, to a great extent caused by increased discharges from Stora Enso, where problems occurred during the running in of a new treatment plant.

2.1.2 Methods for calculation of transports

In this report, transported quantity in the Göteborg branch of Göta Älv has been calculated based on data from the PMK-station Alelyckan (also called Lärjeholm). These data originate from measurements carried out by Sveriges Lantbruksuniversitet and which are part of the environmental monitoring program of Naturvårdsverket and have been collected from SLU, Institutionen for miljöanalys, vattenkemidatabasen (htpp://info1.ma.slu.se/db.html)[1,2].

Discharge data on a daily basis 1990-2003 for Lärjeholm have been obtained from Göta Älvs Vattenvårdsförbund and SMHI. It should however be pointed out, that these data are estimated from the discharge measuring station in Lilla Edet.

Concentrations downstream Lärjeholm and the 3 tributaries have been assumed to be 10 % higher than those measured at Lärjeholm (based upon information from Göta Älvs Vattenvårdsförbund).

[1] On the SLU homepage, transport data can be downloaded for the station at Alelyckan. It is based on flow data from Lilla Edet, though, which is upstream the intersection.
[2] It should be mentioned that DIN koncentrationes in December 2000 exceed tot-N koncentrations (531 µg/l and 402 µg/l respectively). In this case org-N was set to 0 and Tot-N equal to DIN.

Discharges of tributaries downstream Lärjeholm have been assumed to be 20 % of the discharge at Lärjeholm (based upon information from Göta Älvs Vattenvårdsförbund).

Measured discharges at Ryaverket have been obtained from Gryaab .

Losses via supply network and pumping stations have been calculated from *Miljörapport från VA i Göteborg för 2003* (Göteborgs va-verk. 2003; hereafter named VA-report) and information from Annicka Malm (VA-verket/Göteborg municipality).

The total transport to the coastal area is calculated from:

$$L_{tot} = L_{alelyckan} + C_{aleyckan} * 1{,}10 * Q_{lokalt} + PK_{ryaverket} + PK_{ledningsnät}$$

where

$$L_{alelyckan} = \sum_{i=1}^{365(366)} Q_i * c_i$$

Q_i is the 24 hr mean discharge
C_i is the linearly interpolated 24 hr concentration based upon the monthly water samples.
Q_{lokalt} is the discharge contribution downstream Alelyckan, calculated as:
$Q_{lokalt} = Q_{alelyckan} * (0{,}20)$ where 0,20 is the mean ratio between discharge in the local creeks and Alelyckan according to model results (the PULS model) from Göta Älvs vattenvårdsförbund 1997 to 2000.
$PK_{ryaverket}$ is the point source contribution from Ryaverket including overflow. Data are obtained from Gryaab.
$PK_{ledningsnät}$ is the overflow losses that have not been included in the point source contribution from Ryaverket ($PK_{ryaverket}$). The calculation method and the basis for it are explained in more detail below. In the VA-report estimated total discharges to the recipient of phosphorous and nitrogen respectively from supply network and pumping stations are given, and the quantities are based upon conventional values and estimated volume. In this report, VA-verket has compiled most of the source information about phosphorous- and nitrogen concentrations in household sewage and stormwater. The basic data for the report are on one hand a compilation of literature on stormwater quality data and on the other an evaluation of results from measurements of owerflow discharges and of stormwater in Göteborg. At the assessment also the concentrations in overflow water have been considered. The VA-report states that most of the storm water and the waste water is conveyed to Ryaverket (about 95 %). The remaining 5 % that does not reach Ryaverket represents losses in conduits and at pumping stations. Conventional values are partly based upon measurements which exhibit the following concentrations of total-P:
Wastewater (at dry weather) [mg P/l]: 7
Stormwater (mg P/l): 0.3
Provided that waste- and stormwater are distributed as in 2003, the mean concentration of all overflow water becomes 0.8 mg/l. However, information on the distribution waste-/stormwater is not available for all years. For the sake of simplicity we therefore have to use this value for concentration (assuming that the proportions are the same as in earlier years) and then multiply by the measured water quantities. Model simulations of water quantities for 2001-2003 have been made with the help of the DHI Mouse model.

2001 3968 000 m^3 of which 191 000 waste
2002 5090 000 m^3 of which 346 000 waste
2003 3990 000 m^3 of which 272 000 waste
For other years, values for a normal year have been used with the overflow 5115 000 m^3 of which 237 000 m^3 waste (Annicka Malm, personal communication).

According to Löfgren and Olsson (1990) the annual atmospheric deposition is 8 kg P / km^2. The phosphorous deposition which falls firectly on the river downstream station Lärjeholm can therefore be neglected, since the river area is of the order 10 km^2 (50 km * 200 m) and will not be considered further in this study.

2.1.3 Transport via watercourses

Phosphorous supply via watercourses normally shows great variation between seasons and between years, mostly due to variations in discharge. The discharge in the strongly regulated Göteborg branch makes the phosphorous transport exhibit a seasonal pattern different from that of an unregulated watercourse. But in spite of the regulation and the urge for a constant discharge, there is a relatively great variation over months and years (**Figure 2** and **Figure 3**)
The transports of nutrients have been calculated on the basis of these data for discharge and concentration (see description of methods above). The results show that the mean annual transports of phosphorous at Alelyckan (1990-2003) have amounted to 100 tons of tot-P and 23 tons of PO_4-P. The variations between years have been large with a total span of 70-137 tons for tot-P (**Figure 5**). The two last years (2002 and 2003) are worth noticing for their low phosphorous transports. Over the whole period of time the monthly tot-P has shown great variations (**Figure 3**). Also a tendency towards increasing transports of PO_4-P with time can be noted (**Figure 4**). Seasonal variations are relatively small, but show increasing transports in the winter months (Dec-Feb), decreasing in summer (**Figure 6**).

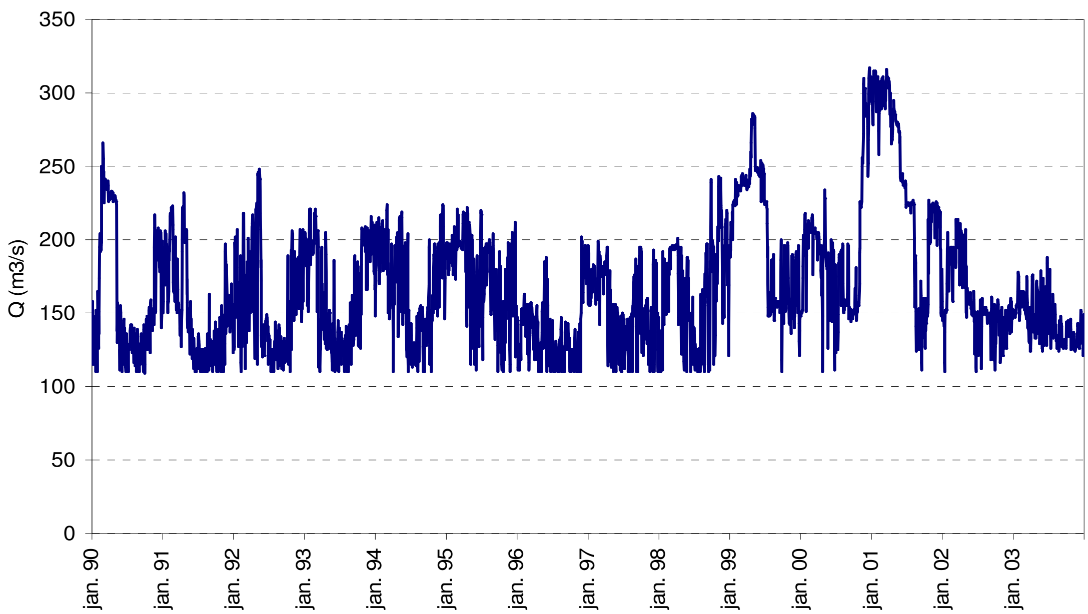

Figure 2. 24 hour mean discharge at Alelyckan/Lärjeholm 1990-2003. Source: SMHI

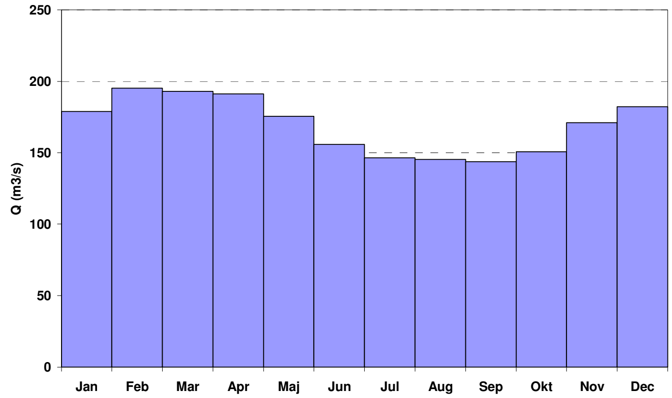

Figure 3. Monthly mean discharge at Alelyckan/Lärjeholm. Based on data 1990-2003. Source: SMHI

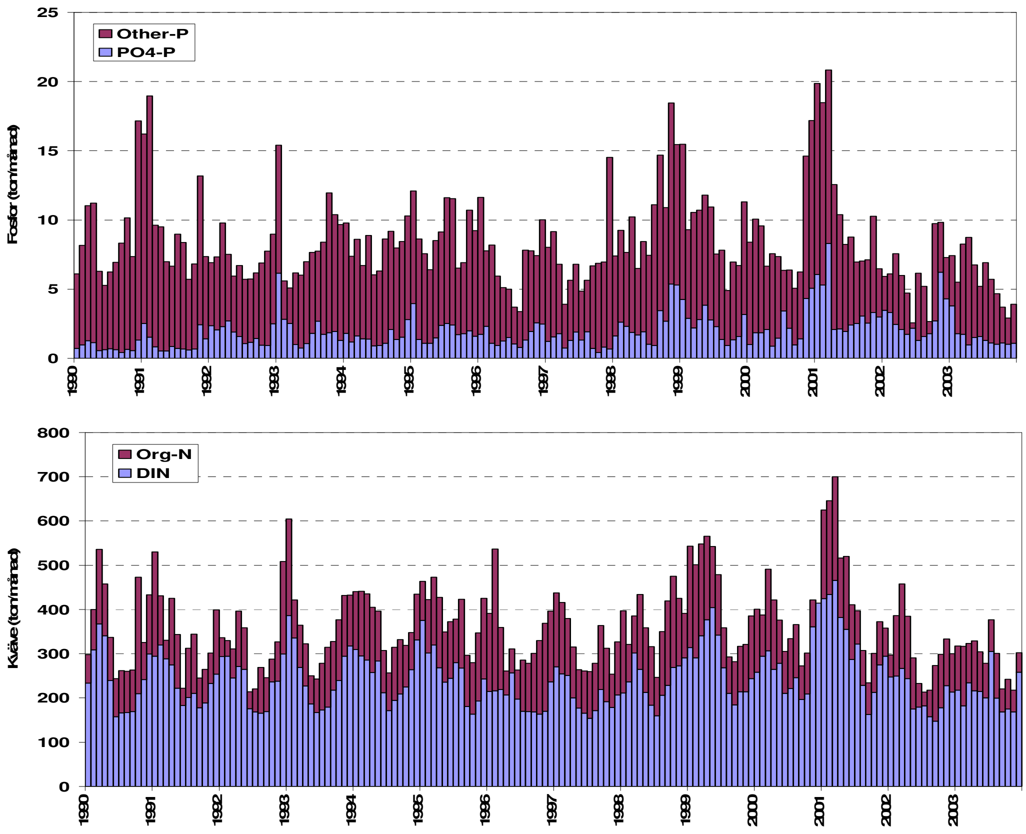

Figure 4. Monthly transport of phosphorous and nitrogen at Alelyckan/Lärjeholm 1990-2003.

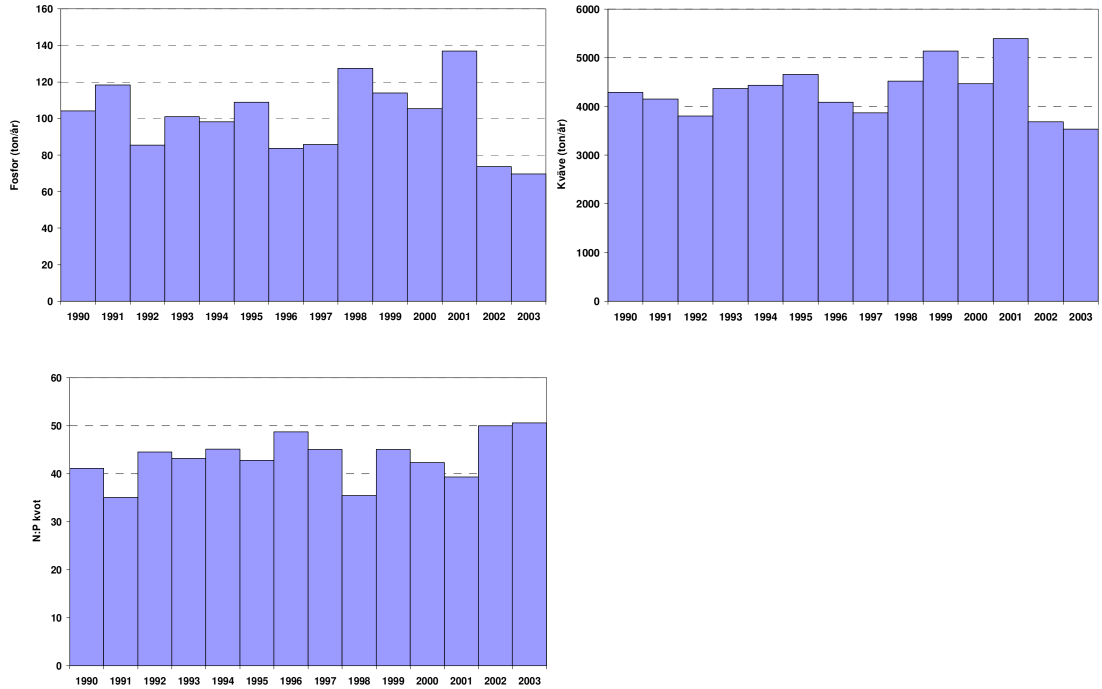

Figure 5. Annual transport of tot-P, tot-N, and N:P-ratio development over years at Alelyckan/Lärjeholm.

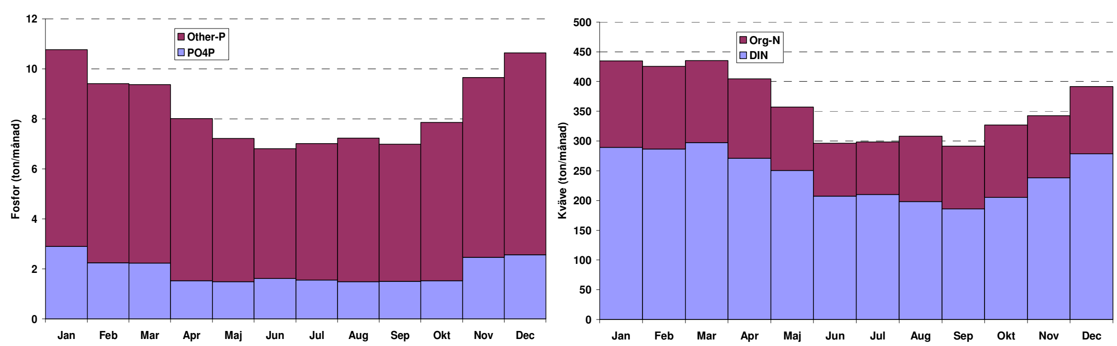

Figure 6. Monthly mean transport (1990-2003) of phosphorous and nitrogen at Alelyckan.

2.1.4 Discharges from Ryaverket

The reduction efficiency at Ryaverket has since the mid 90s been virtually constant around 86-90 % (Table 2). The somewhat lower reduction efficiency in 1994 and 1995 is due to extensive overflow in connection with reconstruction of Ryaverket. Also the nitrogen reduction was improved in 1997/1998 and since year 2000 amounts to 55-60 %.

Table 1. The development of nitrogen and phosphorous reduction in Ryaverket (including overflow) 1990-2003. Source: Gryaab.

Reduction efficiency (%)	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Phosphorous	91	91	94	93	81	79	86	87	89	89	88	90	89	90
Nitrogen	28	28	29	30	24	26	23	35	51	51	54	58	54	61

The phosphorous discharges show a continous decrease with time from slightly more than 100 tons in 1994 to 44 tons in 2003 (**Figure 8**). Corresponding nitrogen discharges have decreased from just above 2000 tons in 1995 to just above 1100 tons in 2003 (**Figure 8**).

If we disregard the two special years of 1994-95, then the overflow contribution is about 25 % of the tot-P discharges from Ryaverket, which is rather much (**Figure 8**). An expansion is now in progress for the purpose of reducing the overflow. The PO_4-P discharges via overflow are throughout calculated under the assumption that 30 % of the tot-P in overflowing water consists of PO_4-P, which is the average from the measuring data available.

The N:P-ratio (by weight) has varied somewhat between years, between 24 and 31 with a mean value of 26. It should however be noted that the overflowing water has had a low N:P ratio about 7-8, while discharges from Ryaverket itself on the average have had 33 with a decreasing trend over the years. The N:P ratio is about the same as in the watercourse itself (**Figure 5**)

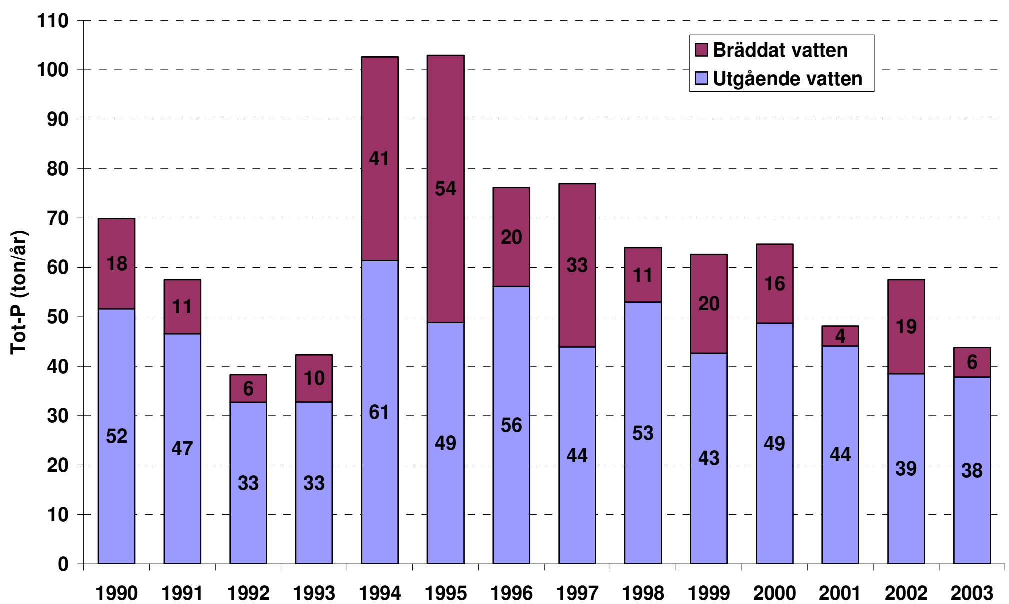

Figure 7. Discharge of tot-P via Ryaverket (including overflow) 1990-2003.

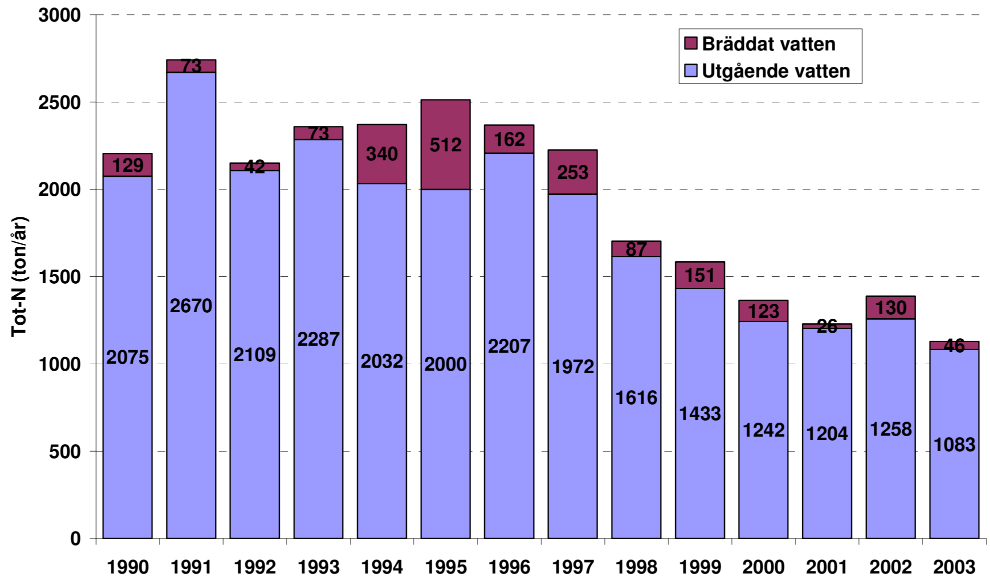

Figure 8. Discharge of tot-N via Ryaverket (including overflow) 1990-2003.

2.1.5 Total supply to the coast

In average over the time period 1990-2003 the total supply of tot-P to the coastal water via watercourses and Ryaverket has been more than 190 tons/year. According to assessments by Sonesten et al (2004) the supply has in 1995 and 1999 been 195 and 153 tons of phosphorous respectively, to be compared with our calculations for the same years of 240 and slightly more than 200 tons. The reason for this rather big difference is difficult to judge, as Sonesten et al (2004) have not given detailed data underlying their calculations. For total nitrogen the mean annual supply (1990-2003) has amounted to 7200 tons.

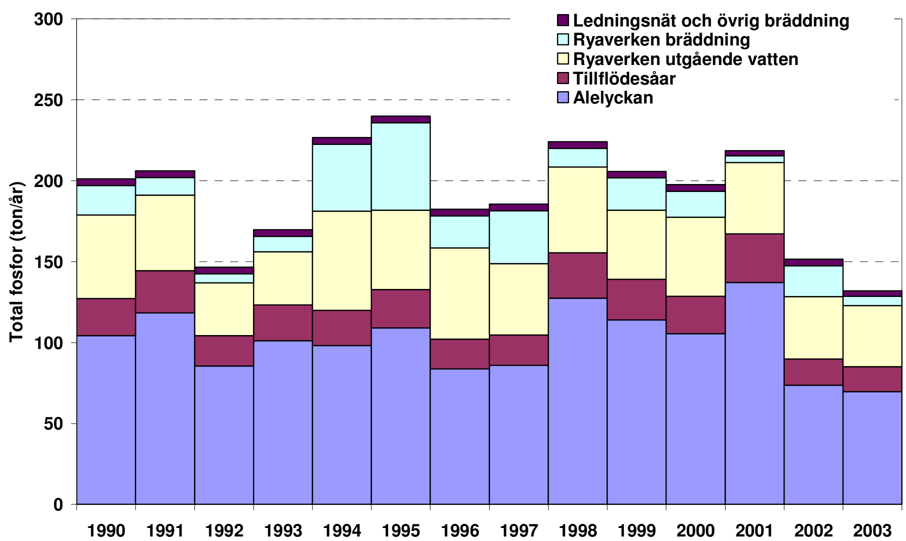

Figure 9. Annual transports and discharges from different sources of tot-P 1990-2003 to the coastal water outside Göteborg. Calculation methods and basic data are presented in chapter 2.1.2

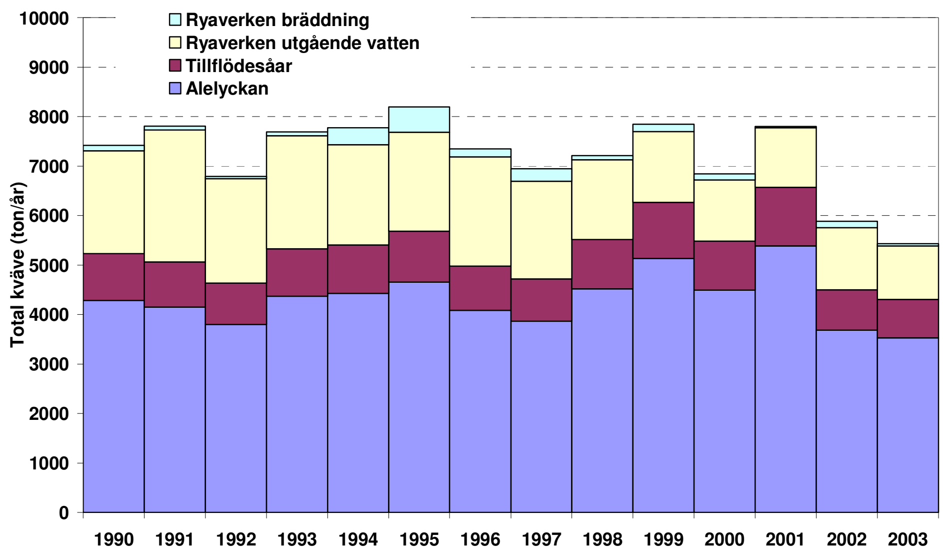

Figure 10. Annual transports and discharges from different sources of tot-N 1990-2003 to the coastal water outside Göteborg. Calculation methods and basic data are presented in chapter 2.1.2

2.2 The supply of phosphorous from the sea via the return current

2.2.1 Description of the estuary

The Göta Älv mouth exhibits a marked estuarine circulation with an outward flowing surface layer with fresh water from Göta Älv and a return current with saltier and heavier bottom water that reaches a distance up the river. The surface current, which flows faster than the return current, entrains water from the return current. Some mixing also takes place in the opposite direction, from the surface current to the bottom water, mainly as propeller-induced mixing. Upward mixing, however, strongly dominates. The discharge from Ryaverket takes place near the surface and virtually all this water will flow along with the surface current out to sea (**Figure 11**).

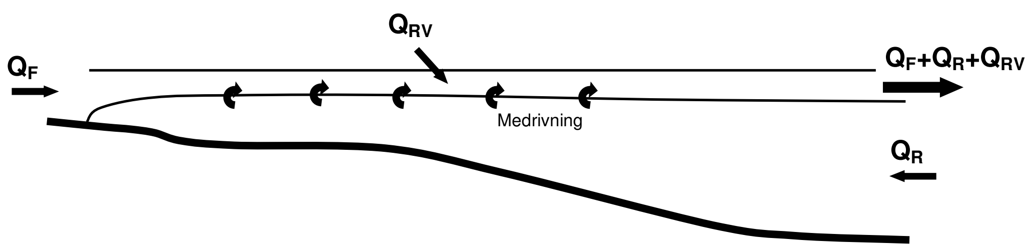

Figure 11. Longitudinal section in the Göta Älv mouth. Q_F is the flow of fresh water from the river, Q_{RV} is the discharge from Ryaverket and Q_R is the flow of the return current from the sea.

Out on its way towards the sea the surface current first meets a northbound current from the southern archipelago (Askims fjord and Asperöfjord). The two surface currents mix and flow on towards Skalkorgarna and Danafjord, two of the control stations in the Bohus Coast monitoring program. At Danafjord the evident influence from the Göta Älv surface current has ceased and the conditions are more determined by the open sea water (Marmefelt et al, 2004). Axe et al (2004) compile the recent hydrographic measurements for the Bohus coast and establish for the Göta Älv mouth that: (i) the concentrations of dissolved inorganic nitrogen (DIN) are very high in the surface water at Älvsborg

Bridge just downstream Ryaverket, whereas the concentrations of dissolved inorganic phosphorous (DIP) are low; (ii) the DIN-concentrations of the surface water diminish out towards Skalkorgarna because of mixing in of salt water; (iii) Danafjord exhibits nutrient concentrations that are similar to those out at sea, and (iv) the oxygen concentrations are good at all three stations.

Of interest to our investigation are the relative contributions of the different supplies – from the river, the return current and Ryaverket – to the tot-P transport out from Göta Älv. There are data to support the contributions from the river and from Ryaverket (see above), but the contribution from the return current must be assessed from calculations of mass balances or other considerations.

2.2.2 Earlier assessments of the return current contributions

Söderström (1986) analyses data for 1982-84 from a number of stations in the area and calculates a mean value for volume flows by use of salt balances. Using measured phosphorous concentrations (tot-P) and the calculated volume flows he then assesses the phosphorous transports. The calculated phosphorous transports are today no longer valid, because the discharges have diminished considerably since the investigations were made. But the calculated volume flows can still be relevant since the salt balances should not have changed significantly. The calculations show that the flow into the estuary with the return current (Q_R in **Figure 11**) is about 80 % greater than the river flow (Q_F) – 320 m^3/s as compared to 176 m^3/s. The whole return current flow is entrained into the surface current so that the flow out from the estuary is 500 m^3/s (320 m^3/s + 176 m^3/s + 4 m^3/s, where the last contribution is that from Ryaverket).

Selmer and Rydberg (1993) present more recent measurements from 1988-90 and 91-92, along a transect from Göta Älv all out to Danafjord. The report deals primarily with nitrogen problems, but also measurements of PO_4-P concentrations are presented. No volume flows are presented, but they can be deducted from presented concentrations and flows of PO_4-P, or alternatively from shown salinities.

With the help of the salinity field given by Selmer and Rydberg (**Figure 12**), the volume flow in the return current (Q_R) can be calculated from:

$$Q_R = \frac{S_1}{S_2 - S_1} Q_F$$

where S_1 and S_2 are the salinities in the upper and the lower layer respectively in the section where the flow is to be assessed. To be able to make a comparison with Söderström's values, we assess the flow in a section at Selmer and Rydberg's station 4, about 4 km downstream Ryaverket (which corresponds to Söderström's station 7). With the annual mean values S_1 = 22 ppt and S_2 = 12 ppt we get that Q_R is 20 % greater than Q_F or 204 m^3/s, which is considerably less than Söderström's values. A check can be made against the concentrations and flows of PO_4-P of Selmer and Rydberg. The PO_4-P flow is not given at station 4, but a linear interpolation gives a flow in the lower layer of 80 mmol/s. The corresponding PO_4-P concentration is 0.4 mol/l, giving a volume flow Q_R = 200 m^3/s.

We have not gone to greater depth to explain the difference in flow assessment in the two reports, but we tend to give more credit to the later results, where the return current is 20 % bigger than the fresh water current, in the average situation.

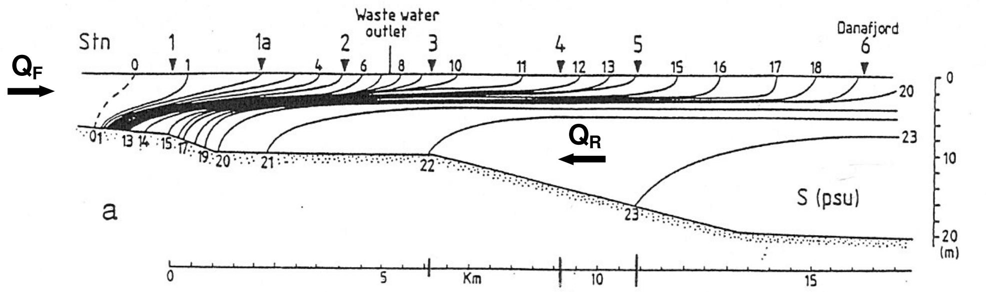

Figure 12. Salinity field from Selmer and Rydberg (1993).

It should also be mentioned that the coastal area model described by Marmefelt et al (2004) in principle should give more accurate assessments of concentrations and flows in the archipelago outside the estuary. This model splits the archipelago into a number of horizontally integrated but vertically resolved basins and computes the flows of water and dissolved substances, e.g. tot-P, between the different basins. Göta Älv estuary out until Skalkorgarna constitutes one basin, B25. Furthermore the basins B26, south of the estuary, and B24, west of the estuary, are of interest to our study. The station Danafjord is situated in the middle of B24. The relevance of the report is however limited because the results are presented in a strongly integrated way, both over time (e.g. tons of tot-P per year) and over depth, which makes it impossible to sort out transports in the surface water, at least as concerns the estuary. Göta Älv estuary and Nordre Älv estuary protrude strongly as regards phosphorous supply from land, with values at least 30 times greater than for the rest of the basins.

2.2.3 Own calculations of the return current contribution

Both Söderström (1986) and Selmer and Rydberg (1993) have confined themselves to showing the annual mean values of tot-P and PO_4-P respectively, while we are also interested in the variations over the year. When the flow of fresh water in the river increases, the lower layer (the salt water wedge) will be pushed outwards, and conversely, when the fresh water flow decreases the salt water wedge will move up the river. The tide has the same effect – at high tide the salt water wedge will move upwards and at low tide it will retire. The tidal amplitude in the area is, however, small (< 20 cm). Furthermore, the position of the salt water wedge and the salinities at a given section are influenced by a number of other factors, e.g. water level, wind, and propeller mixing. If such dynamic effects are small, and the salinities in a given section thus are nearly constant, it should be possible to establish a simple connection between the river flow and the return current – when the flow increases in the upper layer, more of the lower layer is also entrained and thereby the flow of the return current increases. However, we have found that the salinities at the monitoring station at the Älvsborg Bridge vary a lot over the year and that the variations in freshwater flow only to a part can account for this. The fresh water flow and the salinity of the upper layer show a negative correlation, as expected – when the fresh water flow increases, the salinity decreases. But the correlation is weak (r = -0,24). The correlation between the fresh water flow and the salinity of the lower layer also has the expected sign but is even weaker (r = -0,08). See also **Figure 13**. The conclusion is that there is no simple relation between the fresh water flow and the position of the salt water wedge, and thus not between the fresh water flow and the return current. It is therefore only possible to assess the size of the return current on those occasions when salinity data are available. Since salt balances require (quasi-) stationary conditions, we have chosen to use the monthly average of the 24 hour values for the fresh water flow and monthly mean values of salinities at the Älvsborg Bridge. The salinities have furthermore been extrapolated to a section at the Selmer and Rydberg (1993) station 4, that is exactly in the mouth of Göta Älv.

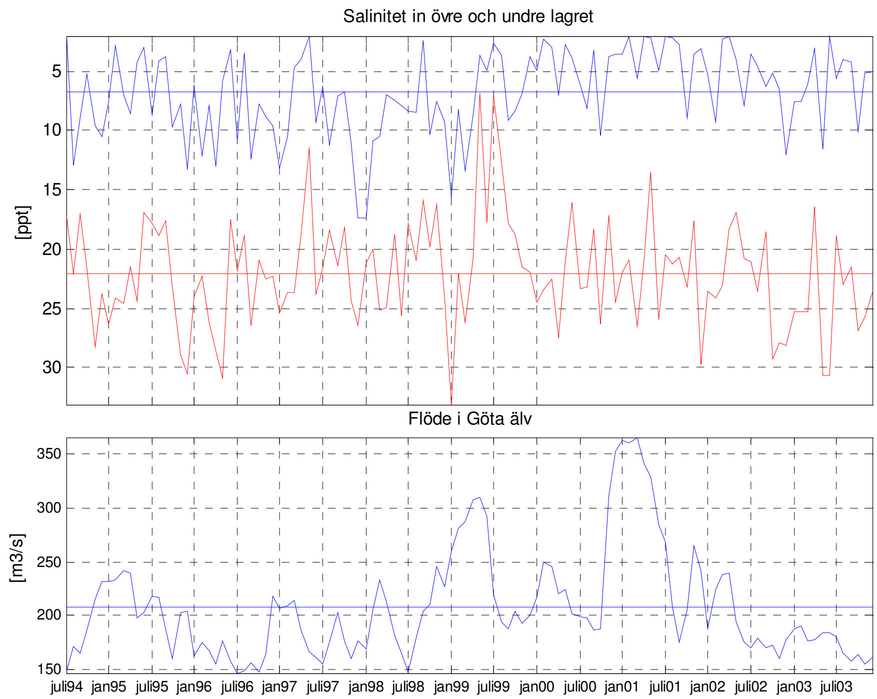

Figure 13. Salinities in the upper and lower layer at the Älvsborg Bridge in the period 1994-2003, and flow in Göta Älv in the same period. The flow measurements were made by SMHI.

The concentrations of tot-P and PO_4-P in the return current have also been extrapolated from measurements at the Älvsborg Bridge. Selmer and Rydberg (1993) state a mean value 0,4 µmol/l for PO_4-P in the lower layer at station 4. Axe et al (2004) present a graph over PO_4-P concentrations in the deep water during 1994-2004 at the Älvsborg Bridge, where the mean value is about 0,5 µmol/l, well in accordance with the value of Selmer and Rydberg for the same area. Our monthly values also have a mean value of 0,4 µmol/l, and a standard deviation of 0,2 µmol/l. Corresponding values for tot-P are 0,9 µmol/l and 0,3 µmol/l. Calculated transports are shown in **Figure 14**.

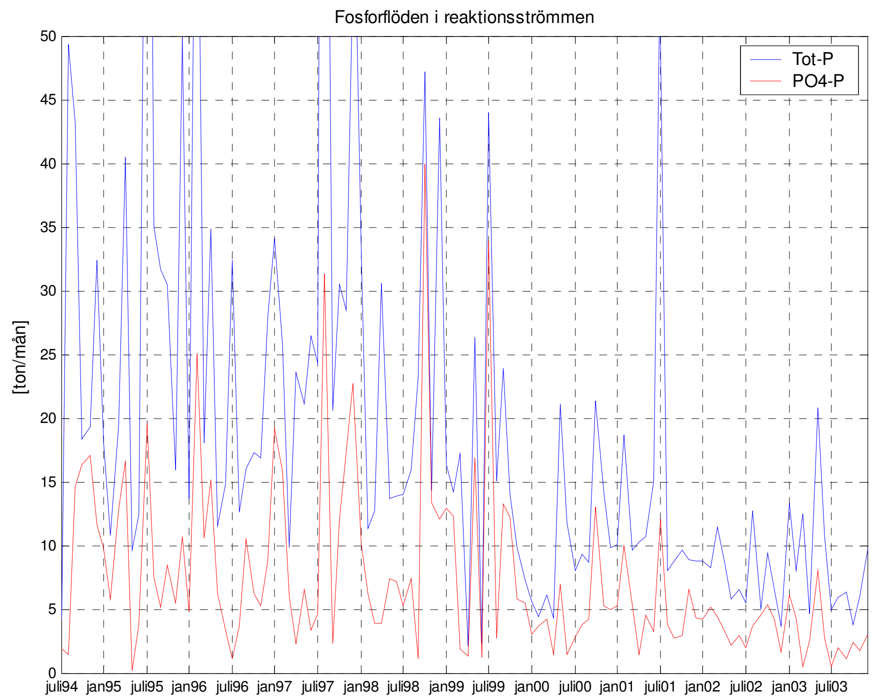

Figure 14. Calcuated phosphorous flows in the return current at the Selmer and Rydberg (1993) station 4 for the period 1994-2003.

2.3 Compilation of phosphorous sources

There has been a strong decrease in the supply of tot-P and PO_4-P to the recipient during 1994-2003, and both have been approximately halved. This has been caused by significant decreases of the discharges from Ryaverket and from the sea via the return current, while no significant changes of supply via Göta Älv have occurred. The compilation of supplies from all important phosphorous sources show that the all dominating source, both for tot-P and for PO_4-P, during the period 1994-1999 is the return current (**Figure 15**). In the period 2000-2003 the tot-P contribution from Göta Älv with tributaries is of the same order of magnitude as that from the return current, whereas the PO_4-P contribution from the return current is still somewhat larger.

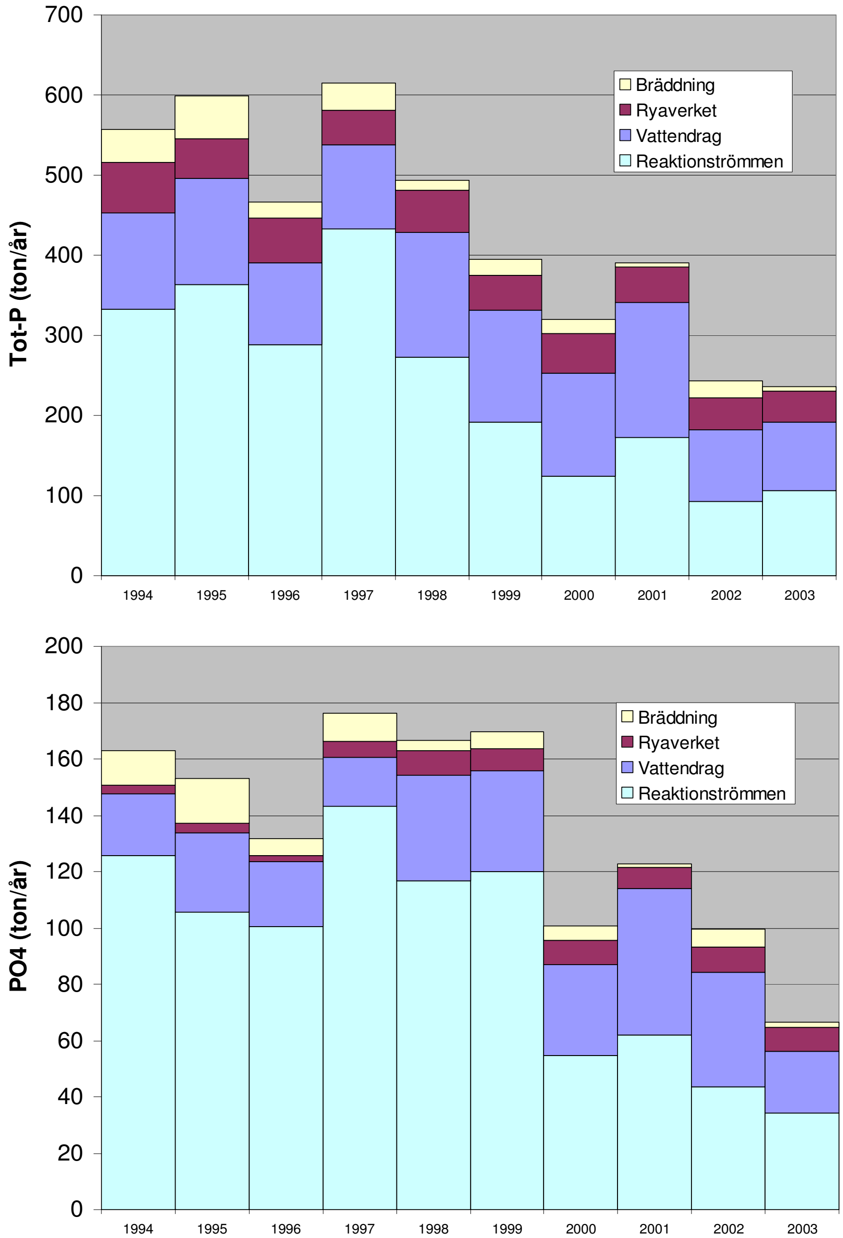

Figure 15. Combined supply of tot-P and PO_4-P to the Göta Älv mouth from different sources 1994-2003.

The Ryaverket share of the tot-P and PO_4-P supply to the recipient has been compiled in **Table 2**. The relative share from Ryaverket has not decreased during the period 1994-2003 despite decreased discharges, because the supply from the sea via the return current has also decreased. This is true both for tot-P and PO_4-P. The share that the prescribed reduction of 12 tons makes out of the tot-P supply is also demonstrated in **Table 2**. A reduction of 12 tons constitutes 5,1 % in 2003, which is a bigger share than in earlier years since the the total pollution load has decreased. The Ryaverket discharge of PO_4-P was on average 19,2 % of the discharged tot-P for the period, and this has been used when assessing which reduction of PO_4-P the prescription implies. If the same proportions would be discharged in the future the result would be a PO_4-P reduction of 2,3 tons annually, and the share which this constitutes of the total PO_4-P supply is also shown in **Table 2**. However, it should be noted that Ryaverket now is expanding in order to decrease overflow substantially, and this means that the total discharge will contain a smaller share of PO_4-P than before, since the overflow water is richer in PO_4-P (see 2.1.4).

Table 2. The Ryaverket share of the total supply of total phosphorous (tot-P) and phosphate phosphorous (PO_4-P) 1994-2003, and the share of the supply which the prescribed reduction of tot-P, and the estimated reduction of PO_4-P, would be.

	Tot-P		PO_4-P	
	The Ryaverket share	Reduction 12 tons	The Ryaverket share	Reduction 2,3 tons
1994	19 %	2,2 %	9 %	1,4 %
1995	17 %	2,0 %	13 %	1,5 %
1996	16 %	2,6 %	6 %	1,7 %
1997	12 %	2,0 %	9 %	1,3 %
1998	13 %	2,4 %	7 %	1,4 %
1999	16 %	3,0 %	8 %	1,4 %
2000	21 %	3,8 %	14 %	2,3 %
2001	12 %	3,1 %	7 %	1,9 %
2002	25 %	4,9 %	16 %	2,3 %
2003	19 %	5,1 %	15 %	3,5 %

There is no trend in the total supply of phosphorous or nitrogen from land to Kattegatt and Skagerrak in the period 1950-2000, but compared with the early 70s, supply was higher during the 80s and 90s for both nutrients (Håkansson 2002).

3. Description of the recipient

3.1 Description of the recipient and the availability of nutrients

In Appendix 7.4 diagrams are shown over trends in nutrient concentrations, chlorophyll and Secchi depth, taken from measurement data in the Bohus coast monitoring programme for Valö, Skalkorgarna and the Älvsborg Bridge. Where possible, measurement values have been compared with Norwegian classes for environmental status. It is illustrative to study the figures in parallell with corresponding figures in the SMHI compilation and assessments of hydrologic measurements along the Bohus coast (Axe et al 2004) where comparisons are found with the preliminary assessment principles of the Water Directive. An excerpt from the Norwegian report, which schematically shows the classification can be found in Appendix 7.3.

There is a marked positive correlation between salinity and PO_4-P (**Figure 16**) which results in sites with a more marine character having relatively high PO_4-P concentrations in the surface water. The opposite is true for dissolved nitrogen (**Figure 17**) where sites of marine character have the lowest concentrations. This means that the N:P-ratios diminish outwards from the coast, and this is verified by data from Axe et al 2004. The measured values exhibit very great variation, but it can generally be said about N:P-ratios that the Älvsborg Bridge usually has a higher ratio than 50 all the year, Skalkorgarna usually has ratios greater than 50 in April-September and between 25-50 Oct-Feb, Danafjord has ratios over 50 in April-June and around 25 during the rest of the year, Valö has ratios around 10-25 the whole year, a little more in April-May, Fladen around or less than 16 all the year. Based upon that phytoplankton needs about 16 times as much nitrogen as phosphorous (the Redfield ratio) we see a pattern where the probability for having a situation where nitrogen is the limiting nutrient for plankton growth is greater in autumn and increases outwards from the Göta Älv outfall, but that the area is mainly phosphorous limited.

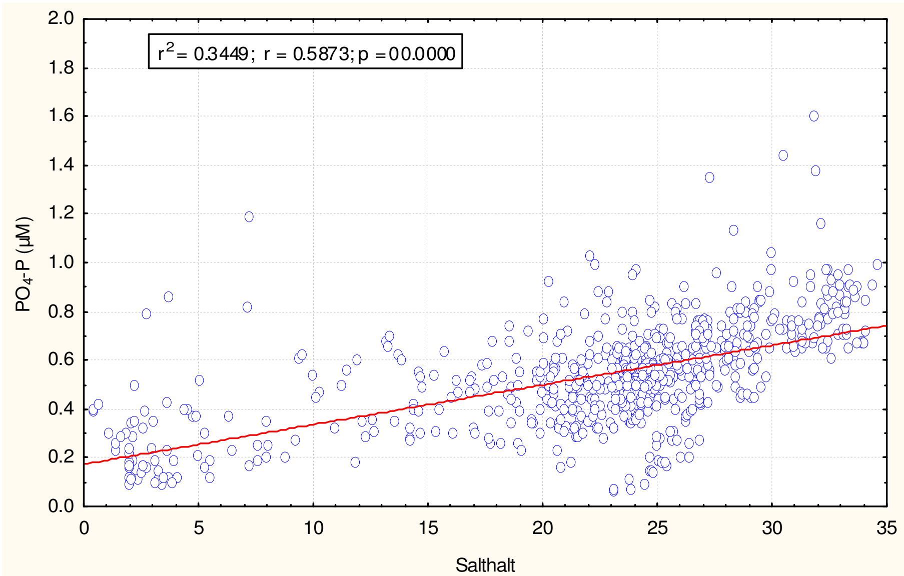

Figure 16. Correlation between salinity (psu) and the concentration of PO_4-P (µM) in the surface water (0-2 m) at Valö, Skalkorgarna and the Älvsborg Bridge 1986-2004.

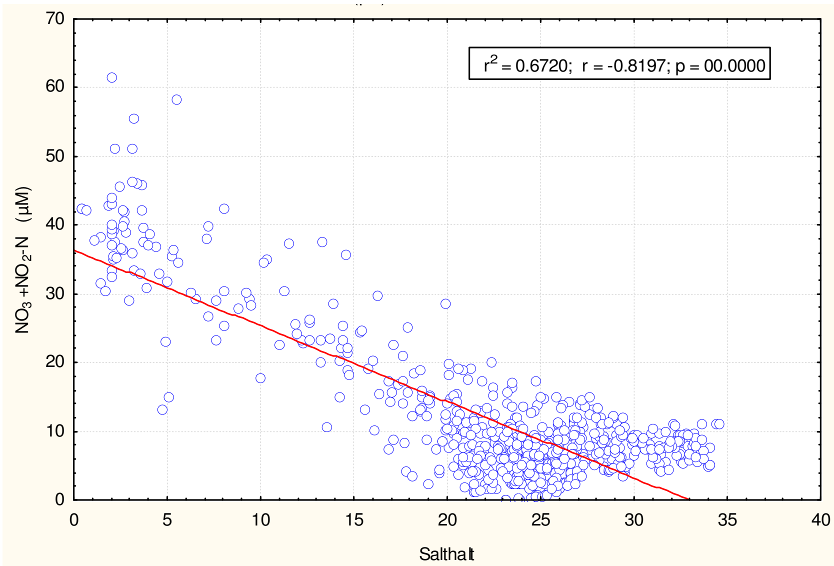

Figure 17. Correlation between salinity (psu) and the concentration of NO_3 + NO_2-N (µM) in the surface water (0-2 m) at Valö, Skalkorgarna and the Älvsborg Bridge 1986-2004.

4. Effects on phytoplankton and macro vegetation

4.1 Effects on the plankton community

The plankton concentration (here expressed as the chlorophyll concentration) varies over the year as a function of temperature, solar influx and the availability of nutrients. In April-September the chlorophyll concentration is high and the PO_4-P concentration usually low (less than 0,2 µmol/l, **Figure 18**) in the area, and we judge that the availability of PO_4-P limits the plankton growth (see also the discussion in Section 3.1 about N:P-ratios). The picture for bioavailable nitrogen (NO_2+NO_3+NH_4) does not show this relation. A change in the quantity of PO_4-P supplied to the area in this period thus ought to give measurable effect on the phytoplankton community, and in the present investigation we have chosen to study this.

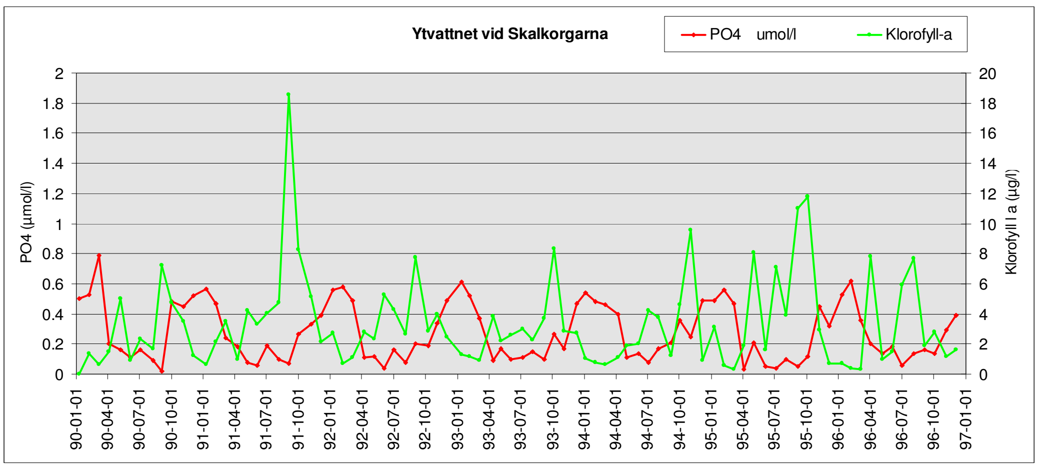

Figure 18. Monthly values of phosphate phosphorous (PO_4-P) and chlorophyll *a* measured in the surface water at Skalkorgarna 1990-1997. The PO_4-P values are in general low April-September, while the chlorophyll values at the same time are high. We have therefore looked for effects on the plankton community (expressed as chlorophyll *a*) of PO_4-P supply in this period.

There is a relation between measured residual-P (the difference tot-P minus PO_4-P) and chlorophyll *a* during April - September. This confirms the reasoning that available PO_4-P is absorbed by plankton biomass. The connection is more marked at sites of marine character (Kosterfjorden, Byttelocket) than at estuary sites (the Älvsborg Bridge, Skalkorgarna) (graphical analyses from the Bohuskustens monitoring programme). This is probably due to the fact that the estuary sites are disturbed by fluctuating salinity and high water exchange with the consequence that all available PO_4-P does not have time to be converted into biomass. Residual-P mainly consists of plankton in marine sites, whereas residual-P in the estuary sites to a greater extent also consists of other organic and non-organic matter supplied via Göta Älv. The picture of PO_4-P as the limiting nutrient thus holds, even if the marine sites generaly show lower N:P ratios. In summa, this leads us to expect a relatively weak response in plankton production (expressed as chlorophyll *a*) to changes in phosphorous supply to the Älvsborg Bridge and Skalkorgarna in spite of their high N:P-ratios.

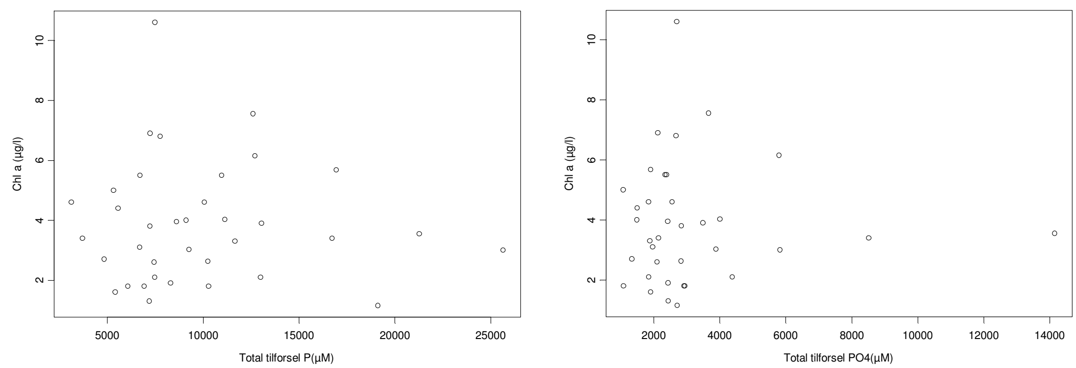

Figure 19. Summer values of chlorophyll *a* in the surface water at Skalkorgarna, plotted against tot-P (left) and PO_4-P (right). There is no significant pattern in any of the cases. Data from Bohuskustens monitoring programme 1998-2003.

We cannot point out any effect from the total supply of PO_4-P or tot-P on the concentration of chlorophyll *a* at Skalkorgarna (**Figure 19**). Indeed, we expected a weak response (see 3.1 and above), but the result is probably also affected by inadequate time resolution. Measurements of chlorophyll are carried out once every month, and phosphorous supply is calculated as monthly average values. The growth response in a plankton community can occur in only one day and such rapid variations cannot be expected to be found out from monthly values. Our first ambition was to calculate phosphorous supply on a 24 hr basis, but input data were insufficient to assess the transport via the return current with such a high resolution; therefore we had to lower our level of ambition to a monthly basis. The recipient Skalkorgarna is also influenced by a northbound current, which enters the area inside the archipelago (see Section 2.2)

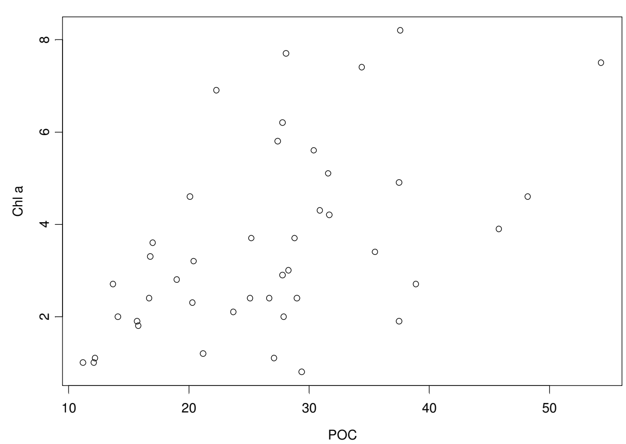

Figure 20. Particulate organic carbon (POC) correlates significantly with chlorophyll *a* in the surface water of Danafjord. Data from Bohuskustens monitoring programme 1997-2004.

It has been proposed that particulate organic carbon (POC) should be analysed instead of chlorophyll *a* since the chlorophyll concentration in plankton varies between species and blooms therefore give different chlorophyll concentration in the water depending on which species that blooms. Unfortunately our POC data (Skalkorgarna 5m 1990-2004, Danafjord also 20 m and 0-3 m 1997-2004) are limited. But out from available surface water data from Danafjord we see that POC and chlorophyll *a* correlate positively (R^2=0,27, p=0,0004) **Figure 20**, which by SMHI (Axe et al 2004) is confirmed to be the general case for the Bohus coast, only not for Danafjord. The SMHI report and our calculations differ because SMHI defines surface water as 0-10 m, whereas we are using data from the very upper layer (0 m in Bohuskustens monitoring program, for POC 0-3 m). The reason why we have chosen to look at the very upper layer is that the recipient from Göta Älv is strongly stratified and the discharges from Ryaverket end up in the surface layer.

4.2 Effects on benthic vegetation

There are two series of reports that are useful for seeking effects on benthic vegetation from supply of phosphorous to the recipient: 1) Air surveys of filamentous algae (Moksnes & Pihl 1995, Pihl et al 1999-2001, Nilsson & Pihl 2002, Jenneborg 2003-2004c)(**Figure 21**), and 2) Annual investigations of the benthic biota that have been carried out with help of a ROV and a dropvideocamera 1996-2002 (Jenneborg 1996-2002a, and the compilation Jenneborg 2000b)(**Figure 22**).

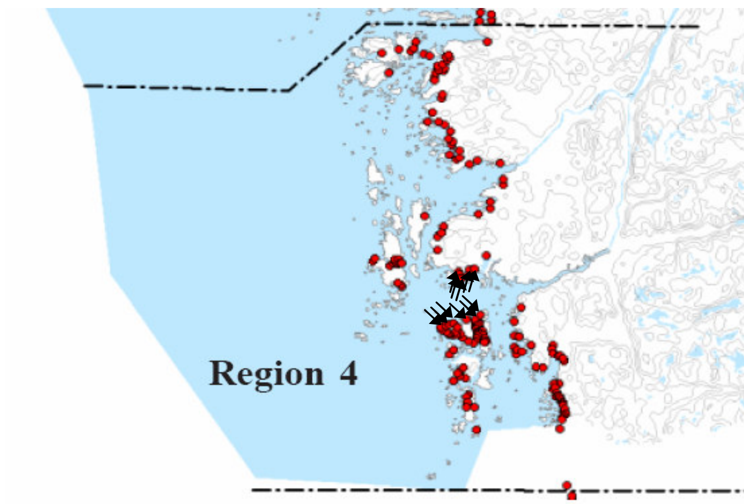

Figure 21. Positions for all those sites in region 4, from where random or chosen selections have been surveyed from the with regard to the cover of filamentous algae 1998-2004. Sites in the recipient area that have been analysed in this study are indicated with in total 11 arrows. The picture is taken from (Jenneborg 2003c).

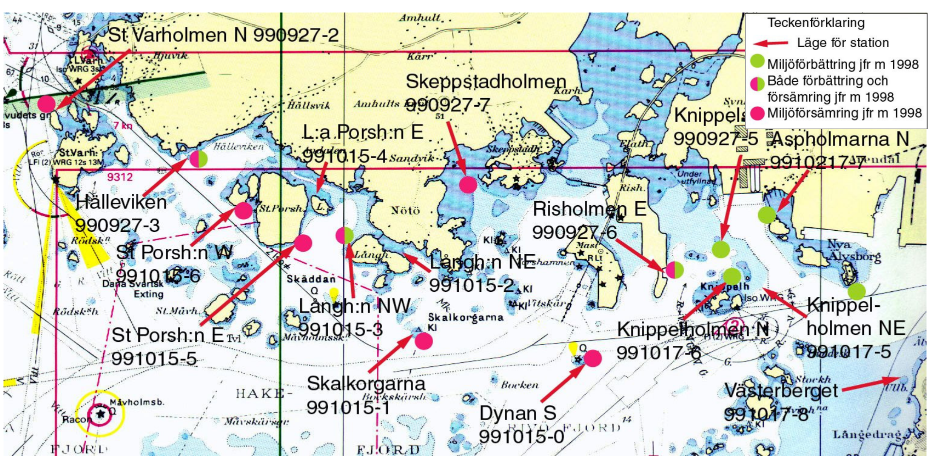

Figure 22. Selection of sites for annual surveys with the help of a ROV or a dropvideocamera 1997-2002. The colours denote improvement or degradation of the environment in 1999 compared to 1998 (legend up right). The picture is taken from (Jenneborg 1999a).

As regards vegetation data, they concern mainly larger occurences of macroalgae, cyano bacteria and some eel grass, and also the macrofauna is surveyed. Survey from aircraft is of course an overview method, and also ROV-surveys must be considered as a clearly less accurate type of survey compared to diving surveys. As a comparison 112+114 species were identified at a diving survey in two sites on the Skagerrak coast of Norway coast, compared with 47+37 species with an ROV (Olsgard et al, in prep). Especially small and less common species are overlooked or underestimated in an ROV-survey On the other hand, dominating species are well identified and the vertical extension is correctly described. But since the methods are much faster and cheaper to use, the monitoring stations can be plenty and the information valuable in spite of the imperfections.

Out of the aircraft survey pictures we have picked 11 stations at Skalkorgarna, situated in the Göta Älv plume, to look for influence on the occurrence of filamentous algae (**Figure 21**). As can be seen in **Table 3** the distribution of filamentous algae is sparse in the area and the difference as compared to northern Bohuslän (Jenneborg 2004c) is evident. At the bottom of **Table 3** the average distribution in region 4 is shown. In August 1999 filamentous algae bloomed heavily in the recipient and south of the region according to the report. Regrettably none of the chosen stations at Skalkorgarna were examined this month. In summer 2003 there is also a bloom, but this time it seems to be confined to the northern part of region 4. From the ROV-investigations it is found that the situation got worse at the more marine characterized sites in the region between autumn 1998 and autumn 1999, which coincides with the bloom of filamentous algae that was registered from the air photos in August 1999. 1999 was also a year with large flows in Göta Älv, but the extreme discharge in the river in 2001 did not bring any marked increase of production in the recipient. There does not seem to have been any marked improvement at the marine characterized stations in the period 2000-2002. Outside the Göta Älv mouth there was on the contrary an improvement 1996-99 with increasing occurrence of *Fucus spp*. and kelp *Laminaria saccharina* at the expense of eutrophically favoured species (Jenneborg 2000b). Bladder wrack and kelp still remained in 2002 (Jenneborg 2001a, 2002a) but no data from later years exist. The change in macro vegetation cannot with certainty be coupled to a particular source of phosphorous, but the improvements in the Göta Älv mouth could well be an effect of decreased phosphorous discharges from Ryaverket, as the sites are close to the point of discharge. Certainly, the phosphorous supply from the return current has also decreased in the period, but its influence ought to have been greater further out, and there the situation has instead got worse. The supply from Göta Älv has not changed significantly during the period, but there is a weak trend towards an increase in supplied PO_4-P.

Table 3. Cover in percent of filamentous algae at aircraft surveys 1998-2003. The results for 2003 and 2004 are only expressed graphically in the BVVF reports, and the values in this table are taken from maps. All of the reported sites are situated at Skalkorgarna which can be seen from Figure 21. At the bottom of the table there is a compilation of the distribution of filamentous algae in 4 (see Figure 21) taken from the HydroGIS report 2004.

Vik nr	Region	Jul-98	Aug 98	Jul-99	Aug-99	Jun 00	Jul-00	aug 00	Jun 01	Jul-01	Aug-01	Jun-02	Jul-02	Aug-02	Jun-03	Jul-03	Aug 03	Maj 04	Jul-04	Aug-04
1.2/b	4					0				0	0		0							
1.5/592	4							0												
1.6/591	4																			
1.7/593	4	0								0	0			0						
1.8/594	4	0						0		0		0	0							
521.1/a	4								0						6-25		0-5	0-5	0-5	0-5
552.0	4						0		0						0-5	6-25				0-5
553.0	4		0								0							0-5		
554.0	4							5	0											
555.0	4										0		0				0-5			
557.0	4		0																	
Region 4	4	1	1	4	25	2	2	1	6	1	1	1	0	2	13	23	17	1	1	3

5. Discussion and conclusions

5.1 Discussion

In the period 1986-2004 the concentrations of tot-P and PO_4-P have generally decreased in the coastal water at most stations along the Bohus coast (Axe et al 2004). This is the same trend as exhibited by the supply of tot-P and PO_4-P to the recipient area. Also ammonium has decreased generally in the coastal water, and total nitrogen at several stations, while no general trends can be found for nitrite and nitrate (Axe et al 2004). In spite hereof there is no decreasing trend in chlorophyll *a* at Skalkorgarna, and at several coastal stations the trend conversely is increasing (Axe et al 2004). The reason for this can be changes in the composition of species (Axe et al 2004), or related to climate. As the concentration of chlorophyll *a* is used as an indicative of eutrophy by the administration, it is important to understand what makes concentrations change. We therefore suggest that this be investigated thoroughly and that alternative indicatives of eutrophy like particulate organic carbon (POC), or direct measurement of production also be evaluated.

Long time trends are reflected in the composition of species and the vertical distribution of macroalgae and stationary animals. These organisms do not respond to rapid changes of nutrients within normal intervals and are thus suitable for analysis of gradual changes. Ongoing mesocosmic experiments at NIVA have shown that a change from eutrophically favoured species of macroalgae to a more normal composition can take place, with a delay of some year after a threshold value in the nutrient concentration has been crossed (Hartvig Christie, word of mouth). We therefore recommend that the annual ROV investigation, now carried out by HydroGIS, should go on but that table data should be standardized. In the table there should also be a classification of the current environmental state of the site, so that changes in environmental quality could more easily be followed. We suggest that also this report series should be available on the Bvvf home page, and also diving investigation data from possible environmental monitoring programmes, sponsored by Länsstyrelsen could be compiled there.

In this study our ambition was to calculate how much bioavailable phosphorous is supplied to the area from Ryaverket and other sources. This proved to be difficult since this is not well investigated in the area and the literature indicated a large spread. The information we have been able to compile in this matter is found in Appendix 7.2. Since this is an important question that influences the assessment of the discharges we think that the bioavailibility of nutrients in the Ryaverket discharges and overflow should be investigated and compared with water from Göta Älv and the return current.

The Ryaverket recipient is strongly influenced by Göta Älv, but also from the current that enters the area from south. Together they give a high rate of water exchange and a transport away along the coast. Variations in the river discharge are relatively great in spite of the regulation, and this causes variation of salinity, the position of the salt wedge and the flow in the return current. This variation is probably an important explanation why we cannot find any effects of the discharge from Ryaverket on the plankton production in the recipient. Göta Älv and the return current that the river flow gives rise to are also the dominating phosphorous sources at the river mouth, together about 4 times greater than the Ryaverket discharges in 2003. These large and varying phosphorous transports mask the effects from todays Ryaverket discharges. Our conclusion is therefore that a further reduction of 12 tons would probably not give any noticeable effects. But most of the phosphorous which discharges to the recipient during the vegetation period will probably be absorbed and contribute to the formation of biomass. The Bohus coast is mainly phosphorous limited which means that even if the discharged phosphorous does not result noticeably in increased production in the near recipient it will probably contribute to production at other places along the coast. A new report from SMHI (Marmefelt et al 2004) among other things point at the flows of tot-P between the coastal basins from basin B25 Rivöfjord, to which Göta Älv discharges, it is estimated that there is a net transport of 179 tons of tot-P annually to the adjacent coastal waters. It can therefore be assumed that much of the discharges from Ryaverket are exported to other parts of the coast. Their effects on the biota can in the present situation only be judged based on the relative contribution the prescribed annual 12 tons of tot-P reduction make compared to other sources and to the eutrophy situation in general of the coast.

5.2 Conclusions

- Supply of tot-P from the sea and Göta Älv have in later years dominated in the recipient and Ryaverket stands for about 20 %. A reduction of 12 tons of tot-P corresponds to about 5 % of the supply.
- The discharge of Göta Älv varies much, which makes the position of the salt water wedge move up- and downstream. This creates a probem for our calculations of mass balances. To improve the model, better measuring data of salinity in the estuary are needed.
- The connection between phosphorous concentrations and supply is weak at the Bohus coast in spite of high N:P-ratios. This should be investigated further.
- The bioavailability of nutrients in the discharges from Ryaverket should also be investigated and compared with other sources in the region.
- Under these circumstances it is difficult to distinguish any effects of phosphorous supply on the biota (measured as chlorophyll *a*).
- 12 tons further reduction of the phosphorous discharges will probably not give any noticeable effects. This is mainly due to the estuarine characteristics with a high rate of water exchange (short retention times), rather than that the phosphorous is not taken up by the biota. Most of the phosphorous discharged to the recipient during the vegetation period will probably be taken up and contribute to the formation of biomass. Its effects on the biota can in the present situation only be judged based on the relative contribution the prescribed annual 12 tons of tot-P reduction make compared to other sources and to the eutrophy situation in general of the coast.

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7. Appendices

7.1 List of literature with comments related to the investigation

MIS Martin Isæus
PGS Per Stålnacke
PST Petter Stenström

Numbering as in Appendix 2 to Invitation for offer.

1. Fosforutsläpp till vatten år 2010, delmål, åtgärder och styrmedel. NV 2004-12-31
The diagrams showing the distribution of sources of phosphorous discharges relevant to the environmental goal for 2010 in total for Sweden are not of relevance for this study./PGS
2. Utsläppsdata från GRYAAB 1970-2003. Gryaabs miljörapport.
Data obtained digitally per month and divided between direct discharges via the Ryaverket WWTP and overflow. Results are given in the main part of the report./PGS
3. Massbalans för fosfor i Göta Älvs estuarium för 1970, 1990 och 2003.
Shows large supply of PO_4-P via marine bottom water from Kattegatt relative to the supplies from Ryaverket and Göta Älv. We have however used own calculations for the supply via Göta Älv and the Rya plant on a monthly basis for 1990-2003. Results are given in the main part of the report./PGS
4. The Chatonella-bloom in year 2001 and effects of high freshwater input from River Göta Älv to the Kattegatt-Skagerrak area. Bengt Karlsson & Lars Andersson, SMHI, RO No 32.
Resultats are discussed in the present study. MIS.
5. Eutrofiering av svenska kustområden samt omgivande hav. NV. Sid. 73 näringstransporter med Göta Älv and Kattegatt. 1993.
6. Göta Älvs vattenvårdsförbunds årsrapport 2003. Näringsämnen
Data are shown for the stations Lärjeholm, Stenpiren and the Älvsborg Bridge. No other assessment of the results is made than simple comparisons in the form of tables with earlier years. We have however used data from Göta Älvs vattenvårdsförbund to calculate river discharges 1990-2003./PGS
7. Effekter av näringstillförsel med Göta Älv från Ryaverket på Göta Älvs mynningsområde. Selmer & Rydberg. Rapport till Göteborgsregionens Ryaverksaktiebolag 1993.
The report and the joined article are primarily aimed at nitrogen balances, but some interesting results and observations are also presented for phosphorous (PO_4-P). For the period studied, 1988-1992 it is stated e.g. (i) that the PO_4-P flows in the estuary were dominated by flows from the sea, while the contributions from Göta Älv and Ryaverket were relatively small, (ii) that the flow pattern right in the rivermouth was remarkably stable which is explained by the regulated river flow, (iii) that the return current originates in the surface water of Kattegatt, and (iv) that there is an extreme (!) excess of nitrogen in the estuary. It is also stated that the supply of tot-P from Ryaverket is 3 to 4 times bigger than the supply of PO_4-P. Threre are several calculation errors in the tables over phosphorous transports. PST
8. Sammanställningar av Bohuskustens vattenvårdsförbunds Hydrografiska mätningar utförda av SMHI 1990-2003.
For "The Göta Älv mouth and the southern archipelago" data from four stations are presented in the report: E the Älvsborg Bridge, Skalkorgarna, Danafjord and Valö. It is however mentioned that Valö is seldom influenced by the discharge from Göta Älv. The results show very high concentrations of DIN, but low concentrations of DIP at the Älvsborg Bridge. At Skalkorgarna the DIN concentrations have decreased and in Danafjord conditions are

governed by the water from the outer sea. The oxygen concentrations are judged good at all three stations. PST

9. Swedish National Report on Eutropication Status in the Kattegatt and the Skagerrak – OSPAR assessment 2002. Bertil Håkansson (ed) SMHI, RO No 31, 2003.
10. Primary production in the Baltic entrance region: trends and variability Rydberg, AErtebjerg and Edler. J, Sea Res. In press
11. Bohuskustens vattenvårdsförbunds mätningar av makroalger 1992-1995
12. Förekomst och utbredning av fintrådiga grönalger 1994-2003
 The series of reports contains one report for 1994-95, and annual reports 1998-2004 with quantitative data and compilations for Bohuslän. In the reports 1994-95, 2003 and 2004 the distribution of filamentous algae is not shown in the form of a table but only graphically as diagrams and maps. One general trend over the whole period is that northern Bohuslän (region 1) has considerably larger occurrences and distributions of filamentous algae than the rest of Bohuslän (region 2-4). The surveys are made by use of aircraft photos 2-3 times every summer 1998-2004. There are no marked trends as regards filamentous algae, but there are two evident blooms in August 1999 and summer 2003. /MIS
13. Sjögräsängars utbredning halverad i Bohuslän. Pressmeddelande 2000-11-29. Länst. Västra Götaland
14. Long-term changes in macroalgal vegetation on the Swedish coast. BK Eriksson. Acta Univ. Upsal. Uppsala 2002.
 This thesis describes overall eutrophication effects and changes in the macroalgae vegetation in two areas at the Swedish coast. The study is made on bottoms that have been surveyed earlier (Öregrund 1943-44 and 1986, Gullmarsfjorden (1) 1941 and (2) 1960-61). There is a limited relevance for our study, since trends on the west coast after 1990 are not treated. There are also interesting studies of the effect of sedimentation on macroalgae etc. in the thesis. /MIS
15. Long-term changes in macroalgal vegetation of the inner Gullmar fjord, Swedish Skagerrak coast. Eriksson, Johansson & Snoeijs. J. Phycol. 38: 284-296. 2002.
 See above (14). /MIS
16. Long-term changes in macroalgal vegetation in the Skagerrak area. Johansson et al. Hydrobiologia 385: 121-138. 1998.
 See above (14). /MIS
17. Epibioses of Gullmarsfjorden: An underwater stereophotographical transect analysis in comparison with the investigation of Gislén in 1926-29. Svane and Gröndahl. Ophelia 28(2):95-110. 1988.
 This article compares macroflora and macro fauna 1986-87 with old surveys 1926-29 in Gullmarsfjorden. The authors conclude that the distribution in depth for macroalgae has decreased generally between the surveys. Eutrophication is mentioned as one possible cause of this, but it is stressed that this may not be a well-founded conclusion. A number of other possible causes are discussed. /MIS
18. Långsiktiga förändringar av makroalgflorans artsammansättning och utbredning i södra Laholmsbukten sedan 1950-talet. Tore Wennberg. SNV rapport 3290. 1987. *The report describes the successive change of the macroalgae flora 1952-86 in Laholmsbukten. In general, Fucus-species have diminished (large perennial sea weeds) and Cladophora and Enteromorpha (filamentous green algae) increased during the period./MIS*
19. Kvävereningens inverkan på de marina bottensamhällena från Ryaverkets avloppsutsläpp i Göta Älv GRYAAB. 1996-2002. L-H Jenneborg, HydroGIS AB, 2002
 See comments regarding methods below (21). /MIS
20. Utbredning av Ulvaria obscura 1982-2001. L-H Jenneborg, HydroGIS.
 Survey data, as they are presented here are regrettably somewhat difficult to interpret. Each GIS-map shows 5 years of surveys butit is not possible to distinguish survey locations between years. The survey areas have not been fixed between the 5-year descriptions, which makes it impossible to discern trends. /MIS

21. Uppföljning av kvävereningens inverkan på bottnarna i Göteborgs norra skärgård. På uppdrag av GRYAAB. L-H Jenneborg, HydroGIS. 1996 – 2002.
The site descriptions in the report series give a good picture of the dominant species in the recipient. The video picture method will of course not give as stringent data as will diving surveys, and many species are certainly overlooked. Still, a good basis for creating a picture of the eutrophication status is obtained. Since the method is considerably simpler and cheaper than diving methods, quantity can be gained in return for the quality lost. It is however difficult to discern possible trends from the texts, and a compilation 1996-2002 would be useful. Such a compilation should present more diagrams from observation data than (19), but also the less stringent assessments serve a purpose. To the annual reports, tables of observed data should be joined. /MIS

Litteratur inte upptagen i Bilaga 2:

22. Miljö i Bohuslän 1986. Rapport om tillsynsverksamheten. Läns. i Göteborg och Bohus län, Naturvårdsenheten. 1987:5
Annual data for waste water treatment plants, nutrient transports in larger water courses and monthly diagrams for chlorophyll/Secchi depth, concentration of tot-phosphorous, inorganic phosphorous, nitrogen, carbon bond. Too old for the present investigation. MIS.
23. Miljö i Bohuslän 1987. Rapport om tillsynsverksamheten. Läns. I Göteborg och Bohus län, Naturvårdsenheten. 1988:2
24. Integrerat Kustzonsystem för Bohusläns skärgård. E Marmefelt et al. SMHI rapport 76 (version 2) 2004.
The report describes development and validation of a coastal area model for the Bohuslän archipelago. The model divides the archipelago into a number of horizontally integrated but vertically resolved basins. The model calculates flows of water and dissolved substances, e.g. tot-P, between the different basins. The Göta Älv estuary out to Skalkorgarna makes one basin, B25. Also the basins B26, south of the estuary, and B24, west of the estuary, are of interest for our study. The station Danafjord is situated in the middle of B24. The relevance of the report is, however, limited because the results are presented strongly integrated, both over time (e.g. tons of tot-P per year) and over depth, which makes it impossible to sort out transports in the surface water, at least in the estuary. Some interesting facts in the report are (i) that Göta Älv and Nordre Älv estuaries protrude strongly as land suppliers of phosphorous, with values at least 30 times bigger than those of other basins, (ii) that the net exchange with the basin south of the Göta Älv estuary, B26, is almost zero, probably because the northgoing surface current and the southgoing bottom current cancel each other, and (iii) that Danafjord is more influenced by the exchange with the coastal basins outside than by the exchange with the estuary. PST
25. Slutlig bedömning av muddringens effekter. HydroGIS. Rapport 369, 2004
26. Sedimentundersökningar längs Bohuskusten 1995 samt nuvarande trender i kustsedimentens miljökvalitet – en rapport från fem kontrollprogram. Ingemar Cato SGU, Uppsala 1997
Sampling of sediments was carried out in 1990 by SMHI and in 1995 by NIVA. The stations 2 Skalkorgarna and 4 Danafjord are situated in the Ryaverket recipient area. Both stations have a higher concentration of tot-P in the upper sediments in 1995 as compared with 1990 like all other stations along the Bohus coast. Significant increases of tot-P in the Göta Älv sediments have been measured at Dösebacka (GÄV 1, upstream GBG) +80 % and at Eriksberg (GÄV2) +6 %. These are explained by increasing (calculated) tot-P flows 1993-96 (Göta Älvs vattenvårdsförbund 1996). Sediments are not treated further in the present investigation. MIS
27. Miljögifter och miljökvalitet längs Bohuskusten 1990-1998 – förändringar, belastningar och samband. Ingemar Cato SGU. Rapporter och meddelanden 103. Uppsala 2000
Analyses of environmental contaminants in the same sediment samples as mentioned above, and biological matter collected from 21 stations 1992-1997 along the Bohus coast. None of these data are of use for the present study. MIS

28. Kustvattnet i Göteborgsregionen 1982-84. Johan Söderström.
The report gives a good survey over current patterns and the relative magnitudes of tot-P flows, but especially the data for Göta Älv and Ryaverket are too out of date to be useful. /PST

7.2 Bioavailable phosphorous

The bioavailability of phosphorous (Bio-P) from different sources is less well studied and suffers from great uncertainty because of questionable and non-compatible methods. Studies from NIVA in Norway and SYKE in Finland (Berge & Källkvist 1998, Ekholm & Krogerus 2003) clearly indicate that different sources of phosphorous in watercourses have different bioavailability (see Table A1). The table shows that non-treated waste water has a high bioavailability which diminishes if treated. The studies also show great spread between different samples and Ekholm (word of mouth) points out that if these results are used in other watercourses or treatment plants they will suffer from great uncertainty. Studies of farmland run off in south eastern Norway have shown that 25-75% of tot-P is available to algae (Blakar & Lövstad 1989) which also confirms the problem of determining correct bio-P coefficients.

At Alelyckan, in addition to tot-P, also PO_4-P is measured. Residual P is defined as the difference between tot-P and PO_4-P. There are no specific studies but it can be assumed that a large part of the residual P in Göta Älv is particule bound (adsorbed) phosphorous due to the mud concentration in the water. Persson (1989) showed that the particulate phosphorous was less available in the runoff from farming (<50%) than in the runoff from forest areas and in chemically treated waste water (iron precipitation).

It should however be pointed out that all these studies are dealing with immediately available phosphorous and shall conventionally only be considered as potentially direct bioavilable (weeks). In the long view (months and years) can of course, following changes in sedimentation, light, pH, redox-conditions, more non-available turn into available. The covered studies are also to a great extent laboratory or mesocosmic studies. The greatest uncertainty seems to be about bio-P linked with erosion. Also, many of the studies deal with algal availability under aerobic conditions. Ekholm & Krogerus (2003) point out that phosphorous combined with iron, oxygen-deficient or anaerobic conditions give rise to great bioavailability. This can be especially complicated for marine sediments whose capacity to bind phosphorous often is low in comparison to fresh water. It should be mentioned that Ryaverket uses iron sulphate as precipitation chemical agent.

Table A1. Percent bioavailable phosphorous from different phosphorous sources to water courses. After Berge & Källkvist (1998) and Ekholm & Krogerus (2003)

Phosphorous source	Bioavailable P acc to Berge & Kællkvist (%)	Bioavailable P acc to Berge & Kællkvist (%)
Erosion from fields of corn	24	19-31
Run off from farmyard manure in autumn	63	
Leachate from dung cellar	79	69
Silo liquid	59	
Natural erosion (glacier)	13	
Forest		16
Non-treated waste water	60	
Sewage from private outflows	95[1]	89
Sewage from WWTP with biol. treatm.	-	83
Sewage from WWTP with chem. treatm.	-	36
Detergents	76	

1) Sand filtered
2) Runoff in autumn

Based upon these literature reports we have in the present study made the following assumptions regarding bioavailable phosphorous:

- 36 % of the tot-P discharge from Ryaverket is bioavailable.
- 60 % of the tot-P discharge from overflow in Ryaverket and overflow/losses in sewers and pumping stations is bioavailable.
- 100 % of PO_4-P as measured at the monitoring stations in watercourses is bioavailable.
- 50 % of residual-P (the difference between measured tot-P and PO_4-P) in a watercourse is bioavailable.

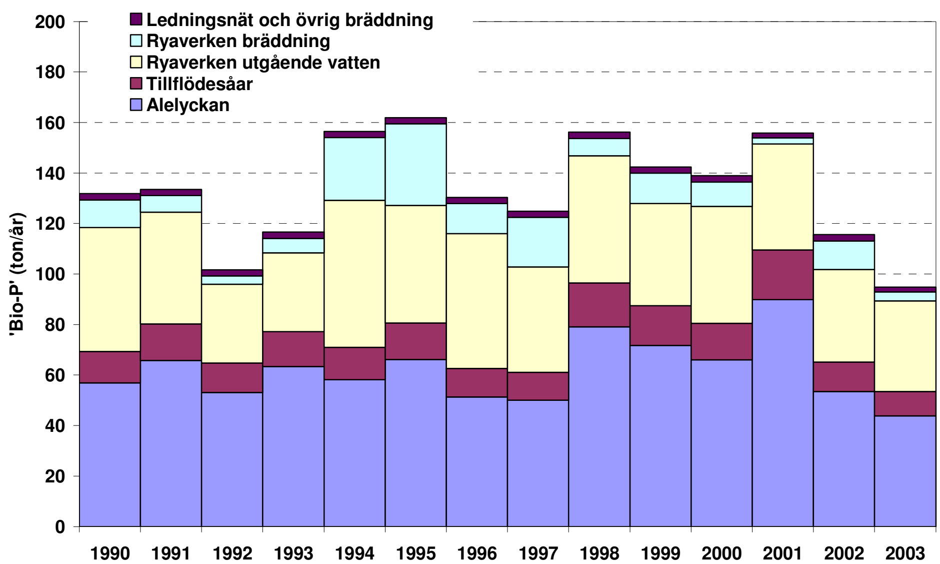


Figure A1. Approximate annual transports and discharges from different sources of bioavailable phosphorous 1990-2003 to the coastal water outside Göteborg.

7.3 Tables for Norwegian classification of environmental status

Exerpt from

Molvær, J., Knutzen, J., Magnusson, J., Rygg, B., Skei, J., Sørensen, J., 1997, Klassifisering av miljøkvalitet i fjorder og kystvann. Veiledning, Statens forurensningstilsyn, Oslo, Veiledning 97:03, 36 sidor.

Assessment of the water chemical results is made with reference to Norwegian quality criteria for the environment. The calculation is valid for water bodies with salinity in excess of about 20.

Table 4. Classification of status for nutrients, chlorophyll *a* and Secchi depth in the surface layer, and oxygen in the deep water. The oxygen measurements are valid for a salinity of 33 and a temperature of 6 ^{o}C.

	Parameters	Status class				
		I Very good	II Good	III Not so good	IV Bad	V Very bad
Surface layer Summer (June-August)	Total phosphorous (µg P/l)*	<12	12-16	16-29	29-60	>60
	Phosphate-phosphorous (µg P/l)*	<4	4-7	7-16	16-50	>50
	Total nitrogen (µg N/l)*	<250	250-330	330-500	500-800	>800
	Nitrate-nitrogen (µg N/l)*	<12	12-23	23-65	65-250	>250
	Ammonium-nitrogen (µg N/l)*	<19	19-50	50-200	200-325	>325
	Chlorophyll *a* (µg/l)	<2	2-3.5	3.5-7	7-20	>20
	Secchi depth (m)	>7.5	7.5-6	6-4.5	4.5-2.5	<2.5
Surface layer Winter (December-February)	Total phosphorous (µg P/l)*	<21	21-25	25-42	42-60	>60
	Phosphate-phosphorous (µg P/l)*	<16	16-21	21-34	34-50	>50
	Total nitrogen (µg N/l)*	<295	295-380	380-560	560-800	>800
	Nitrate-nitrogen (µg N/l)*	<90	90-125	125-225	225-350	>350
	Ammonium-nitrogen (µg N/l)*	<33	33-75	75-155	155-325	>325
Deep water	Oxygen (ml O_2/l)**	>4.5	4.5-3.5	3.5-2.5	2.5-1.5	<1.5
	Oxygen measurement (%)	>65	65-50	50-35	35-20	<20

* The conversion factor from µg/l to µg-at/l is 1/31 for phosphorous and 1/14 for nitrogen.
** The conversion factor from mlO_2/l to mgO_2/l is 1.42

There are no criteria for dissolved nutrients in fresh water, and the concentrations of nitrate and PO_4-P are therefore calculated in proportion to total nitrogen and tot-P for winter and summer with observations from Glomma. The criteria for dissolved nutrients should thus only be used in southern Norway areas. Figur 1 shows examples as how Table 5 can be used for classification diagrams for nitrate. At present such diagrams should be used with caution, and together with other classification parameters.

Table 5. Classes for nutrients and Secchi depth at salinities in the interval 0-20.

Surface layer	Parameters	Salinity	Status class				
			I Very good	II Good	III Not so good	IV Bad	V Very bad
Summer:	Total phosphorous (µgP/l)	0 20	<7 <12	7-11 12-16	11-20 16-29	20-50 29-60	>50 >60
(June-August)	Phosphate-phosphorous (µgP/l)	0 20	<1.5 <4	1.5-2.5 4-7	2.5-4.5 7-16	4.5-11 16-50	>11 >50
	Total nitrogen (µgN/l)	0 20	<250 <250	250-400 250-330	400-550 330-500	550-800 500-800	>800 >800
	Nitrate-nitrogen (µgN/l)	0 20	<125 <12	125-200 12-23	200-275 23-65	275-400 65-250	>400 >250
	Secchi depth (m)	0 20	>7 >7.5	4-7 6.2-7.5	2-4 4.5-6.2	1-2 2.5-4.5	<1 <2.5
Winter:	Total phosphorous (µgP/l)	0 20	<7 <21	7-11 21-25	11-20 25-42	20-50 42-60	>50 >60
(December-February)	Phosphate-phosphorous (µgP/l)	0 20	<4 <16	4-5 16-21	6-10 21-34	10-25 34-50	>25 >50
	Total nitrogen (µNg/l)	0 20	<250 <295	250-400 295-380	400-550 380-560	550-800 560-800	>800 >800
	Nitrate-nitrogen (µgN/l)	0 20	<160 <90	160-260 90-125	260-360 125-225	360-520 225-350	>520 >350

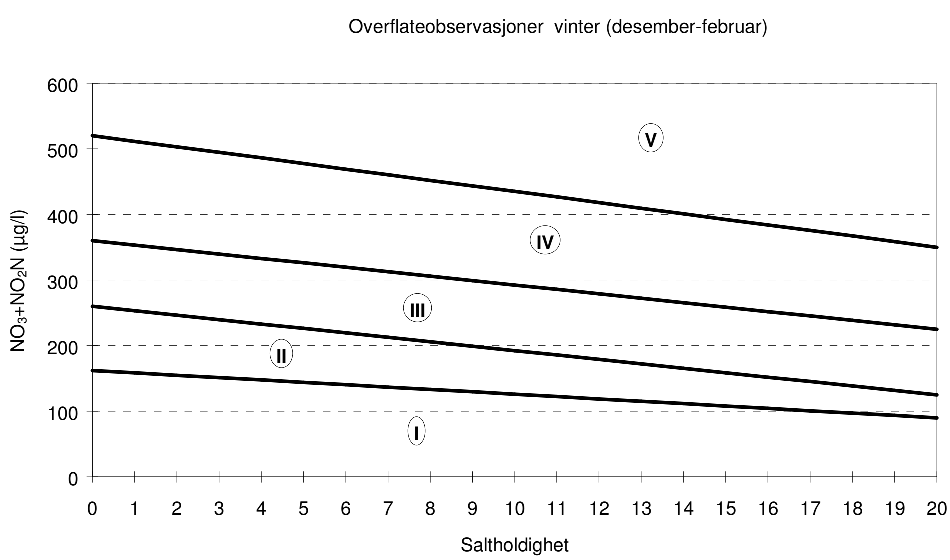


Figure 1. Diagram for classification of nitrate-nitrogen (µgN/l) in winter at a salinity in the interval 0-20.

7.4 Trends in the recipient area compared to Norwegian quality criteria

Below, a description is given of trends in measured nutrient concentrations for the Älvsborg Bridge, Skalkorgarna and Valö 1990-2004. The analyses are based on data from Bohuskustens monitoring programme and the stations are chosen to highlight the gradient from areas strongly influenced by Göta Älv, via the intermediary Skalkorgarna to Valö which is mainly marine influenced. In the figures the values are classified according to the Norwegian classification system for environmental quality in coastal water (Molvær 1997). The figures are best studied in parallel with the corresponding figures in the SMHI compilation and evaluation of hydrological measurements along the Bohus coast (Axe et al) where there are comparisons with the preliminary assessment principles in the Water Directive. An excerpt from the Norwegian report, showing the schematics of the classifications, is given in Appendix 7.3. In short, the Norwegian criteria for the eutrophication state are divided into five classes of state. Very good, good, not so good, bad and very bad.

For the winter season, before the bloom in spring, the criteria are corrected for the salinity in the following way:

1. In the river mouth (salinity 0 psu) the criteria are the same as for the corresponding parameters and classes of state for fresh water.
2. For salinities of over 20 psu the criteria are the same as for marine conditions.
3. Linear interpolation has been used for obtaining criteria for salinities between 0 psu and 20 psu.
4. The results of the interpolation method have been tested in the region of Hvaler and were found satisfactory.

For the presented figures, first the salinity variation with depth has been examined in order to establish whether salinity must be taken into account, and which depth interval can be regarded as surface water (above the halocline). For nutrients, only winter values have been used. They are considered to best represent nutrient supply, as nutrients are not absorbed by organisms to any greater extent in winter. For Secchi depth and chlorophyll no winter values are available and so summer values from June-August have been used.

Valö

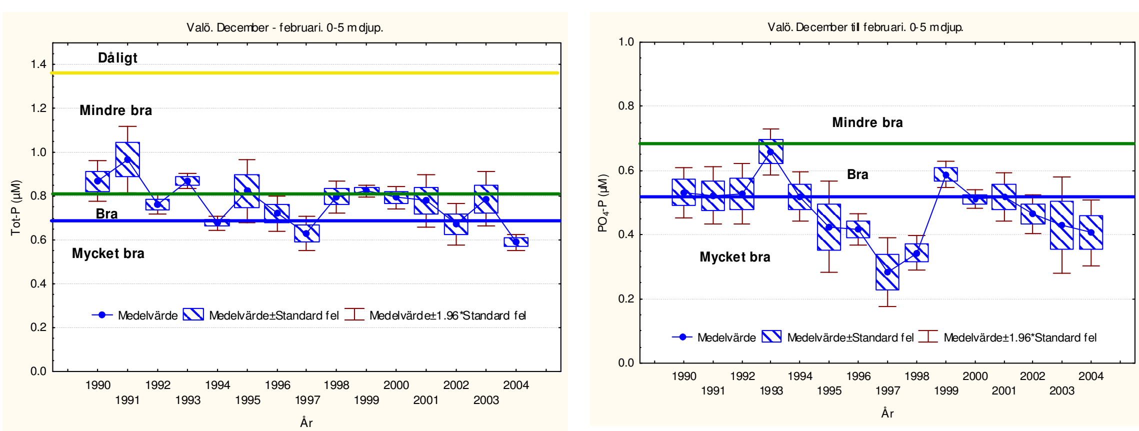


Figure 23. Measured values for tot-P and PO_4-P in the surface water (0-5 m) at Valö 1990-2004 (µM) compared to Norwegian criteria for environmental classification (Molvær et al 1997). Winter values (Dec-Feb).

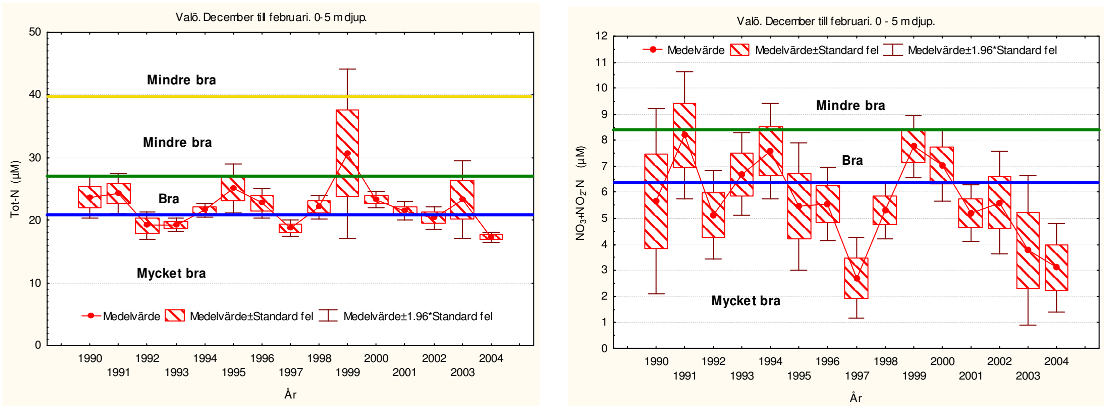


Figure 24. Measured values for total nitrogen and nitrite plus nitrate nitrogen (NO_x-N) in the surface water (0-5 m) at Valö 1990-2004 (µM) compared to Norwegian criteria for environmental classification (Molvær et al 1997). Winter values (Dec-Feb).

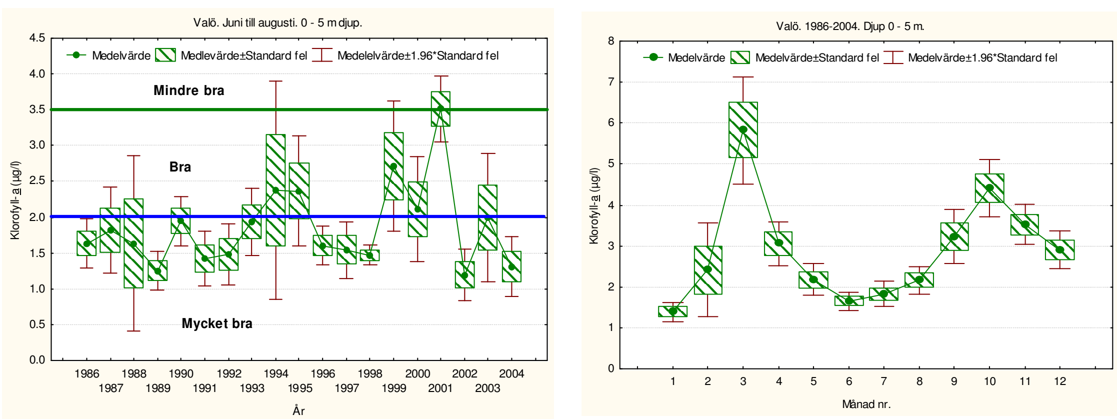
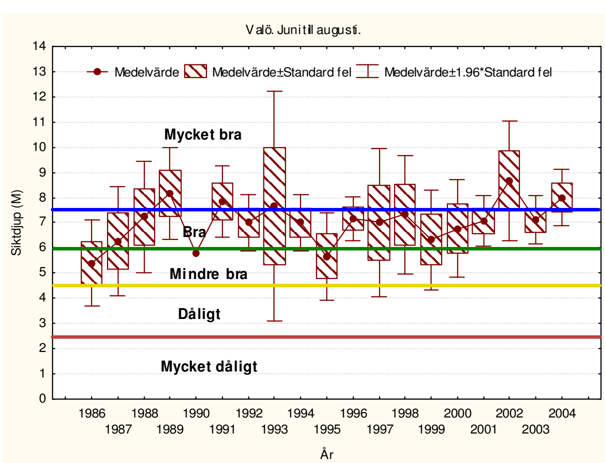


Figure 25. Measured values for chlorophyll *a* in the surface water at Valö 1986-2004 (µM). To the left are summer values (Jun-Aug) compared to Norwegian criteria for environmental classification (Molvær et al 1997). To the right the variation of chlorophyll a over the year.



Figur 26. Measured values for Secchi depth during the summer (June-Aug) at Valö 1986-2004 (µM) compared to Norwegian criteria for environmental classification (Molvær m fl 1997).

Skalkorgarna

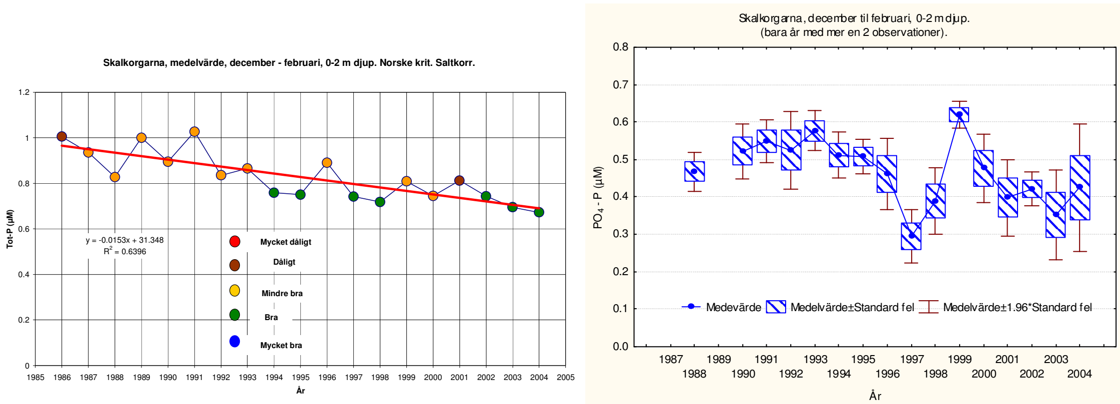


Figure 27. Measured values for tot-P and PO_4-P in the surface water (0-2 m) at Skalkorgarna 1986/88-2004 (µM) compared to Norwegian criteria for environmental classification (Molvær et al 1997). The values are corrected for salinity. Winter values (Dec-Feb).

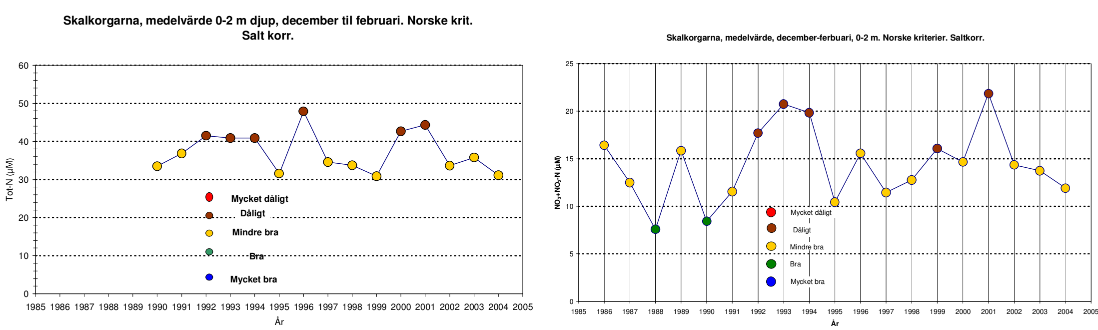


Figure 28. Measured values for total nitrogen and nitrite plus nitrate nitrogen (NO_x-N) in the surface water (0-2 m) at Skalkorgarna 1986/90-2004 (µM) compared to Norwegian criteria for environmental classification (Molvær et al 1997). The value classes are corrected for salinity. Winter values (Dec-Feb).

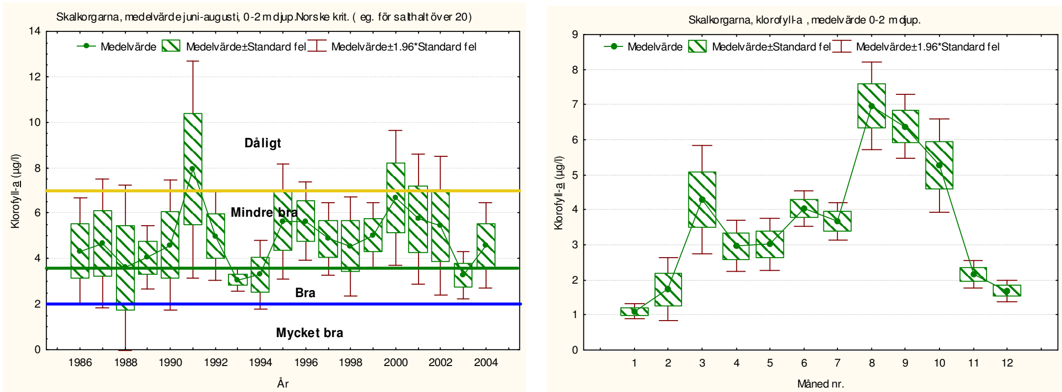


Figure 29. Measured values for chlorophyll *a* in the surface water (0-2 m) at Skalkorgarna 1986-2004 (µM). To the left compared to Norwegian criteria for environmental classification (Molvær et al 1997). To the right the variation of chlorophyll a over the year. Summer values (Jun-Aug)

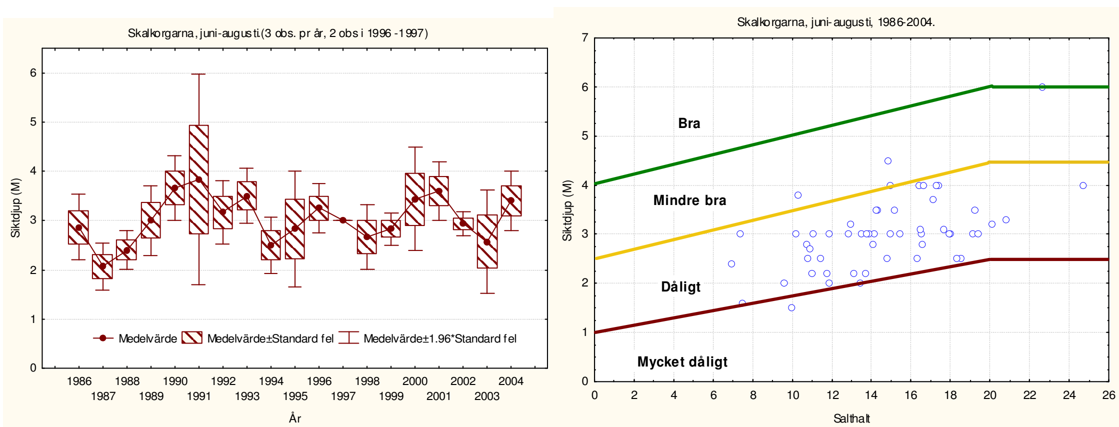


Figure 30. To the left measured values for Secchi depth at Skalkorgarna 1986-2004 (µM). To the right are same data plotted against salinity and compared to Norwegian criteria for environmental classification (Molvær et al 1997). Summer values (Jun-Aug)

The Älvsborg Bridge

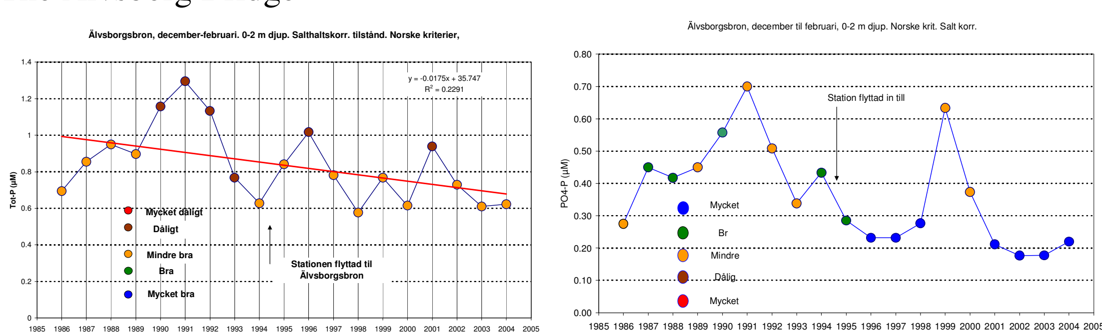


Figure 31. Winter values (Dec-Feb) for tot-P and PO_4-P in the surface water (0-2 m) at the Älvsborg Bridge 1986-2004 (µM) compared to Norwegian criteria for environmental classification (Molvær et al 1997). The value classes are corrected for salinity. The arrow marks the relocation of the measuring station in 1994.

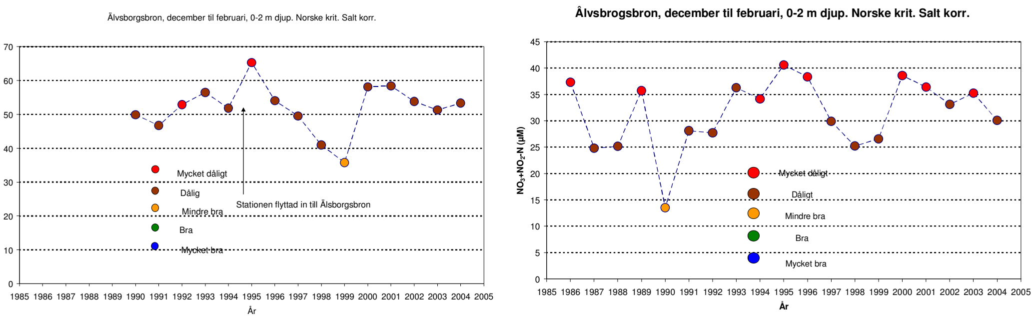


Figure 32. Winter values (Dec-Feb) for total nitrogen and nitrite plus nitrate nitrogen (NO_x-N) in the surface water (0-2 m) at the Älvsborg Bridge 1990/86-2004 (µM) compared to Norwegian criteria for environmental classification (Molvær et al 1997). The value classes are corrected for salinity. The arrow marks the relocation of the measuring station in 1994.

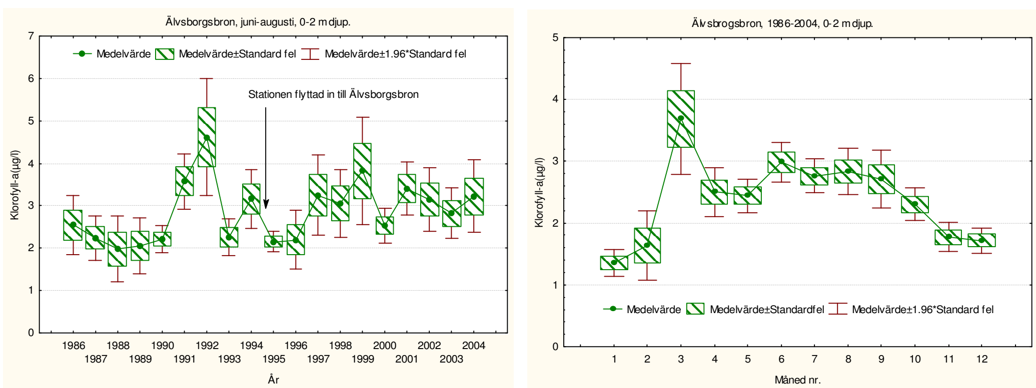


Figure 33. Summer values (Jun-Aug) for chlorophyll *a* in the surface water (0-2 m) at Skalkorgarna 1986-2004 (µM). To the right the variation of chlorophyll a over the year.

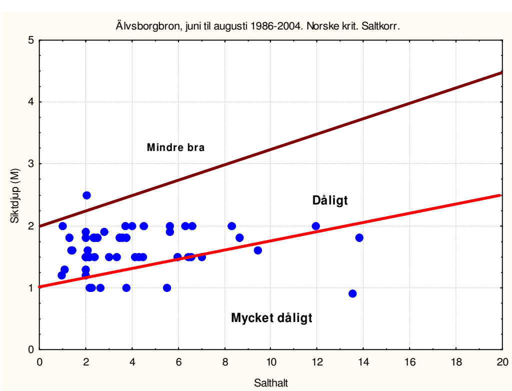


Figure 34. Summer values (Jun-Aug) for Secchi depth at Skalkorgarna 1986-2004 (µM) plotted against salinity and compared to Norwegian criteria for environmental classification (Molvær et al 1997).