Development of cyanobacteria in Årungen

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Sammendrag

Algeblomst på grunn av cyanobakterier har blitt et vannkvalitetsproblem, spesielt i landbruksområder i sørøstre deler av Norge, hvor næringsrik avrenning når vann og vassdrag. Årungen har en målsetning om å oppnå god økologisk og kjemiske status innen 2015, ifølge første fase av EUs vannrammedirektiv (VRD). En rekke tiltak er gjennomført for å redusere fosfortilførslene til innsjøen, spesielt i 1980-årene. Tilbakeføringen til god vannstatus er imidlertid svært tidkrevende. Konsentrasjonene av total fosfor og klorofyll *a* er fremdeles veldig høye og siktedypet forblir lavt. Årungen er en svært eutrof innsjø med omfattende oppblomstring av cyanobakterier i sommerperioden. Cyanobakterier innen slektene *Planktothrix* og *Microcystis*, var tidligere de dominerende artene, mens heterocystedannende arter som *Anabaena planktonica* and *Aphanizomenon* cf. *klebahnii* synes å bli mer dominerende i nyere tid. Årsak til endringen i artsdominans er ukjent. Dette har trolig ikke sammenheng med et redusert forhold mellom total nitrogen (TN) og total fosfor (TP), siden TN:TP forholdet alltid har vært svært høyt i Årungen. Analyser av cyanotoksiner er svært sjeldent foretatt i innsjøen. Høye konsentrasjoner av mikrocystin ble imidlertid målt sommeren 2007. For å øke kunnskapen om faktorer som fremmer vekst av cyanobakterier og deres produksjon av toksiner, er det økt behov for forskning på området samt overvåking av cyanobakterier.

Summary

Algal bloom of cyanobacteria has become a water quality problem, especially in agricultural districts in the south eastern parts of Norway, where nutrient rich runoff enters streams and lakes. The Årungen catchment is supposed to reach the requirements of good ecological and chemical status within 2015 (first phase) according to the EU`s Water Framework Directive (WFD). Several countermeasures have been made to reduce the external loading of phosphorus, especially during the 1980's. However, the recovery process of Årungen proceeds very slowly. The concentrations of total phosphorus

and chlorophyll *a* are still very high and the Secchi disk transparency remains low. Årungen is a highly eutrophic lake with severe cyanobacteria blooms during the summer. Previously, cyanobacteria species within the genera *Planktothrix* and *Microcystis* generally dominated. Recently, the heterocystous species *Anabaena planktonica* and *Aphanizomenon* cf. *klebahnii* tend to become more dominating. The reduced ratio of total nitrogen (TN) to total phosphorus (TP) is hardly an explanation to the shift in species dominance, since the TN:TP ratio has always been extremely high in Årungen. Samples for cyanotoxin analyses have rarely been taken in the lake. However, high concentrations of microcystin were measured in the summer of 2007. In order to improve our knowledge on factors promoting the growth of cyanobacteria and their toxins, research within this field as well as increased monitoring of cyanotoxins are needed.

Introduction

Eutrophication of freshwater is a major environmental problem worldwide. Phosphorus and nitrogen are, generally, recognized as the limiting nutrients for algal growth. Increased human population and water usage result in large amounts of nutrient rich waste water which enter aquatic ecosystems. Eutrophication problems are often not recognized until a state where the enrichment of nutrients becomes visual, mainly through reduced water transparency and high algal production. At high algal production, during the summer months, the algal biomass can accumulate on the water surface or be carried by water movements to sheltered parts of the lake forming algal blooms.

Algal blooms can both be an aesthetic and a health problem, especially in lakes which until recently were used for recreation, drinking water or irrigation. Cyanobacteria are often the dominant algae in algal blooms. A number of morphological and physiological characteristics and adaptive ecological strategies make them very competitive to different environmental conditions (Utkilen, 2003). A former study from several lakes in southern Norway, carried out in 1896 to 1899, indicates the presence of only 6 species of cyanobacteria (Skulberg, 2005 after Huitfeldt-Kass, 1906). Now, 50 cyanobacteria species are identified in Norwegian lakes, where 20 species are common and several of them are able to form algal blooms (Skulberg, 2005). The most common cyanobacteria are from the genera *Anabaena, Aphanizomenon, Planktothrix, Microcystis, Snowella* and *Woronichinia.*

The consequences of water eutrophication have become more noticeable in Norway in recent years. In the WFD region Glomma, which lake Årungen belongs to, eutrophication is regarded as the dominating water pollution problem in water courses included in the first phase of the Water Framework Directive (WFD). As algal bloom of cyanobacteria is one of the major challenges in eutrophied waters, this article gives an overview of cyanobacteria development in Årungen based on collected data and research done in the period from 1973 to 2008.

Lake Årungen

Lake Årungen is a shallow north temperate lake located in the south-eastern part of Norway, about 25 km south of Oslo. Six small inlet streams which range from 1.5 to 5 km length supply the lake with water. The lake outflows through a 3 km long stream, Årungenelva, to Bunnefjorden, the inner part of Oslofjorden (Fig. 1). Årungen is a dimictic lake with a summer thermal stratification and a whole water column mixing in the spring and autumn. The lake is oriented in south-north direction and is highly exposed to wind. Some morphometrical and hydrological characteristics of the lake are presented in figure 1.

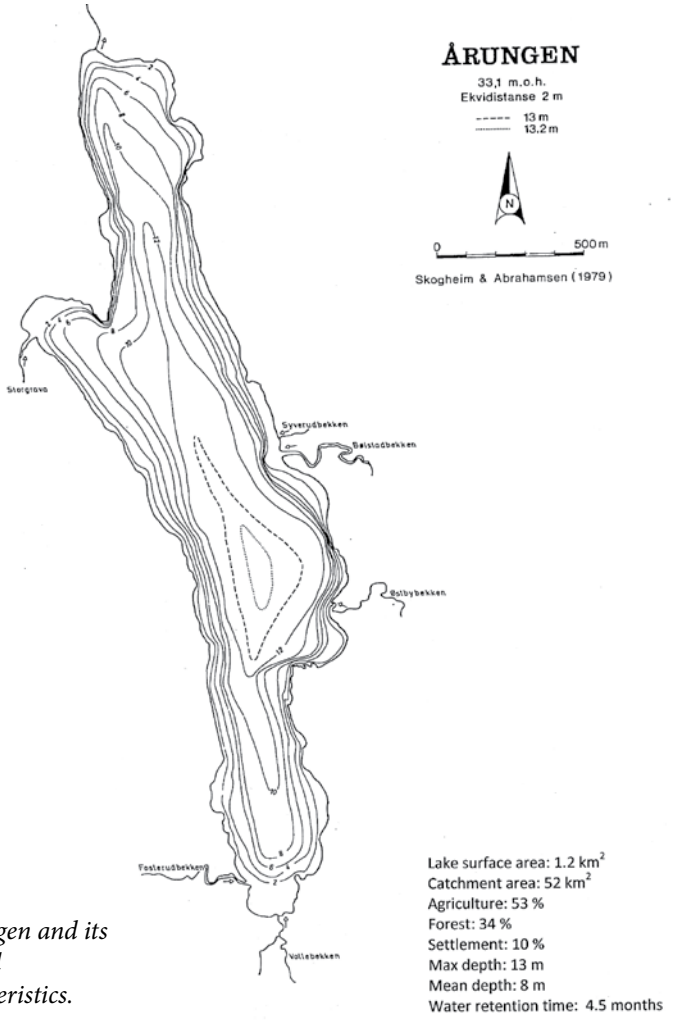

Figure 1. Lake Årungen and its morphometrical and hydrological characteristics.

The state of the lake changed from mesotrophic, which is probably the natural state of the lake, to eutrophic in the 1950's. In 1980 it became a highly eutrophic lake with severe algal blooms in the summer period (Borch et al., 2007). During recent years, frequent fluctuations in the phytoplankton biomass and their composition are observed, where strongly eutrophic species have become more dominant. The lake is of great public interest, being a national rowing stadium and a popular site for recreation and anglers activities. High biodiversity makes the ecological state of the lake of great interest to the local public and managers, as well as for scientific and education purposes. A number of reports and studies of the lake have been made, but it is difficult to get a complete overview of long term changes, as the different data sets cannot easily be compared.

Cyanobacteria in lake Årungen

Now, lake Årungen is classified as a highly eutrophic lake with high concentrations of phosphorus and nitrogen and high algal production, mainly of cyanobacteria. During late summer, algal blooms of cyanobacteria are frequently observed. Cyanobacteria are the dominant group of algae in Årungen, and they tend to dominate throughout the whole algal growing season. The dominance of cyanobacteria is particularly expressed in years with hot and dry summers, such as the years of 1997 and 1999, when very high biomasses of cyanobacteria were measured in Årungen, figure 2.

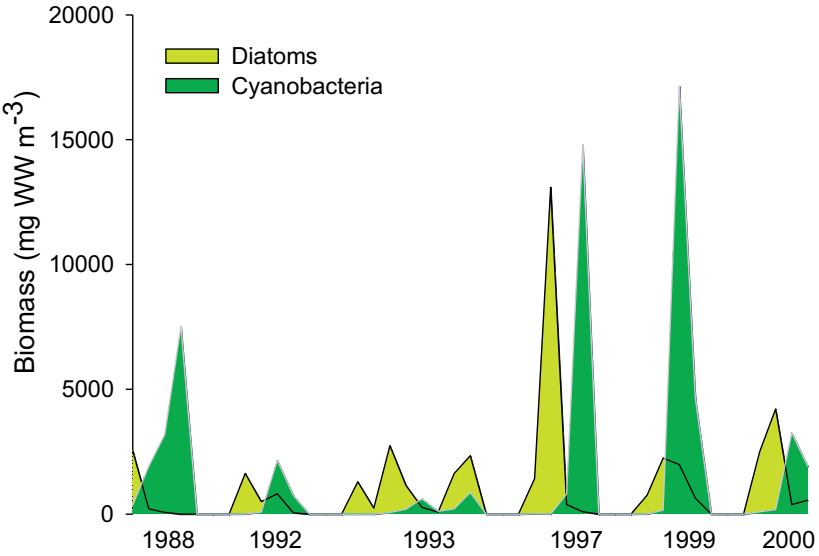

Figure 2. Biomass of diatoms and cyanobacteria in Årungen in the algal growing season of the period 1988 to 2000.

The dominant cyanobacteria species in Årungen, *Microcystis aeruginosa*, *Anabaena planktonica* and *Aphanizomenon* cf. *klebahnii* are all bloom forming species. A non-blooming cyanobacteria, *Planktothrix agardhii*, is also present in Årungen. This species is homogenously distributed in the water mass and might reach very high biomasses, especially during periods with low light conditions. *Planktothrix agardhii* was the dominant phytoplankton species in Årungen during the 1980's.

The cyanobacteria diversity and abundance in Årungen has also been detected genetically by micro array hybridization, using sequence-specific labelled 16S rRNA gene oligonucleotide probes (Rudi et al., 2000). Genetic detection of cyanobacteria is in agreement with previously determinations made through microscopic examination of plankton net samples.

A limnological study, made by Brettum et al. (1975), is probably the first investigation which contains detailed analysis of biological parameters such as phytoplankton and zooplankton biomass, concentration of chlorophyll *a*, and community composition of phytoplankton, zooplankton and periphyton in lake Årungen. The study indicates an increased production of algae in the summer period and algal bloom formation. Only one species of cyanobacteria, *Microcystis flos-aquae*, was registered in 1973, and from this it was concluded that the formed algal bloom came from *Micro-*

Year	1973	1981	1991	2000	2007	2008
Spring	_	_	*Planktothrix agardhii*	*Planktothrix agardhii*	*Planktothrix agardhii*	*Aphanizomenon klebahnii*
Summer	*Microcystis flos-aquae*	*Planktothrix agardhii* *Microcystis aeruginosa*	*Aphanizomenon flos-aquae* *Microcystis aeruginosa* *Planktothrix agardhii* *Anabaena solitaria*	*Anabaena spp.* *Aphanizomenon klebahnii* *Planktothrix agardhii*	*Microcystis aeruginosa* *Anabaena planctonica* *Aphanizomenon klebahnii*	*Aphanizomenon klebahnii* *Anabaena planctonica* *Planktothrix agardhii*
Algal bloom	✓	✓	✓	No data	✓	-
Cyanotoxins	-	-	✓	No data	✓	-
References	Brettum et al., 1975	Ensby, 1984	Løvstad and Krogstad, 1991	NIVA, 2000 unpublished	Romarheim, 2007 unpublished	Romarheim, 2008 unpublished

Table 1. The occurrence of cyanobacteria species, algal blooms and cyanotoxins in Årungen in the period of 1973 to 2008.

cystis flos-aquae. Since that time period no observations of algal blooms have been reported, table 1.

The concentration of total phosphorus in the lake was extremely high (up to 400 µg/l) during the 1980's with very low Secchi disk transparency. At that time the species *Planktothrix agardhii* began to dominate in the lake. It is a species that, generally, prevails under high nutrient concentrations and low light condition. *Planktothrix agardhii* NIVA CYA 116 was isolated from Årungen in 1983 (Rounge et al., 2007), a species that has served as reference material in several algae experiments thereafter. *Planktothrix agardhii* from Årungen and *Planktothrix agardhii,* isolated from a Japanese lake, are shown to have similar genetically characteristics despite the great geographical distance of their origin. Co-transport of the distant *Planktothrix* genotype with foreign equipment used in one of the international rowing competition can be an explanation. However, further research in this field is needed in order to confirm this statement (Rounge et al., 2008).

Reduced external loading of phosphorus has improved the water quality, especially during the 1980's. The highest improvement in water quality in respect to phosphorus concentrations, Secchi disk transparency and phytoplankton biomass, was observed just after 1985 (Borch et al., 2007).

Cyanobacteria species, capable of fixing atmospheric nitrogen, were for the first time registered in lake Årungen in the late 1980s, the so-called heterocystous cyanobacteria, figure 3. Schindler (1977) hypothesized that cyanobacteria tend to dominate if the ratio of TN:TP is below 5-10 by mass. It was thus thought

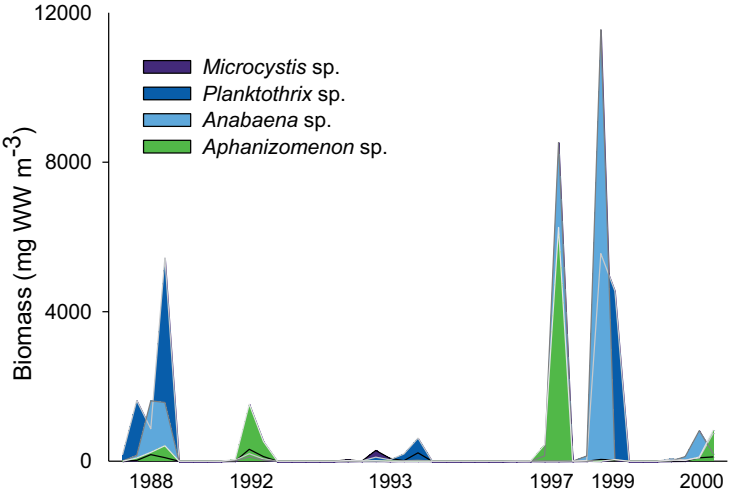

Figure 3. Seasonal variation in biomass of cyanobacteria species in Årungen in the period of 1988 to 2000.

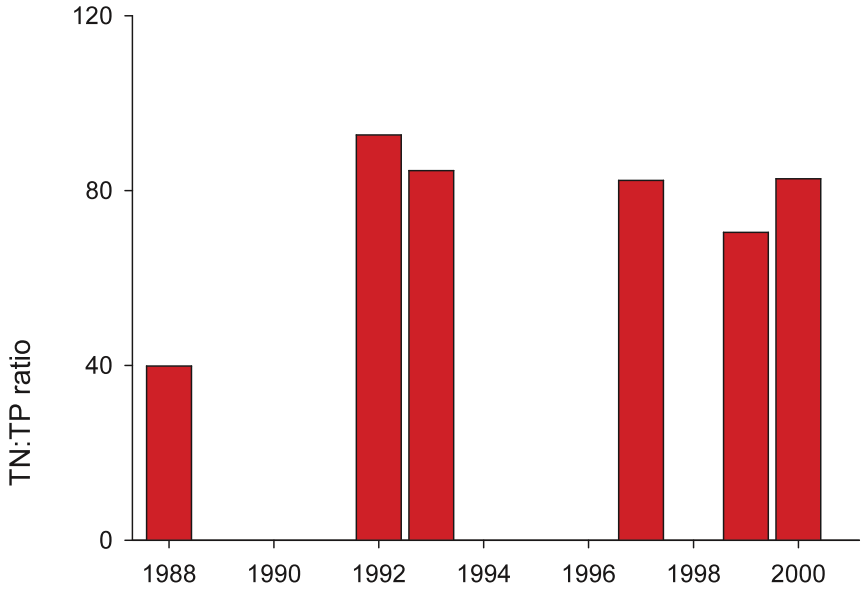

Figure 4. Total nitrogen (TN) to total phosphorus (TP) ratio in Årungen in the period of 1988 to 2000.

that the low ratio of TN:TP in the water column leads to the development of cyanobacteria in the lakes due to ability of heterocystous species to fix nitrogen from the atmosphere (Elser, 1999). *Aphanizomenon* and *Anabaena* have been the dominant algal species in Årungen during the summer months in recent years, especially at times when weather conditions are favourable for algal blooms. The analysis of TN and TP concentrations in the period from 1988 to 2008 show that the TN:TP ratios always have been very high and can certainly not explain the occurrence of these algae, figure 4. However, a nutrient enrichment bioassay, conducted in Årungen in 1973, did prove nitrogen limitation during the summer months (Brettum et al., 1975).

The appearance and growth of algae, especially of cyanobacteria, seems no longer to be limited to the summer period. Due to enhanced spring and autumn temperatures, the algae growth season appears to be extended. The algal production starts shortly after the ice melts, and may last until the end of October.

Cyanotoxins in Årungen

Based on available literature, the first analysis of cyanotoxins from Årungen was carried out in 1992 (Løvstad and Krogstad, 1993). In 1994 a concentration as low as 0.52 µg/l of Microcystin-RR was reported (Løvstad and Krogstad, 1995). In the following time period, the presence of cyanotoxins in Årungen is scarcely reported. In the summer of 2007

Figure 5. Photo of lake Årungen from the rowing stadium.

the problem of cyanotoxins came into focus again when extremely high concentrations of cyanotoxins were measured (Norwegian Institute for Water Research, 2007). The concentration of microcystin was higher than 80 µg/l which is eight times higher than the concentrations allowed in water intended for recreation, figure 5. There was no measured production of cyanotoxins in Årungen in 2008, and the concentration measured in Årungenelva in 2009 was quite low (Rohrlack, pers.com.).

Conclusion

Although a large number of studies have been carried out in Årungen since the 1980's, data on the development of cyanobacteria in the lake is limited. Comparison with data from other eutrophic lakes in the northern temperate region of Europe could be of great help in a reconstruction of the cyanobacteria development. However, as Årungen has a relatively short water retention time, is very exposed to wind and the stability of the thermal stratification varies, the lake is very sensitive to changed weather conditions. The biological response of the lake is therefore hard to predict due to large fluctuations in algal biomass, composition and bloom forming. Further research on the impact of varying environmental factors on the lake's dynamic is, therefore, required.

Furthermore, there is a need for risk assessment of cyanobacteria and their toxins via hazard identification and as-

sessment of their effect on humans. There is a lack of knowledge on cyanotoxic algal bloom formation as well as on cyanotoxins production, accumulation, transformation and degradation. Monitoring system on cyanobacteria and models for the estimation of cyanobacteria biomass, composition and blooms formation in Norwegian freshwater are highly needed. Such data are useful as input variables in eutrophication models forecasting the future state of water ecosystems in a changing climate.

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