

**Probable effects on the production of macrovegetation and
phytoplankton of a possible reduced phosphorous discharge
from the Rya WWTP**

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Summary

The eutrophication of the Swedish west coast has increased heavily in the last 20-30 years, with more frequent phytoplankton blooms and increased production of short-lived filamentous algae in shallow bays as a result. This has among other things led to that more long-lived macroalgae (e.g. *Fucus*) have become a little scarcer, that the species diversity of the macrofauna has been reduced and that the breeding habitats for many fish species (e.g. plaice and cod) have vanished. It is likewise possible that the contracting of eel grass meadows along the west coast in the recent 20 years is connected with the large increase of filamentous algae. In particular, it is thought that supply of phosphorous and nitrogen plays an important role for the eutrophication problem we observe today.

The purpose of this study was to analyse whether a reduction of the phosphorous discharge from 0.4 mg/l to 0.3 mg/l from the Rya plant at the Göta Älv mouth will have an effect on the production of macro- and microalgae in the recipient zone. We have tried to answer this question in a general way by investigating effects of the phosphorous discharge from the Rya plant on the distribution of algae, temporally and spatially. We have based our analyses on data from earlier reports and studies, and tried to use as many statistical tests as possible, since such had been used very little in the earlier studies. We have focussed upon how occurrence, distribution and biomass of filamentous algae have changed during 1994-2004 both in the recipient zone and in the whole Bohuslän coastal zone, and upon possible relations to phosphorous and nitrogen discharges. Also the local variation within the Göteborg archipelago was analysed, and the changes in phytoplankton density in the recipient zone in later years. We have also analysed the distribution of a species indicative of eutrophication, the green alga *Ulvaria obscura* in the northern and southern part of the recipient zone, and the different occurrences of this alga close to or far away from the Rya plant in 1982-2001. We have related the occurrence of *U. obscura* to the discharge of phosphorous and nitrogen from the Rya plant during these years.

The results show a high occurrence and a wide distribution of filamentous algae in the beginning of the 1990-s, followed by a marked decline at the end of this millennium. Phosphorous- and nitrogen discharge from the Rya plant exhibited the same changes, which means a positive relation between phosphorous/nitrogen discharge and the occurrence of filamentous algae in the Göteborg archipelago in 1994-2004. In the region around Tjörn-Orust a positive relation was also found between phosphorous discharge from the Rya plant and the occurrence of filamentous algae, while such a relation could not be established in the two northernmost regions in Bohuslän. The relation between occurrence of filamentous algae and nitrogen discharge was somewhat more pronounced and this may indicate that nitrogen is the restricting nutrient for filamentous algae in the recipient zone. According to a linear regression model a reduction of phosphorous discharge from 0.4 to 0.3 mg/l should result in a reduction in occurrence (number of bays with >5% cover percentage) of filamentous algae from 30% to 11% in the recipient zone. These values are, however, rough predictions since the dependence was not strong and other factors may well also be of importance.

We could not find any changes of the occurrence of *U. obscura* between different time periods, even if phosphorous and nitrogen discharges from the Rya plant have decreased considerably from the 1980-s and up to today. *Ulmaria* however appeared more frequently closer to the Rya plant (due either to its discharge or the nutrient supply from the Göta Älv itself) and in the northern part (probably an effect of the northbound current) of the recipient zone, although these patterns did not

deviate significantly between the periods of 1982-1986 and 1997-2001. The density of phytoplankton was considerably higher in the recipient zone in spring 1999 compared with 1998 and 2000-2003, but we could not find any co-variation with the phosphorous- and nitrogen discharge from the Rya plant.

from the analysed data it was also obvious that variation in space, time of occurrence and distribution of algae can be very large and for more reliable conclusions, there is a need for better replication on different spatial and temporal scales in future studies (at the same time as variation in discharge of phosphorous and nitrogen will be needed). Crucial problems in this study were: how much of the particulate-bonded phosphorous become biologically available; is phosphorous or nitrogen the restricting factor in the recipient zone; how are nutrients regenerated from sediments in shallow bays. These problems are discussed in the present study.

Our conclusion is that today we have no definite answer to if a reduction of phosphorous discharge from the Rya plant (from 0.4 to 0.3 mg/l) will have positive effects on the environment or not, but we know that this cannot be precluded. Indirectly we have been able to show that the Rya discharges of nitrogen and phosphorous give some effect, but the effects of the release of these substances cannot be separated. The fact that a phosphorous effect cannot be verified is on the other hand not equal to state that phosphorous is without effect. A possible effect can furthermore be temporally and/or spatially limited.

Introduction

Eutrophication of coastal waters has been and is still a serious problem globally and locally. The obvious causes include increased human populations, and increased use of fertilizers and industrial processes, over the past hundred years (de Jonge 2002). Swedish coastal waters, the Baltic Sea and the west coast, are severely affected by eutrophication owing to discharge of phosphorous and nitrogen, with strong algal blooms as one consequence. Farming, local discharges in rural areas, wastewater treatment plants and industry are the main sources of these nutrients.

In fresh water, like in certain coastal waters, phosphorous is usually the limiting factor for algal growth (e.g. Ekholm & Krogerus 2003), while nitrogen normally is limiting algal growth in the open sea. Optimal growth of phytoplankton takes place when the ratio between nitrogen and phosphorous is 16 (mol proportion) or 7 (weight proportion), which is called the Redfield ratio. If a water body has a N/P-ratio greater than 16 (7), this indicates that phosphorous is the limiting nutrient, while a lower value indicates that nitrogen is restricting. Along the Swedish coast nitrogen is considered limiting in Skagerrak, Kattegat and the greater part of the Baltic Sea, while phosphorous is restricting in Bottenviken. Close to the coast phosphorous can also be restricting at the west coast too.

During the last 20 years the eutrophication of the west coast has led to a considerably increased production of short-lived filamentous algae (mostly green algae like *Enteromorpha* and *Cladophora*) in shallow (0-1 m) bays (Johansson et al 1998, Pihl et al 1999, Eriksson et al 2002). These algae grow in summer, and they can produce thick floating mats covering large areas of these bays (ca 30-50%). Those filamentous algae are a threat to the biologic multiplicity, because they can compete successfully with more long-life algae (e.g. *Fucus*) and eel grass (*Zostera marina*), and also reduce the species diversity of macrofauna and destroy breeding habitats for e.g. plaice and cod (Johansson et al 1998, Pihl et al 1999, Pihl 2001, Eriksson et al 2002). These algal mats are furthermore consuming large quantities of carbon and nitrogen, which influences the carbon and nitrogen conversion of the archipelago, and oxygen

consumption in deeper water (Moksnes & Pihl 1995). Also to man these algal mats can constitute a problem, since they make fishing, swimming and boating difficult. In the last two decades the eel grass meadows (which are an important habitat for many marine organisms) have along the Swedish west coast diminished in extent and in distribution according to some studies. In average, 52% of the eel grass meadows are thought to have disappeared along the whole coast (82% in the community of Kungälv) since the beginning of the 1980-s (Gullström et al 2001). The phytoplankton production has also generally increased somewhat in this period, and the frequency of toxic phytoplankton blooms ha also increased. When these algae settle and decompose, much oxygen is consumed which can result in large areas of oxygen-free bottoms along the coast (Rosenberg et al 1990).

There are a number of species or groups of organisms which are classified as indicators for eutrophication in the sea. Under long-time and constant influence of nutrients an increase follows of occurrence and distribution of the leaf-formed green alga *Ulvaria obscura* (probably the most important indicator species) and *Enteromorpha (Ulva) linza* (Jenneborg 2002). Heavy layers of cyanobacteria (blue-green algae) are produced when eutrophication is so pronounced that even the bottom societies can get damaged, and sulphur bacteria occur in bottoms where mats of blue-green algae have dominated, these bacteria indicate " dead bottoms" with severe lack of oxygen (Jenneborg 2002).

This investigation is carried out at the request of Bohuskustens vattenvårdsförbund and Gryaab for the purpose of evaluating the effects of a possible reduction of phosphorous discharge from the Rya WWTP at the mouth of the Göta Älv. Gryaab (who manages the Rya plant) has by the environmental authorities been instructed to decrease the discharge of total phosphorous from 0.4 mg/l to 0.3 mg/l, which implies an annual reduction of about 12 tons of phosphorous. The Rya plant has reduced its phosphorous discharges successively since 1970 (1970: 650 tons of Tot-P/year; 2003: 40 tons of Tot-P/year). In the middle of the 1980-s phosphorous reduction by chemical precipitation was introduced, and from the end of the 1980-s up to the beginning of the 1990-s an extension for further phosphorous reduction was made. In 1997, also an extension for nitrogen reduction was taken into service. In spite of these substantial reductions of discharge the Rya plant contributes about 50% of the Göta Älv total phosphate supply to the sea. The technique that now may be put to use in order to further reduce the phosphorous discharge constitutes a finishing touch of the effluent in a final filtering stage which will cost around 150 million SEK. After the environmental authorities made their decision there has been a debate in Swedish media about whether this extra phosphorous reduction is meaningful at all.

Objectives and questions

The overall objective of this investigation is to answer the question "How will a reduction of total phosphorous discharge from 0.4 mg/l to 0.3 mg/l from the Rya plant influence production and distribution of macrovegetation (macroalgae and eel grass) and phytoplankton in the recipient zone?". With the data at hand it is not possible to answer this question directly, but we have tried to do so indirectly, that is by induction rather than by testing specific hypotheses. For future evaluations it would be desirable to test hypotheses concerning discharge effects, but in order to do this a well designed monitoring programme is needed. With the existing basic information we have focussed our study on the following aspects and questions:

Temporal variation (there were large fluctuations in level of phosphorous and nitrogen discharges from the Rya plant under these periods):

- 1) Have the occurrence and distribution (% cover percentage and biomass) of filamentous algae in shallow bays changed between 1994 and 2004, especially in the recipient zone, but also in the whole Bohuslän coastal zone?; Are there any relationships between these changes and the discharges of phosphorous and nitrogen from the Rya plant?
- 2) Does the occurrence of the green alga *Ulvaria obscura* (indicative species for eutrophication) fluctuate in the recipient zone between 1982-1986, 1987-1996, and 1997-2001 (a substantial decrease of phosphorous and nitrogen discharge from the Rya plant took place between the first and the last period)?
- 3) Has the total density of phytoplankton in the surface water during the spring bloom changed in the habitat Danafjord in the recipient zone in 1998-2003?

Spatial variation

- 1) What differences are there in distribution (% cover and biomass) of filamentous algae in shallow bays within four zones along the Bohuslän coast in relation to discharge of phosphorous and nitrogen, and the occurrence in confined bays in the respective zones?
- 2) Has there been a biomass variation of filamentous algae between habitats within the recipient zone; or a relation between phosphorous/nitrogen in sediments and biomass of filamentous algae in these habitats during 2001 and 2002?
- 3) Is the occurrence of *U. obscura* different between one zone close to and one far away from the Rya plant, and between the northern and southern parts of the recipient zone; and do these patterns change between 1982-1986 and 1997-2001?

We have focussed upon attempts at analysing changes and differences in distribution and occurrence of macro- and microalgae statistically as far as possible (based upon data from earlier investigations), since this has been done very sparsely (mostly not at all) in earlier studies and reports concerned with the effect of eutrophication on marine organisms in the Göteborg archipelago. Even if it has not been possible to analyse data statistically, yet we have sometimes chosen to discuss observed changes and differences from other studies. This is perhaps especially carried out for the distribution of eel grass meadows in the recipient zone. We also discuss which factors probably restrict algal production in the recipient zone; the bioavailability of the different forms of phosphorous; and the regeneration of nutrients from sediments.

Methods

Temporal variations

1) Filamentous algae, 1994-2004

We have based these studies on a number of earlier reports (Moksnes & Pihl 1995, Pihl & Svensson 1996, Pihl et al 2000, Pihl et al 2002, Nilsson & Pihl 2002, Jenneborg 2004, Jenneborg 2005), who have all investigated the occurrence (number of bays with >5% cover percentage) and the distribution (mean cover percentage of all investigated bays) of filamentous algae in shallow bays (0-1 m) within four different regions along the west coast of Bohuslän, 1) Idefjorden-Fjällbacka, 2) Fjällbacka-Gullmarsfjorden, 3) Tjörn-Orust, 4) the Göteborg archipelago: Marstrand-Billdal. Field work of the reports were made every summer (June-August) (except in

1997) between 1994 and 2004. Air photography was used to analyse cover percentage of algae in 40-60 randomly chosen bays within each region. Also algal biomass, species composition and sediment samples were determined /analysed in most studies. We refer to each single study for more details of materials and methods.

We compiled data on occurrence, distribution and average biomass of filamentous algae in the Göteborg archipelago in the period 1994-2004, and also on phosphorous and nitrogen discharge from the Rya plant in 1994-2003. Also linear regression analyses were made between discharge of phosphorous/nitrogen (mg/l and tons/year) from the Rya plant and occurrence (probably a more reliable estimate than mean cover) of filamentous algae in the Göteborg archipelago and other regions along the Bohuslän coast in 1994-2003. A 2-factor "nested" variance analysis (a hierarchical design with primary factors and secondary factors; see Quinn & Keough 2002) of the biomass was also made in order to see whether any difference existed between 2003 and 2004, and between June and August these same years. The factor month was "nested" in the factor year (which was a fixed factor). Since the variances were heterogeneous we log-transformed data before analysis.

2) *U. obscura*, 1982-2001

We used four maps of distribution for *U. obscura* in the recipient zone (the Göteborg archipelago) in the periods 1982-1986, 1987-1991, 1992-1996, and 1997-2001, shown as Appendix 1-4 (data collected by L-H. Jenneborg). A certain number of habitats on these maps were not included in the statistical analysis, since they were at greater depths than 6 meter, where *U. obscura* does not grow (Jenneborg 2003). In the analysis, the time periods 1987-1991 and 1992-1996 were combined to one single period, since there were too few habitats in a too limited zone within each period. We made a Chi-2-test (Quinn & Keough 2002) to analyse whether an irregular distribution of *U. obscura* existed between the three time periods, that is, if this green alga was more frequent during some of these periods. Phosphorous- and nitrogen discharges (mg/l) from the Rya plant were also compiled for each year and mean values for the different time periods were calculated.

3) *Density of phytoplankton, Danafjord, Spring 1998-2003*

From the homepage of Bohuskustens Vattenvårdsförbund data were obtained on density (cells/l) of different phytoplankton species in the surface water (0-10 m) in spring at the habitat Danafjord in the recipient zone. The total density of phytoplankton was analysed in a 1-factor variance analysis (e.g. Quinn & Keough 2002) in order to test whether any variation existed between years in 1998-2003. Since the variances were heterogeneous, we log-transformed data before analysis. We also tested if this variation was related to a variation in phosphorous- and nitrogen discharge from the Rya plant during these years.

Spatial variation

1) *Filamentous algae along the Bohuslän coast*

We did not statistically evaluate the differences in occurrence, distribution and biomass of filamentous algae between the four regions along the Bohuslän coast in 1994-2004, but we compiled results from the different existing reports and articles (Moksnes & Pihl 1995, Pihl & Svensson 1996, Pihl et al 1999, Pihl et al 2000, Pihl et al 2002, Nilsson & Pihl 2002, Jenneborg 2004, Jenneborg 2005). For a more detailed information about material and methods, see literature cited above for each study.

2) *Filamentous algae within the Göteborg archipelago*

A 2-factor variance analysis with year as a fixed factor and habitat as a random factor (see Quinn & Keough 2002) was carried out to test whether there were differences in biomass of filamentous algae between 2001 and 2002, and between five random habitats in the Göteborg archipelago. Since the variances were heterogeneous, we log-transformed data before analysis. In addition, we made four covariance analyses (Quinn & Keough 2002), with the phosphorous- or nitrogen content of the sediments as covariates, to analyse the connection between phosphorous and nitrogen contents in sediments and the biomass at different habitats in the recipient zone. Such analyses were made separately for 2001 and 2002. Raw data were obtained from Pihl et al (2002) and Nilsson & Pihl (2002).

3) *U. obscura, spatial differences 1982-2001*

Appendices 1-4 show the four distribution maps for *U. obscura* in the recipient zone (the Göteborg archipelago) in 1982-1986, 1987-1991, 1992-1996, and 1997-2001. Only habitats with a depth less than 6 meter were included in the analysis (see above). In the analysis the periods 1987-1991 and 1992-1996 were not included, since too few habitats were investigated during these periods to allow for a reliable analysis. We made a Chi-2-test (Quinn & Keough 2002) to investigate whether the occurrence of *U. obscura* was more frequent either closer to or further away from the Rya plant within the Göteborg archipelago, and whether these patterns looked different between 1982-1986 and 1997-2001 (between these periods a large difference in phosphorous and nitrogen discharge from the Rya plant was accomplished). We measured the distance between the position of Rya and the west borderline of the map in Appendices 1-4 (the investigated habitats were in certain cases situated very far to the west). Half this distance was then measured with a pair of compasses and a semicircle was drawn on the maps. This was done in order to determine which habitats were close to or far away from Rya plant. Chi-2-test was also carried out to analyse whether the occurrence of *U. obscura* differed between the northern and the southern part of the Göteborg archipelago in 1982-1986 and 1997-2001.

Results

Temporal variations

1) *Filamentous algae, 1994-2004*

The different investigations of the occurrence and distribution of filamentous algae in shallow bays along the Bohuslän coast in summer (Moksnes & Pihl 1995, Pihl & Svensson 1996, Pihl et al 2000, Pihl et al 2002, Nilsson & Pihl 2002, Jenneborg 2004, Jenneborg 2005) show that the cover of these algae decreased in all four zones between 1994-1996 and 1998-2004. Occurrence and distribution decreased most in the three southernmost zones and least in the northern part (Idefjorden-Fjällbacka). In the southernmost region (the Göteborg region: Marstrand-Billdal), that is the recipient zone of the Rya discharges, the occurrence of filamentous algae in 1994-1996 varied between 50 and 75 % (share of bays with a cover >5%) and their distribution between 25 and 35 % cover (mean value of all investigated bays within the region), while the same measurements in 1998-2002 showed between 5 and 35 % occurrence and 1-15 % distribution (Nilsson & Pihl 2002; Figure 1). In 2003-2004 the occurrence of filamentous algae varied between 10-60 %, while the distribution variation was between 1 and 20 % (Jenneborg 2004, Jenneborg 2005; Figure 1).

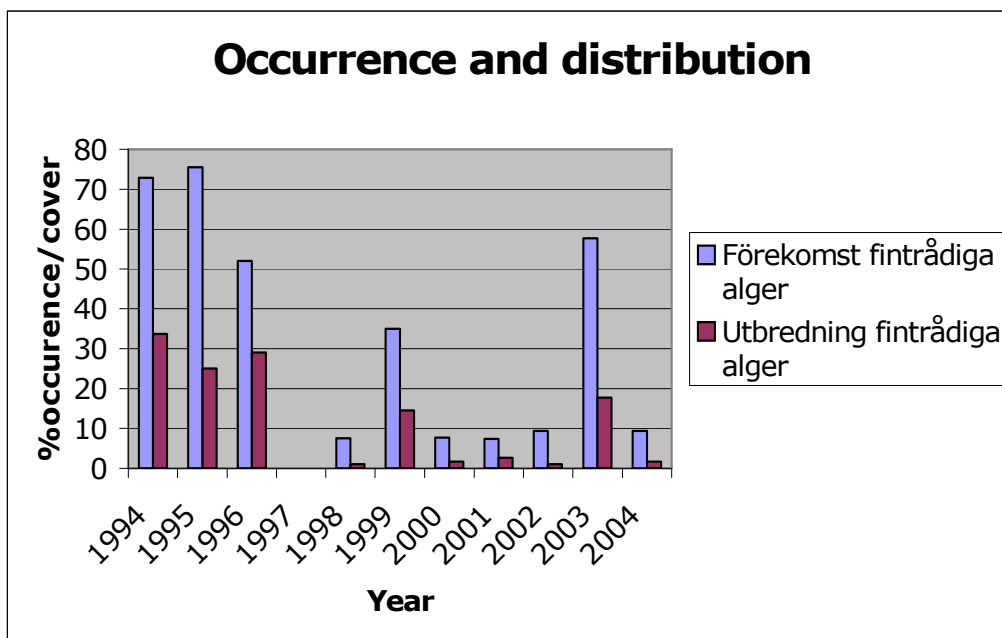


Fig. 1. Occurrence (% of habitats with more than 5% cover) and distribution (mean value of % cover in all habitats within the region) of filamentous algae within region 4 (Marstrand-Billdal) in summer between 1994-2004. For 1997 no data were available.

The marked decrease in occurrence and distribution of these algae between 1996 and 1998 coincided with a reduction of the phosphorous discharge from the Rya plant from 0.60 mg/l to 0.39 mg/l, or from 76 to 64 tons/year, but also with a reduction of nitrogen discharge from 24.1 mg/l to 12.7 mg/l, or from 2384 to 1704 tons/year (Gryaabs miljörapport 2003; see Figure 2 and 3). It should be noted that the Göta Älv discharge of phosphorous has not changed during the period 1994-2003 (NIVA rapport, 2005).

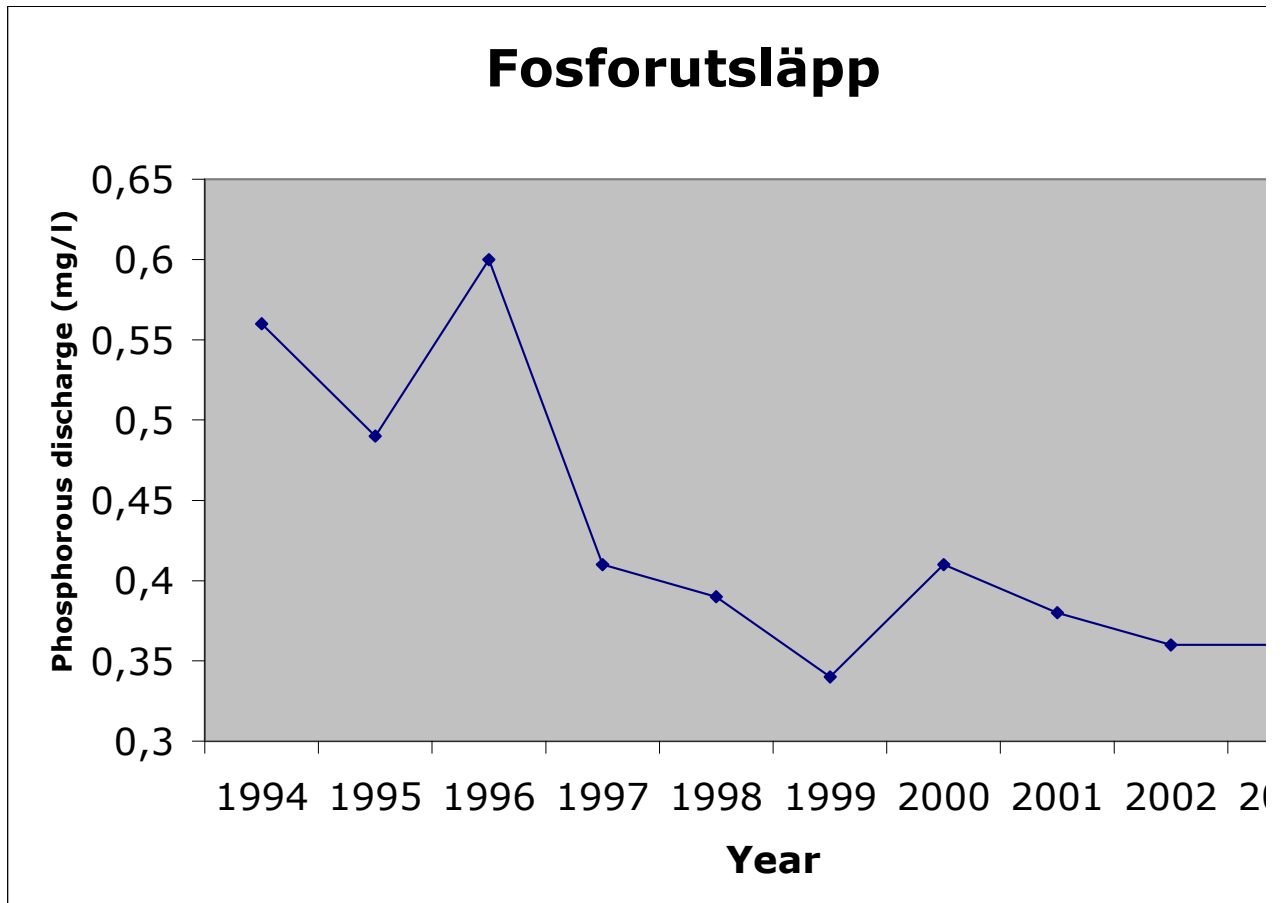


Fig. 2. Discharge of total phosphorous (mean value of content per year) from the Rya plant during 1994-2003.

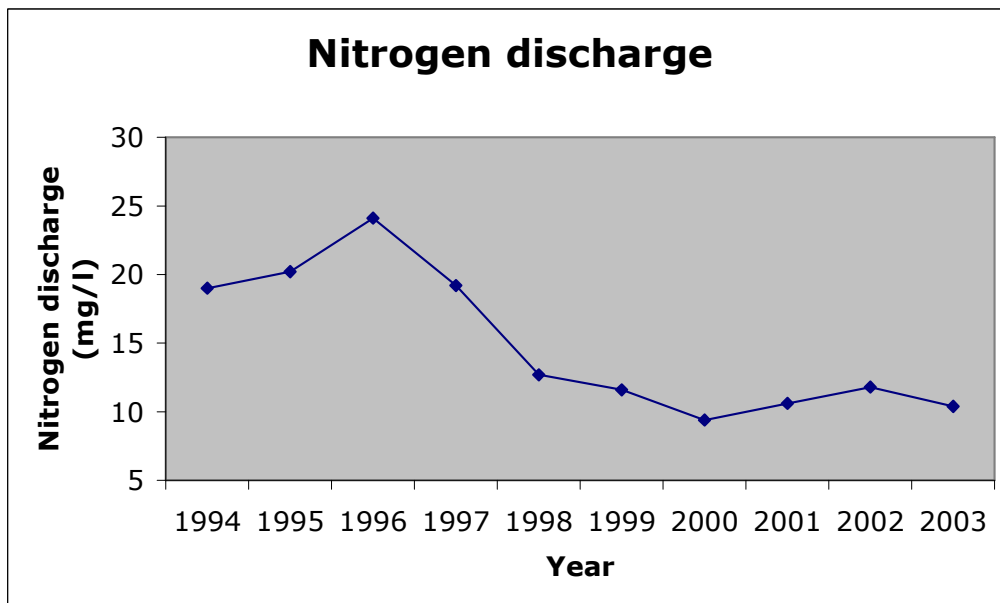


Fig. 3. Discharge of total nitrogen (mean value of content per year) from the Rya plant during 1994-2003, contents do not include overflow.

Between 1998 and 2004 the occurrence and distribution of filamentous algae peaked in 1999 and 2003 in all four regions (Pihl et al 2000, Nilsson & Pihl 2002, Jenneborg 2004), and in the recipient zone the occurrence and distribution of algae increased heavily between 1998 and 1999, and between 2002 and 2003 (Pihl et al 2000, Nilsson & Pihl 2002, Jenneborg 2004; Figure 1). In 2000 and 2004 occurrence and distribution of filamentous algae returned to similar values as in 1998 and 2002 respectively (Jenneborg 2005; Figure 1).

A positive correlation was found between occurrence of filamentous algae in the recipient zone and phosphorous discharge (mg/l and tons/year) from the Rya plant between 1994 and 2003, and also between occurrence of filamentous algae in the recipient zone and nitrogen discharge (mg/l and tons/year) from the Rya plant in the same period (see Figure 4-7). These circumstances were significant ($p < 0.05$) in all regression analyses except the correlation between phosphorous content (mg/l) and the occurrence of filamentous algae (Figure 4-7). The correlation was also positive between phosphorous discharge from the Rya plant and the occurrence of filamentous algae in the region around Tjörn-Orust (mg total phosphorous/l & occurrence: degrees of freedom (df)=8, $r^2=0.40$, $p=0.07$; tons of total phosphorous/year & occurrence: df=8, $r^2=0.44$, $p=0.05$), while this type of correlation was weak in the two northernmost regions in Bohuslän (Idefjorden-Fjällbacka: mgP/l & occurrence: df=8, $r^2=0.11$, $p=0.37$; tonsP/year & occurrence: df=8, $r^2=0.15$, $p=0.31$; Fjällbacka-Gullmarsfjorden: mgP/l & occurrence: df=8, $r^2=0.28$, $p=0.14$; tonsP/year & occurrence: df=8, $r^2=0.37$, $p=0.08$). The two middle regions also showed a positive correlation between nitrogen discharge from the Rya plant and occurrence of filamentous algae (Tjörn-Orust: mgN/l & occurrence: df=8, $r^2=0.65$, $p=0.01$; tonN/year & occurrence: df=8, $r^2=0.62$, $p=0.01$; Fjällbacka-Gullmarsfjorden: mgN/l & occurrence: df=8, $r^2=0.49$, $p=0.04$; tonsN/year & occurrence: df=8, $r^2=0.45$, $p=0.05$), while there was no sign of such a correlation in the northernmost region (mgN/l & occurrence: df=8, $r^2=0.24$, $p=0.18$; tonsN/year & occurrence: df=8, $r^2=0.22$, $p=0.21$).

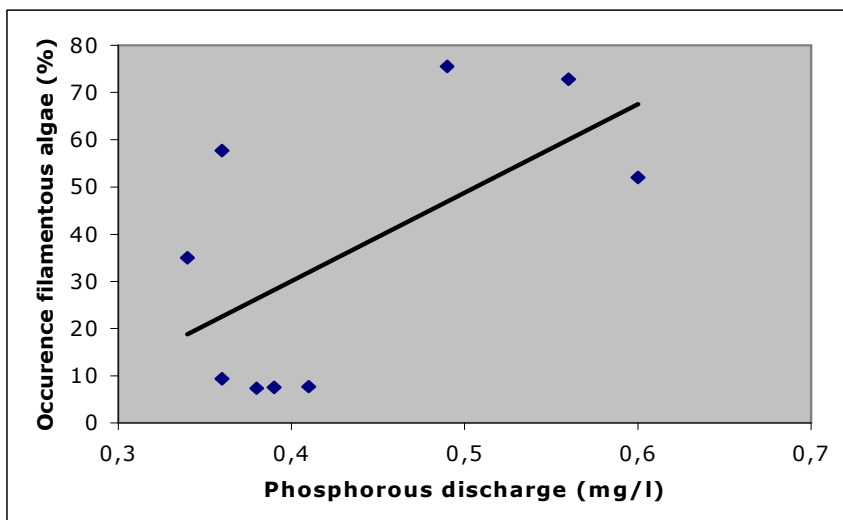


Fig. 4. Relation between discharge of total phosphorous (mg/l) from the Rya plant and the occurrence (% of habitats with more than 5% cover) of filamentous algae in summer in the

region #4 (Marstrand-Bilddal) in 1994-2003. Regression analysis: $df=8$, $r^2=0.37$, $p=0.08$. (linear regression model: $y=187.6x-45.0$).

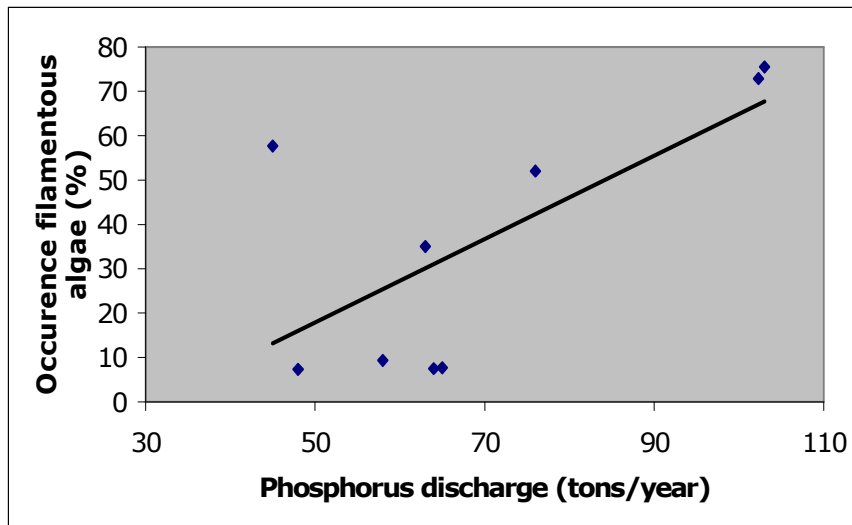


Fig. 5. Relation between discharge of totalphosphorous (tons/year inclusive of overflow) from the Rya plant and the occurrence (% of habitats with more than 5% cover) of filamentous algae in summer in region #4 (Marstrand-Bilddal) in 1994-2003. Regression analysis: $df=8$, $r^2=0.46$, $p=0.04$. (Linear regression model: $y=0.941x-29.17$).

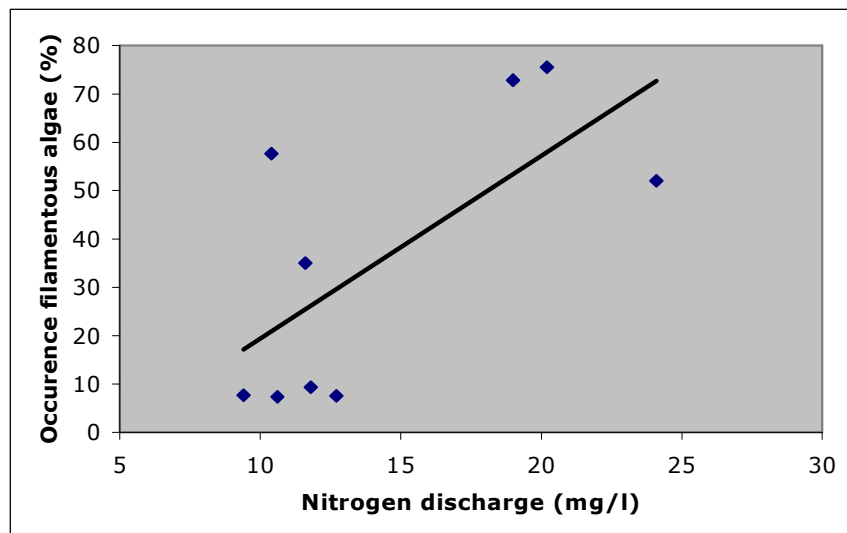


Fig. 6. Relation between discharge of totalnitrogen (mg/l) from the Rya plant and the occurrence (% of habitats with more than 5% cover) of filamentous algae in summer in region 4 (Marstrand-Bilddal) 1994-2003. Regression analysis: $df=8$, $r^2=0.47$, $p=0.04$. (Linear regression modellen: $y=3.78x-18.41$).

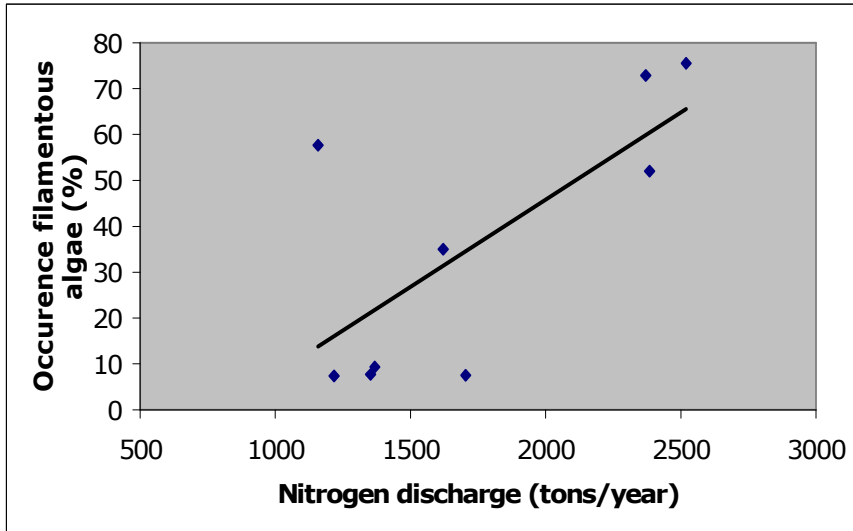


Fig. 7. Relation between discharge of total nitrogen (tons/year including waste water overflow) from the Rya plant and the occurrence (% of habitats with more than 5% cover) of filamentous algae in summer in region #4 (Marstrand-Billdal) 1994-2003. Regression analysis: $df=8$, $r^2=0.50$, $p=0.03$. (Linear regression model: $y=0.038x-30.17$).

The change in the biomass of filamentous algae (g dry weight/ m^2) in the years 1994-1995 and 1998-2004 in the recipient zone (the Göteborg region: Marstrand-Billdal) can be followed in Figure 8 (Moksnes & Pihl 1995, Pihl & Svensson 1996, Pihl et al 2000, Pihl et al 2002, Nilsson & Pihl 2002, Jenneborg 2004). With the available facts we cannot show a relationship between changes in the algal biomass in this region and the discharge of phosphorous or nitrogen from the Rya plant (see Figure 2, 3 & 8). The decrease in the biomass of filamentous algae from 2003 to 2004 (Figure 8) was statistically significant ($df: 1, 16$; $F=8.4$; $p=0.01$), whereas the differences between June and August in these years were not significant. Statistical tests could not be carried out for differences between other years, since different sampling methods were used or raw data were lacking (except between 2001 and 2002: see hereafter).

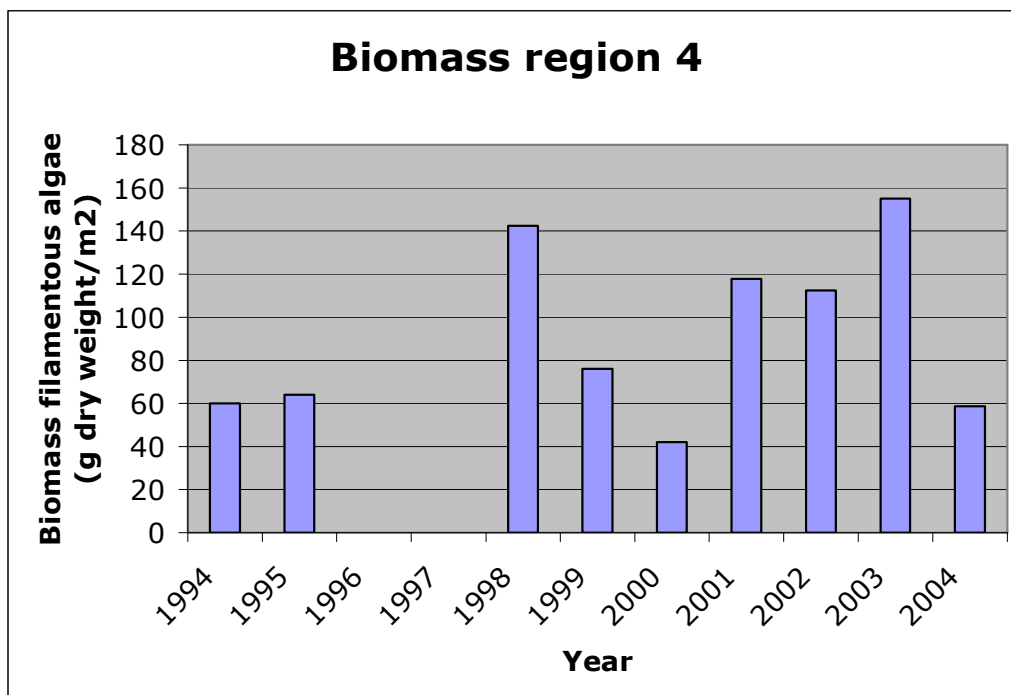


Fig. 8. Average biomass (g dry weight/m² in algal covered zones) of filamentous algae within region #4 (Marstrand-Bilddal) in summer between years 1994-2004. 1996 and 1997 no measured values were available.

2) *U. obscura*, 1982-2001

With a Chi-2-test we could not show any significant difference in the occurrence of *U. obscura* between the three time periods (Table 1). The same result was obtained if only the two time periods 1982-1986 and 1997-2001 were compared. The discharge of total phosphorous from the Rya plant decreased successively from 1982 to 1986 (Table 2a; mean value=2.0 mg/l), exactly like in 1987-1991 (Table 2b; mean value=0.53 mg/l). An increase was found between 1992 and 1996 (Table 2c; mean value for the whole period 1987-1996 was 0.49 mg/l). Then at first a decrease and thereafter a small increase in 1997-2001 (Table 2d; mean value=0.39 mg/l). Nitrogen discharge in the three different periods was in average 16.5, 19.3 and 12.7 mg/l, and thus did not decrease substantially until in 1997-2001 (Table 2a-d). *U. obscura* has not occurred less frequent (according to Chi-2-test) at the end of the 1990-s and the beginning of 2000, when the phosphorous and nitrogen discharges from the Rya plant were substantially reduced. For other eutrophication indicating species, as the green algae *Enteromorpha (Ulva) linza*, *E. intestinalis*, *Cladophora flexuosa*, and cyano bacteria (blue-green algae) there were no data available to map how their distribution did change over time.

Tab. 1. The distribution of investigated habitats where *U. obscura* is present and is not present within the Göteborg archipelago (the recipient zone) during three different periods of time (see Appendix 1-4). Degrees of freedom (df): 2; Chi-2 (X^2)=1.59; Distribution not significantly altered between the time periods (for $p < 0.05$ it is required $X^2 \geq 5.99$).

	1982-1986	1987-1996	1997-2001	Total

Occurrence	77 (19%)	21 (23%)	44 (23%)	142 (20%)
No occurrence	331 (81%)	71 (77%)	149 (77%)	551 (80%)
Total	408	92	193	693

Tab. 2. Discharge of total phosphorous and total nitrogen (annual average content) from the Rya plant in 1982-1986, 1987-1991, 1992-1996, and 1997-2001 with mean values and standard deviation (SD) given for these periods (raw data from Gryaabs miljörapport 2003).

a)

Discharge (mg/l)	1982	1983	1984	1985	1986	Mean value	SD
Phosphorous	3.1	2.7	1.8	1.4	1.0	2.0	0.88
Nitrogen	17.2	15.1	17.9	15.4	16.8	16.48	1.19

b)

Discharge (mg/l)	1987	1988	1989	1990	1991	Mean value	SD
Phosphorous	0.80	0.51	0.49	0.43	0.41	0.528	0.16
Nitrogen	17.0	15.7	18.3	18.1	20.7	17.96	1.85

c)

Discharge (mg/l)	1992	1993	1994	1995	1996	Mean value	SD
Phosphorous	0.28	0.30	0.56	0.49	0.60	0.446	0.15
Nitrogen	18.5	21.0	19.0	20.2	24.1	20.56	2.21

d)

Discharge (mg/l)	1997	1998	1999	2000	2001	Mean value	SD
Phosphorous	0.41	0.39	0.34	0.41	0.38	0.386	0.03
Nitrogen	19.2	12.7	11.6	9.4	10.6	12.7	3.83

3) Density of phytoplankton, Danafjord, in spring 1998-2003

The density of phytoplankton (0-10 m depth) in spring at the habitat Danafjord in the recipient zone had similar levels in 1998, 2000, 2001, 2002, 2003, but was considerably higher in 1999 (df: 5, 12; F=4.17; p=0.02; see Figure 9). The higher density of phytoplankton 1999 did not correspond to any increase in phosphorous and nitrogen discharges from the Rya plant this year (see Figure 2 & 3 and Table 2d).

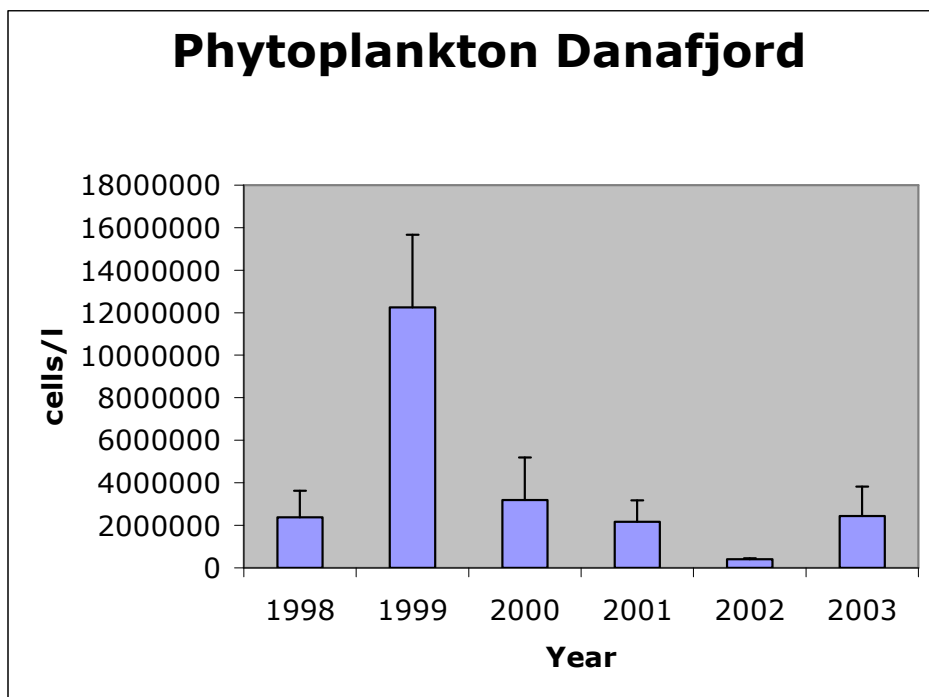


Fig. 9. The density of phytoplankton (cells/l) at a depth of 0-10 m at Danafjord in the recipient zone in spring 1998-2003. Vertical lines show standard error. N=3.

Spatial variation

1) Filamentous algae along the Bohuslän coast

The three southernmost regions along the Bohuslän coast (Fjällbacka-Gullmarsfjorden, Tjörn-Orust, Marstrand-Billdal) exhibited similar occurrence and distribution of filamentous algae in shallow bays in 1998-2004. The region which exhibited the smallest values was not the same each year (Pihl et al 2000, Pihl et al 2002, Nilsson & Pihl 2002, Jenneborg 2004, Jenneborg 2005). The northernmost region (Idefjorden-Fjällbacka) in this period always had the highest occurrence and distribution of filamentous algae (Pihl et al 2000, Pihl et al 2002, Nilsson & Pihl 2002, Jenneborg 2004, Jenneborg 2005). We did not carry out any statistical tests of these observations, but if this had been possible it would very probably have resulted in significant differences. In 1994-1996 the distribution (e.g. the cover percentage) of filamentous algae was also highest in the northernmost region (significant difference: see Pihl et al 1999), but the occurrence (share of bays with more than 5% cover percentage) was about equal in the northernmost and southernmost (e.g. the Göteborg archipelago) region (Moksnes & Pihl 1995, Pihl & Svensson 1996). The biomass of filamentous algae exhibited considerably more variation between regions, (Moksnes & Pihl 1995, Pihl & Svensson 1996, Pihl et al 2000, Pihl et al 2002, Nilsson & Pihl 2002, Jenneborg 2004, Jenneborg 2005), and there was no significant difference between these regions either (Pihl et al 1999).

2) Filamentous algae within the Göteborg archipelago

There was no significant difference in biomass of filamentous algae between 2001 and 2002 at 5 randomly chosen habitats within the recipient zone, but a significant variation between these habitats existed (df: 4, 40; F=7.83; p=0.0001; Figure 10).

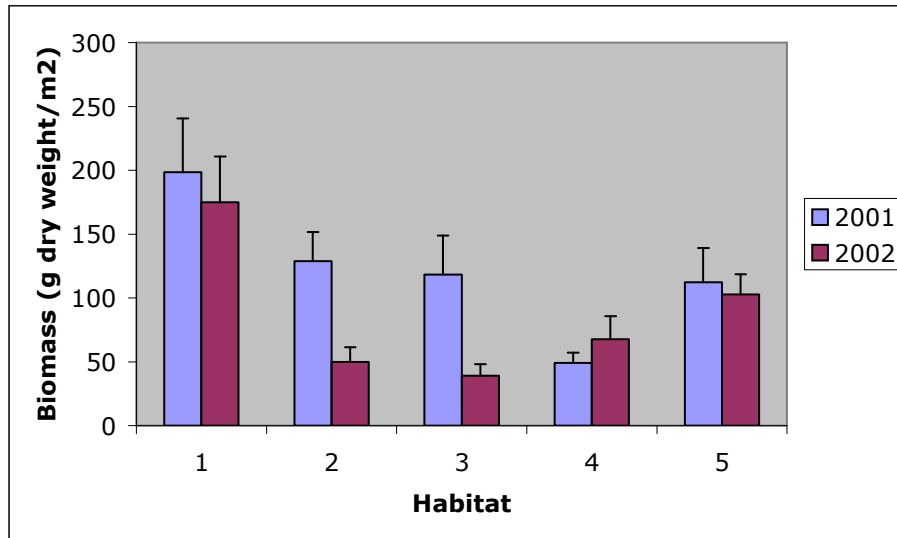


Fig. 10. Spatial variation of the biomass of filamentous algae within the recipient zone in summer 2001 and 2002. Vertical lines show standard error. N=5.

Neither in 2001 nor in 2002 a statistically firm connection between phosphorous or nitrogen in the sediments (mg/g) and the biomass of filamentous algae at these habitats could be found (covariance analysis: covariate phosphorous 2001, df=1, 15, $F=0.008$, $p=0.93$; covariate phosphorous 2002, df=1, 15, $F=0.001$, $p=0.98$; covariate nitrogen 2001, df=1, 15, $F=1.11$, $p=0.31$; covariate nitrogen 2002, df=1, 15, $F=0.74$, $p=0.40$).

3) *U. obscura*, spatial differences 1982-2001

The Chi-2-test shows that both in 1982-1986 and in 1997-2001 a significant distribution pattern existed with greater occurrence of *U. obscura* in the northern part of the recipient zone than in the southern (Table 3a & 3b). This pattern was more significant in 1997-2001 (Table 3). Analyses of differences in occurrence at smaller and larger distances from the Rya plant show that during both periods there were significantly greater occurrence of *U. obscura* close to the Rya plant than further away (Table 4a & 4b). In 1982-1986 the phosphorous discharge from the Rya plant was, on average, 2.0 mg/l and the nitrogen discharge 16.5 mg/l, while during 1997-2001 the corresponding values were 0.39 and 12.7 mg/l (see Table 2a & 2d). For other species that are considered indicators of eutrophication (see above), data were not available as habitats where these organisms could not be found were not reported, which would allow similar analyses as for *U. obscura*. But an attempt at interpreting the variation in distribution of e.g. the green alga *E. linza* and cyanobacteria, during a time span of 20-25 years, suggests that the same pattern is valid also for these organisms, that is, these algae have a greater occurrence in the north and close to the Rya plant in the recipient zone, than elsewhere (Jenneborg 2002). But this interpretation is as already said, uncertain.

Tab. 3. The distribution of habitats in the northern and southern part of the Göteborg archipelago (the recipient zone) with occurrence or not of *U. obscura* in a) 1982-1986 (df: 1; $X^2=4.39$; $p\leq 0.05$) and b) 1997-2001 (df: 1; $X^2=7.92$; $p\leq 0.01$).

a)

1982-1986	North	South	Total
Occurrence	42 (23%)	35 (15%)	77 (19%)
No occurrence	137 (77%)	194 (85%)	331 (81%)
Total	179	229	408

b)

1997-2001	North	South	Total
Occurrence	32 (30%)	12 (14%)	44 (23%)
No occurrence	73 (70%)	76 (86%)	149 (77%)
Total	105	88	193

Tab. 4. The distribution of habitats close to and far away from the Rya plant within the Göteborg archipelago (the recipient zone) with occurrence or not of *U. obscura* in a) 1982-1986 (df: 1; $X^2=11.70$; $p\leq 0.001$) and b) 1997-2001 (df: 1; $X^2=13.65$; $p\leq 0.001$).

a)

1982-1986	Close to Rya	Far away from Rya	Total
Occurrence	47 (26%)	30 (13%)	77 (19%)
No occurrence	131 (74%)	200 (87%)	331 (81%)
Total	178	230	408

b)

1997-2001	Close to Rya	Far away from Rya	Total
Occurrence	38 (31%)	6 (8%)	44 (23%)
No occurrence	83 (69%)	66 (92%)	149 (77%)
Total	121	72	193

Discussion

Restricting factors for the algal production in the recipient zone

In Figure 2 of Selmer & Rydberg (1993) it can be seen that discharge from the Rya plant gives a direct increase in the phosphate and ammonium contents in the surface water, but that an additional source near the estuary bottom exists as well. The Rya discharge of phosphate is indeed quantitatively important if compared to the content of phosphate of the Göta Älv River, but related to the more phosphate-rich deep water in the estuary (e.g. surface water from Kattégatt) the Rya phosphate discharges are small (Selmer & Rydberg 1993). Stenberg et al (2000) maintain that there is a large excess of nitrogen in the combined flow from the Göta Älv and the discharge from Rya, which according to them makes the ratio nitrogen to phosphorous larger than the so called Redfield ratio (16:1 by mole, about 7:1 by weight) for phytoplankton in the recipient zone. This would mean that phosphorous is the limiting nutrient for the algal production in the recipient zone. But according to the SMHI report (Axe et al 2004), investigating 4 localities in the mouth of the Göta Älv and the southern archipelago (the recipient zone), a variation in both space and time exists as to which of the nutrients is the limiting one according to the Redfield ratio. This is to say that at certain localities (close to the Göta Älv river mouth) and certain times of the year, phosphorous is limiting while at other localities (further away from the mouth) nitrogen is limiting (the N:P-ratio fluctuates around 16). Furthermore some studies have investigated how big a similar N:P ratio is for filamentous green algae at the Swedish west coast, and they found it to be between 24:1 and 27:1, even if this

measurement was based upon a few replicates only (Sundbäck et al 2003). Consequently, at least for filamentous algae, nitrogen may well be the limiting nutrient in the recipient zone.

Other factors can potentially be limiting factors for the algal production in the recipient zone. The discharge from the Göta Älv, for example, reduce visibility in the river mouth, and cause salinity variations. Söderström (1986) established that both the ratios Total-N/Total-P and inorganic N/inorganic P 1982-1984 were clearly greater than the Redfield ratio in the discharge of the Göta Älv (consequently P should be the limiting nutrient), while these ratios diminished further out and instead ammonium ought to be limiting in the light-saturated surface layer. During these years the visibility was successively reduced (as a result of greater production of detritus and bacteria), and globally there was an excess of both nitrogen and phosphorous in the Göteborg archipelago, suggesting light being the limiting factor (Söderström 1986). Söderström (1986) further suggested that a reduction in phosphorous discharge could reduce the eutrophication of the coastal water of south Bohuslän, but that this effect probably only can be reached through measures also in south Sweden, Denmark, and the southern Baltic Sea.

Temporal variations

In 1992-1996 the occurrence and distribution of filamentous algae were remarkably extensive along the whole west coast (Moksnes & Pihl 1995, Pihl & Svensson 1996, Pihl et al 1999), whereas less so in 1998-2004 (Pihl et al 2000, Pihl et al 2002, Nilsson & Pihl 2002, Jenneborg 2004, Jenneborg 2005). This was also the case in the Göteborg archipelago, e.g. the recipient zone (Fig. 1). Between the same periods of time, the phosphorous and nitrogen discharges from the Rya plant (Fig. 2-3) decreased, and we found a positive relation between occurrence of filamentous algae in the recipient zone and phosphorous/nitrogen-discharges from the Rya plant in 1994-2003 (Fig. 4-7). Also in the region around Tjörn-Orust there was a positive relation between discharges of phosphorous/nitrogen from the Rya plant and occurrence of filamentous algae, while a relationship between phosphorous discharge and occurrence of filamentous algae could not be found in the two northernmost regions in Bohuslän. This means either that the Rya discharges affects at least the regions closest to the Göteborg archipelago, or that these relationships appear by chance and could be better explained by other factors. The connections were somewhat stronger between nitrogen discharge and occurrence of filamentous algae than those between phosphorous discharge and occurrence of filamentous algae according to regression analyses (r^2 -values somewhat higher and p-values a little lower; Fig. 4-7). This indicates that nitrogen may be more important for the production of filamentous algae, and that ammonium might be the limiting nutrient (see also above).

Pihl et al (1999) could not find any coupling between discharge of phosphorous and nitrogen and the occurrence/distribution of filamentous algae along the west coast in 1994-1996, but their analyses were made over larger spatial scales (the whole coast of Bohuslän; they may also have overlooked Norwegian discharges crossing the Swedish border) than in the present study (within the Göteborg archipelago), and not over time. Instead Pihl et al (1999) found a relationship between algal distribution and exposure to wind and waves, and the organic content of the sediments. Our results, however, suggest a coupling between the occurrence of filamentous algae in the recipient zone and the discharge of nitrogen and phosphorous from the Rya plant. A reduction of the phosphorous discharge from 0.4 to 0.3 mg/l

would (according to the linear regression model) result in an approximate reduction of occurrence of filamentous algae in the recipient zone from 30% to 11%. These are however uncertain values since the relationship is not very strong. This implies that also other factors can be of importance for the occurrence of filamentous algae in the zone. More extensive studies are therefore needed to decide whether a reduction of phosphorous discharge from Rya from 0.4 to 0.3 mg/l will have any greater effect on the production of filamentous algae in the recipient zone.

The biomass of filamentous algae in the recipient zone did not change in relation to the phosphorous and nitrogen discharges from the Rya plant during 1994-2003, but it remains to be seen whether the decrease in biomass 2004 coincides with a reduced discharge. It may be that if the influence of wind and waves is large, the algal mat will be packed more together and the biomass of filamentous algae increases, but on the same time this causes the occurrence and distribution to decrease, which seems to have been the case in 1998-1999 (Pihl et al 2000).

The occurrence of the nutrient-favoured green alga *U. obscura* in the Göteborg archipelago did not differ between 1982-1986, 1987-1996, and 1997-2001 (Tab. 1), in spite of the fact that discharges of both phosphorous and nitrogen from the Rya plant decreased substantially between the first and the last period (Tab. 2). The cover of this alga may have diminished during this time, but it was not possible to analyse this from available data. If the cover of this alga has not diminished, this is probably negative for the distribution of eel grass meadows, since *U. obscura* can reduce the density of shoots of the eel grass *Zostera marina* (Nelson & Lee 2001).

We have not been able to make statistical analyses of changes in the distribution of eel grass meadows (*Z. marina*) over different periods of time in the Göteborg archipelago. According to different studies of the eel grass distribution in the Göteborg archipelago, the distribution seems to be largest and the populations most vital in the estuary of the Nordre Älv river and in the south west archipelago of Göteborg, while eel grass has less dense populations, that is also in a poor condition in the Göta Älv estuary and the south east archipelago (Jenneborg 1998, Jenneborg 2000a). It seems also that there has been an improvement in the distribution of eel grass meadows in the Göteborg archipelago in the 1990-s compared with earlier years (Jenneborg 1998, Jenneborg 2000a). Between 1996 and 1999 there has also been some improvement in the macroalgal stands in the Göta Älv estuary after Rya introduced nitrogen reduction (Jenneborg 2000b). At the same time the total abundance and the biodiversity of the soft bottom fauna at Danafjord in the recipient zone decreased dramatically between 1998 and 1999, and the brittle star *Ophiura sp.* which was common in the recipient zone before 1996 thereafter diminished gradually and disappeared totally in 1999 (Jenneborg 2000b), to reappear in 2000 (Jenneborg 2001).

The density of phytoplankton in spring at Danafjord was very high in 1999 (in average 12 000 000 cells/l), but was considerably much lower in 1998 and 2000-2003 (Fig. 9). It is difficult to state what could have caused this high density in 1999, but it does not seem to have anything to do with phosphorous and nitrogen discharges from Rya that year, as they were relatively low (Fig. 2-3). The density of phytoplankton can vary tremendously both spatially and temporally, and in order to detect spatial and temporal patterns of plankton occurrence and distribution, sampling is needed in a considerably greater number of sites (see below).

Spatial variations

All investigations of the distribution of filamentous algae along the Bohuslän coast have concluded that the largest summer occurrences and covers of these algae exist in the northernmost region, i.e. Idefjorden-Fjällbacka (Moksnes & Pihl 1995, Pihl & Svensson 1996, Pihl et al 1999, Pihl et al 2000, Pihl et al 2002, Nilsson & Pihl 2002, Jenneborg 2004, Jenneborg 2005), and this result is statistically significant (Pihl et al 1999). This might seem puzzling since the clearly greatest nitrogen and phosphorous supply along the Bohuslän coast occurs in the southernmost region (around the city of Göteborg) and the smallest one in the northernmost region (Pihl et al 1999). There can be many explanations for this. Considering that the northern region lies very close to a heavily populated area in Norway, make this result less remarkable, even if ocean currents in the zone are principally directed north and most of the time prevents Norwegian water to reach shallow zones south of Strömstad (Jenneborg 2004). An important outflow of nutrients in Norway takes however place from e.g. Glomma and Idefjorden, and this has influence upon the water down to the Koster archipelago (Jenneborg 2004).

In the northern part of Bohuslän bays are furthermore considerably more shallow than in the three southern regions, and these protected habitats have a higher cover percentage of filamentous algal mats (Pihl et al 1999, Eilola & Stigebrandt 2001, Sundbäck et al 2003). Nutrients in the many semi-enclosed bays will accumulate easily into sediments, and can later be released into the water (for example with the help of bioturbation of tube-building animals) and in this way increase the production of algae (see below). Sulphur bacteria were more confined to the semi-enclosed shallow bays in 2003-2004, while cyano bacteria were distributed over different types of bays (Jenneborg 2004, 2005). It may well be that there is an excess of both nitrogen and phosphorous along the Swedish west coast and that other factors restrict the production and distribution of filamentous algae, e.g. turbidity, influence from wind and waves, decomposition and grazing (Söderström 1986, Pihl et al 1999). If so, this means that it will not be possible in short time to detect a decrease in the distribution of filamentous algae, even if the discharge of nitrogen and phosphorous decreases, but that a decrease of these discharges in the long run would result in an effect (see below).

There was a significant variation in biomass of filamentous algae between different habitats within the recipient zone (Fig. 10). This shows the importance of well replicated studies, i.e. investigating a great number of different habitats, to be able to conclude how reduced phosphorous and nitrogen discharge from the Rya plant can influence the algal production. Depending upon bay topography, morphology, position, biotic and abiotic relations etc. these effects will look different (Eilola & Stigebrandt 2001). For example, there is greater occurrence and distribution of filamentous algae in the inner than in the outer archipelago on the west coast (Pihl et al 1999).

In our analysis of the indicator species *U. obscura* we can conclude that this green alga was found to a greater extent in the vicinity of Rya (the nearest zone in a half circle around the Rya plant; see the part Methods) and in the northern part of the Göteborg archipelago both in 1982-1986 and 1997-2001 (Tab. 3-4). The reason why *U. obscura* was more frequent in the northern part is probably the northbound current in the Göta Älv estuary. This distribution pattern was not influenced by the substantial reduction of nitrogen and phosphorous discharge between these two periods of time. The difference in occurrence between north and south was, however, more significant in 1997-2001, which may be related to the reduced discharge. If it had been possible

to analyse cover in the different habitats, then we might have found different patterns of distribution between the time periods. What these analyses show, however, is that the distribution of *U. obscura* is generally influenced, either by the Rya discharges and/or other nutrient supplies from the Göta Älv. It is difficult to separate the effects from the river and from the Rya plant on the environment, but a detailed analysis of the variations in the Rya discharge and the Göta Älvs discharge over the years and simultaneous changes in the algal flora could be a possible way. The pattern seems to be similar also for other indicator species, although it has not been possible to analyse their distributions as accurately as for *U. obscura*.

Release of nutrients from the sediment and phosphorous bio-availability

The distribution of filamentous algal mats in summer in shallow bays along the Swedish west coast is influenced by many interacting factors, such as depth and water level, bay area and width of the bay opening, nutrients in the coastal water and supply of fresh water, water exchange, wind and wave exposure, and release of nutrients from sediments (Eilola 2001, Eilola & Stigebrandt 2001). According to the model by Eilola & Stigebrandt (2001), the most important explanation for how these algal mats are produced is that nutrients fixed in organic matter is accumulated into the sediments of the bays. These nutrients have, according to the model, been supplied to the sediments through the sedimentation of particulate organic matter which has been produced in the upper layer of the coastal water outside the bays. After remineralization of organic matter, nutrients can be released and cause increasing contents of nutrients in the bays, which in turn causes heavy growth of filamentous algae (Eilola & Stigebrandt 2001). A 50% decrease of nutrients in the coastal water will diminish the potential growth of filamentous algae to about 20% of the present values (Eilola & Stigebrandt 2001). The morphology of the bay is however also of importance. As an example, if the depth were 0.5 m instead of 1 m the growth would increase with 20-200%, very much dependent upon the area of the bay (Eilola 2001). Also the opening width of the bay, that is how enclosed the bay is, will affect how large exchange of water is possible and thus is an important parameter for the amounts of nutrients in a bay.

The importance of release of nutrients from sediments has also been shown in a study where the regeneration of nutrients could satisfy 55-100% of the nitrogen needs of filamentous algae and 30-70% of their phosphorous needs during their early growth period in May-June in two shallow bays at the Bohuslän coast (Sundbäck et al 2003). Since phosphorous in its circulation is not an object of equally many biological transformations as is nitrogen (e.g. denitrification, nitrification), the circulation is often quicker and simpler. The bonding of phosphorous to sediments is however very dependent on oxygen and leakage will easily occur when there is a lack of oxygen (K. Sundbäck, pers. commun.). Sundbäck et al (2003) concludes that there is a time displacement between a decrease in the nutrient supply to the coastal water and the recovery of shallow bays, caused by re-circulation of nutrients from the sediments. In other words, it cannot be expected that a decrease of nitrogen and phosphorous discharges will result in an immediate and rapid improvement of the eutrophication in shallow bays along the west coast. It is more likely that it will be a delayed effect through the fact that nutrients from earlier years and spring of the present year will be accumulated into the sediments and then released in summer that same year (Eilola & Stigebrandt 2001, Sundbäck et al 2003).

There are different opinions as to how available different forms of phosphorous are to the algae upon being released to the recipient, and therefore how

important different phosphorous forms are for eutrophication. No consensus exists regarding which fraction of particulate bonded phosphorous is or can become available for algae (Ekholm & Krogerus 2003). Particulate phosphorous is considered to be least bioavailable of the different phosphorous forms, and to become available, it must first decompose while dissolved phosphate phosphorous is the form which is best available for algae (Ekholm & Krogerus 2003). Ekholm & Krogerus (2003) found the biological availability of total phosphorous in biologically treated (mechanically filtered) waste water to be, on average, 83%, and in biologically-chemically treated waste water 36%, but the variation around the mean value was very great and thus the differences were not statistically significant. The phosphorous availability can furthermore vary between different types of water bodies receiving the waste water, due to their physical and chemical properties (Ekholm & Krogerus 2003). Gryaab is of the meaning that the filter equipment which will be needed for reducing the phosphorous discharge from 0.4 to 0.3 mg/l Tot-P, will only reduce the discharge of particulate bonded phosphorous, and that only a small fraction of this phosphorous form, according to Ekholm and Krogerus (2003), is biologically available anyway (J. Mattsson, pers. commun.). The critical question is thus how much of the particulate bonded phosphorous in the waste water from Rya can be re-dissolved into the water, becoming available for algae in the recipient zone after decomposition and transformation into inorganic phosphorous in the water or in the bottom. At present it seems as if reliable data for assessing this process do not exist. This could be studied with similar methods as used by Ekholm & Krogerus (2003).

Conclusions and suggestions

This report shows that there has been a relationship between reductions of the phosphorous and nitrogen discharges from the Rya plant and the occurrence of filamentous algae in the recipient zone. It is however uncertain how much a lowered discharge of total phosphorous from 0.4 to 0.3 mg/l would influence the algal occurrence, even if the results indicate that a rather large effect might be possible. It seems however, that nitrogen discharge is more important since this relation is stronger, and because nitrogen may be the limiting nutrient for filamentous algae in the recipient zone, at least at certain habitats during certain times of year. It is thus possible that it can be more advantageous for Rya to reduce nitrogen discharge further than to reduce phosphorous. The case may however be that there is an abundance of both phosphorous and nitrogen at many habitats in the zone and that other factors are limiting for the algal production, e.g. light and visibility.

It is not likely that reduced discharges will reduce eutrophication very much in a short time because nutrients will be regenerated from sediments in shallow bays (harvesting filamentous algae may be a necessary measure), but in the long run reductions of nutrient discharges should improve the situation. Since the species acting as an indicator of eutrophication, *Ulvaria obscura*, occurred more frequently closer to the Rya plant and in the northern part of the Göteborg archipelago, there are spatial differences in the effects of phosphorous and nitrogen discharges from the Rya plant or from the city of Göteborg. Probably confined shallow bays in the inner archipelago of the recipient zone are more influenced by high nitrogen and phosphorous contents in the surrounding coastal water and in sediments due to poor water exchange. On a greater scale, along the whole west coast there is more filamentous algae in the northern region than elsewhere along the coast, where protected shallow bays are more frequent. Probably the same pattern could be

recognized also in the recipient zone with greater algal distribution in semi-enclosed bays.

The results from many of the analyses made in this report could have been more reliable if the data from field studies upon which the present report is based, had been collected in a more consistent and carefully way. If so, more analyses could have been carried out on data which could not be analysed in the present report. Earlier reports are mostly descriptive in nature, and without statistical analyses or even any information of the size of variation of the data. In future studies it is important that before the onset of sampling, the questions to be addressed are well defined.. An appropriate design also includes accurate temporal and spatial replication, and an optimization of the statistical strength of the study. In order to give a more direct answer to the question whether a reduction of phosphorous discharge will have any effect on algal distribution, data for areal cover, biomass or density of macro- or microalgae (and at the same time tests of phosphorous and nitrogen in sediments and water) should be collected in different seasons during a number of years at a substantial number of different habitats within the Göteborg archipelago. This, in order to statistically assess the size of the variation. And these years must exhibit clear differences in discharges of phosphorous and nitrogen from the Rya plant so that algal variations can be related to discharge levels. Indeed, a lot of data have already been collected, but most of these cannot be used for statistical analyses, since available information is inconsistently scattered (something is done at one occasion or at one place, but at no other occasions or places). Regarding the distribution of filamentous algae it will also be possible to determine the distribution and cover of bays (confined/open, large/small, shallower/deeper etc.) in different parts of the Göteborg archipelago during a period with fluctuating discharge levels from the Rya plant to see where the discharge influences the algal distribution most and if these patterns change over time.

A crucial point of the problem is also the bioavailability of phosphorous. It is important that the question of how much of the particulate bonded phosphorous in the Rya plant wastewater is biologically available. This is necessary for answering the question whether a reduction of total phosphorous discharge from 0.4 to 0.3 mg/l will have any effect on the production and distribution of macro- and microalgae.

Our conclusion is thus that we cannot present a definite answer to the question whether a reduction of phosphorous discharge from the Rya plant (from 0.4 to 0.3 mg/l) will yield positive effects on the environment, only that this cannot be excluded. We have indirectly shown that the Rya discharges of nitrogen and phosphorous have an effect on the recipient, but that the effects of these discharges cannot be separated. The fact that we cannot show a separate effect of phosphorous is however not equivalent to asserting that phosphorous has no effect. A possible effect can furthermore be local over time and/or space. The fact that an effect cannot be excluded should by the principle of precaution lead to a reduction of both phosphorous and nitrogen at the Rya WWTP as far as this is economically feasible. If an extended phosphorous removal is carried out, a precise study should be started that can answer the question whether the extension gives an effect or not. It is important that such a study is started as early as possible, before the reduction measures are carried out.

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Appendices

1. Utbredning av grönalgen *Ulvaria obscura* inom Göteborgs skärgård under tidsperioden 1982-1986
2. Utbredning av grönalgen *Ulvaria obscura* inom Göteborgs skärgård under tidsperioden 1987-1991
3. Utbredning av grönalgen *Ulvaria obscura* inom Göteborgs skärgård under tidsperioden 1992-1996
4. Utbredning av grönalgen *Ulvaria obscura* inom Göteborgs skärgård under tidsperioden 1997-2001