HARMFUL PHYTOPLANKTON IN NORWEGIAN WATERS - AN OVERVIEW

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Abstract

Harmful algal blooms are part of the natural history in Norwegian coastal waters and date back at least a century. The recorded number of potentially harmful algae is increasing and includes about 30 different species representing several algae classes, including dinoflagellates, prymnesiophytes, diatoms, and various flagellates. Acute massive mortality in farmed and wild fish stocks has been associated with blooms of Gyrodiniwn artreoltirn, Atexandritimexcavattun, Chrysocliroini4litia polylepis, Chrysochromulina leadbeateri, and Prymnesium parvum. The estimated losses amount to at least 5000 metric tonnes. Shellfish toxicity, mainly documented in mussels, includes the detection of PSPrelated to the occurrence of Atexandrium species and DSP associated with various Dinophysis species. Serious PSP epidemics, in one case with two fatalities, date back to 1901. A large number of DSP epidemics have been recorded during the last 25 years. Shellfish toxicity (PSP and DSP) is recorded in north Norway during thelast years, indicating a northwardgeographical expansionof the actual algae populations, and there is also a documented extended seasonal occurrence of PSP in mussels.

I. INTRODUCTION

Algal blooms occur regularly in Norwegian coastal and offshore waters and harmful blooms are so common that they may be considered as part of the natural history of these waters. The first documented case that may be related to toxic algae, human intoxication after consumption of mussels, extends back to 1870. Since then numerous incidents due to harmful phyloplankton have been recorded, including epidemics of human shellfish poisoning 11-21, widespread mortality in farmed and wild fish Stocks 13.,I, 51, and serious damage of natural ecosystems by algae blooms has aroused great public attention III. Table I summarizes the history of the potentially harmful phytoplankton in Norway in a chronological list of events. The table dates the first observations of certain species, toxins, and fish kills, and shows the documented geographical spreading or introduction to new districts.

The status in 1993 is serious economic effects on the fish farming industry and a retarded development in the mussels farming. The secondary effects include far-reaching political impacts on the international regulations and conventions related to the pollution of the North Sea with associated consequences on national budgets.

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II. RECORDS OF POTENTIALLY HARMFUL SPECIES

The species composition of the phyloplanklon in Norwegian waters is farily well known after more than a century of taxonomic studies and field surveys. A large number of classical species and new species from various algae groups were originally described from these waters and the seasonal and geographical distribution of the majority of species is in general known. Af ter the first record of Gyrodinitan aureoli4m in Norwegian waters in 1966[7]. I this species has become one of the most common bloom forming dinoflagellates in European waters[2]. During the last 15 years several harmless and potentially harmful species (e.g. Prorocentrum minimun4 Chrv,vocitrorntiliria polylepis, Clirysochromi4litiei leadbeateri, Prymnesii4m parvum) have made their appear- ance, first usually occurring in bloom proportions, and later apparently becoriiing natural members of the phytoplankton, sometimes in repeated blooms. It is probable that some of the "new" species have long unattended history in these waters. The number of algae associated with various adverse effects is now reaching about 30.

1870	First human intoxication (DSP) (Sognefjord)
1901	First PSP epidemic in Norway (two deaths) (Oslo – 60^0N)
1966	Gyrodinium aureolum - first bloom (in Europe)
1968	PSP epidemic (Alexandyium excavatum) in mid Norway (63,5 ^{o}N)
1971	DSP epidemic (Dinophysis) in South Norway (Oslofjoa 59.5 'N)
1976	First mortality in fish farms due to Gyrodinium aureolum
1979	First bloom (in Scandinavia) of Prorocentrum minimum
1981	Massive wild fish mortality due to Gyrodinium aureolum
1982	First fish mortality in north Norway due to Gyrodinium aureolum
1984	Documented toxicity in Gymnodinimin gakaheanum First bloom (in Scandinavia) of Alexandrium (Goniodoma) pseudogoni,autax (goniodomin toxins ?)
1986	First detection (in Europe) of DTX- I as dominant DSP profile
1987	Detection of undefined toxins (not PSP or DSP) in mussels Detection of DSP in mid Norway (Trondheimsfjord 63.5^0M
1988	Chrysochrommlina polylepis causing massive mortality in fish farms and marine ecosystems
1989	Skeletonema costatum associated with fish kills First morwity in fish farms due to Prymnesium paryum Detection of DSP in north Norway (Donna, 66 ^{0}N)
1991	Phaeocysds pouchedi associated wi0i fish kills Mortality in fish farms due to Clirysochroimulina leadbeateri
1992	Fish mortality caused by Alexandrium excavatum. Detection of PSP in northernmost Norway (Tromso, 70^0N)
1993	Detection of PSP in the winter period (January)

Table 1. The history of harmful algae In Norway.

species representing several taxonomic classes (Table 2). Atexandrium excavatiim is the morphotype earlier described[8,9] to be different from the type of the former Gonyautax tamarensis Lebour by possessing an ex cavated sulcus.

III. FISH MORTALITY

Fish that are kept in net pens are exposed to the ambient phytoplankton without being able to escape and the effects of harmful algae are easily observed. Documented mortality in farmed fish has been associated with species from the taxonomic classes Dinophyceae, Pryninesiophyceae/Haptophyceae and Bacillariophyceae. The dinoflagellates Gyroditiiwn aureoltim (several blooms after 1966;[13,4] and Alexandrium excavation (one bloom, 1992 (10) and the rkymnesiophytes Prymnesirim parvumlpatellifer7im (blooms every year after 1989), Chrysochromtili?iapolylepis(one bloom, 1988[11] and Chrysochromulina leadbeatery (one bloom, 1991[5] have been associated with massive mortality. Except Chr. leadbeateri and P. parvum these species also have caused mortality in wild fish stocks and natural biota, mainly benthic organisms. Minor cases of mortality in fish farms have occurred during various blooms of the prymnesiophyte Phaeocystis pouchetii, the diatom Skeletonema costatum, and mixed blooms of flagellates and diatoms[12]. Chaetoceros spp. and some flagellates (Dictyocha specult4m., Heterosigm,(i akastiiwo), which have caused serious fish mortality in other waters, are frequently observed in Norwegian waters but are so far not documented to be associated with fish kills.

The fish kills in net pens are summarized in Table 3. The economic impacts in Norwegian fish farming have beenon loss of dead fish, reduced productivity after reduced feeding and food uptake, lower rating of fish product quality, and market mechanisms resulting in lower first-hand prize of fresh fish during some of the major blooms. There is probably a considerable additional loss due to secondary effects on the health status of the fish, as seen after several blooms of Gyrodinium aureolum and the major blooms of Chrysochromulina and Prymnesium,

Dinoflagellates	
Alexandrium excavatum	Dinophysis norvegica
Alexandrium minutum	Dinophysis rotundata
Alexandrium ostenfeldii	Dinophysis spp.
Alexandrium pseudogoniaulax	Gymnodinium gakuheanum
Amphidinium carterae	Gyrodinium aureolum
Dinophysis acuminata	Prorocentrum linia
Dinophysis acuta	Prorocentrum minimum
Prymnesiophytes	
Chrysochromulina leadbeateri	Phaeocystis pouchetii
Chrysochromulina polylepis	Prymnesium parvum
Chrysochromulina spp.	Prymusium patelliferum
Diatoms	
Chaetoceros borealis	Pseudonitzschia pseudodelicatissima
Chaetoceros concavicornis	Pseudonitzschia pungens f. multiseries
Chaeloceros convolutus	Pseudonitzschia delicatissima
Chaetoceros, spp.	Skeletonema costatum
Other species	
Dictyocha.speculum	Heterosigma akashiwo
Dicycha fibula	Nodularia spumigena

Table 2. Potentially harmful algae in Norway.

which have been followed by outbreaks of lethal fish diseases (e.g. furunculosis, infectious salmon anemia, cold- water vibriosis).

Some of the largest blooms of Gyrodiniwn atireolum (e.g. 1976, 1981) and the Chrysochromulina polylepis bloom in 1988 caused serius damage also to natural ecosystems [3,6,13,14] including wild finfish and invertebrates. Fishermen have reported that living catches of cod, eel, sprat, saithe, and lobsters that were kept temporarily in cages and net pens had an extraordinarily high mortality in localities where the water was discoloured by Gyrodinitun atireolum during the 1976 and 1981 blooms. In addition to these cases of mortality, which were caused by exposure of the toxic algae or ichthyotoxins contained in the surrounding water, intoxication of finfish through the food chain was reported by Tangen & al. I'll during the 1992 bloom of Alexandritim excavalum. In this case plaice and other species of flatfish were poisoned and killed by paralyzing shellfish poison (PSP) through the consumption of PSP contaminated sand-dwelling bivalves, whereas sprat were killed by PSP contained in their diet (copepods). It has not been possible to confirm that a significant reduction in the stock of eider ducks in Mid Norway during the last few years [15] is due to PSP contaminated mussels.

IV. SHELLFISH TOXICITY

Shellfish toxicity in Norway, mainly documented in mussels, includes detection of PSP toxins related to the presence of Alexandrium excavatum and Atexandrium ostenfeldii, and detection of DSP toxins associated with the occurrenceof various Dinophysis species (mainly D. acuta, D. acuminata, D. Norvegica, D. rotundata). Additionally, there is a number of cases of undefined "niouse toxicity" observed In various bioassays, where the corresponding toxins have not been identified. Several massive blooms of Pseudonitzschia species have occurred without the detection so far of the ASP toxin Domoic acid.

Serious PSP epidemics, in one case with two fatalities, date back to 1901 (161 and have occurred repeatedly thereafter [I], with the last documented case in 1992 I'll. PSP is shown to reach high concentrations in mussels (> 5000 MU/100 g mussel meat) when Alexandrium excavalum has occurred in very low concentrations (4000)

Causative organism	Estimated loss	Season
Gyrodinium aureolum	2000 tonnes	Autumn (Summer)
Prywmesium parvunvpatelliferum	1300 tonnes	Summer
Chrysochromulina polylepis	800 tonnes	Early summer
Chrysochromulina leads	620 tonnes	Early summer
Alexandrium excavatum	120 tonnes	Early summer
Other organisms	300 tonnes	Spring - summer

Table 3. Mortality of salmon and rainbow trout In Norwegian fish farms due to algae.

Cell/L) in the seawater [18] In 1992 PSP values reached 96492 MU/100 g with 110000 cells/L as the highest concentration of Alexandrium excavatum detectedatthe same locality(Trondheim,63.5^{0}N, IOE), indicating that this species in Norwegian waters is extremely toxic "Ol. Atexandrium ostenfeldii and Alexandrium minutum are frequently observed in low concentrations but have so far not been shown to be the main source of PSP in mussels in Norway.

The observations of Alexandrium excavatum and PSP in mussels indicate that there has been a spreading northwards during recent years. Repeated records of PSP in mussels in the Trondheim area during the last 30 years have been followed by several records further north during the last ten years, e.g. in the Helgeland district (660N) inl9891101,an dinl992 PSP was detected for the first time in the Tromso area(70^{0}N) associated with a minor bloom of Atexandrium excavatum 1121. There is also a clear change in seasonal occurrence. Before 1981 the records of PSP were restricted to the early summer (May-June) [1], then in the spring (April) [19], and during the last few years human posoning due to PSP has occurred in the autumn (September-October) [12] and traces of PSP were detected in the winter (January-February) in 1993 [12]. In the Trondheims fjord, which has been monitored extensively during the last 10 years, there is a clear trend of an increasing presence of Alexandrium excavatum through the autumn-winter season and this species is now observed in most net hauls throughout the year.

Epidemics of DSP intoxication after consumption of mussels have been recorded repeatedly during the last 25 years [12,18] with Dinophysis spp. as the causative organisms [2]. Lee & al. [20] investigated the DSP toxin profiles in Norway and for the first time in Europe detected multiple toxin profiles, with either DTX- I or OA as the major toxin and with a minor component of yessotoxin. Although DSP producing species (Dinophysis spp., Proroce itrtim lima) are common along the entire Norwegian coast, DSP has not been detected in mussels from northernmost Norway. However, the monitoring of DSP during the last years give a clear indication of a northward spreading, from the west coast (60^0N) before 1986 to Mid Norway (64^0N) in 1987 and north Norway (66^0N) in 1989.

The first diatom documented to produce Domoic acid (DA-ASP), Pseudonitzschia pungens f. multiseries, was originally described from the Oslofjord, and other potentially ASP species (Pseudonitzschia delicatissima and P. pseudodelicatissima), occur in bloom proportions in Norwegian coastal waters. So far DA is not detected in mussels collected from such blooms in Norway. In several cases toxicity has been demonstrated by the mouse biossay without the presence of known toxins (PSP, DSP, ASP) in detectable concentrations. The nature of this ,'mouse toxicity" is so far not clarified.

V. FREQUENCY AND GEOGRAPHICAL EXPANSION

As mentioned above, several species which are "new" in Norwegian coastal waters may seems to have expanded their geographical distribution after the initial observation, although for some species this may he a wrong interpretation, taking into account The increased awareness and observation frequency. However, for several species there are good reasons to assume a geographical spreading.

After 1968 when incidents related to harmful algae were restricted to the coast south of 63' N PI such incidents have been observed along the whole coast from Sweden in the south (57-58' N) to near Russia in ft north (71^0 N). The documented northward spreading of detections of PSP and DSP in mussels and an expansion of the season, resulting in the detection of PSP on a year-round basis, has coincided with a period of mild winters in the area and comparatively high seawater temperatures. The effect of the climatolocigal factors on the changes in geographical and seasonal occurrence on the Norwegian coast of Important harmful species has so far not been thoroughly analyzed.

In a summary of dinoflagellate blooms in Norwegian waters Tangen[3] referred 21 cases from 1969 to 1978 and only 19 cases prior to 1969 in spite of a fairly large number of investigations along the Norwegian coast from the turn of the century. In the Oslofjord massive blooms of dinoflagellates have also appeared after 1978. Both in the Oslofjord and in a few other Norwegian localities, as well as in larger adjacent regions, like the southern part of the North Sea and the baltic, there is good reason to claim that there has been age neral increase in intensity and frequency of algal blooms due to eutrophication. 'Me documented reduced annual number of phyloplankton blooms in the Seto Inland Sea, Japan, is assumed to be associated with reduced eutrophicadon [21], which may also explain the generally lower phytoplankton biomass in the 0slofjord during the last few years after reduced anthropogenic inputs of nutrients [22]. However, some of the major blooms of Gyrodinium aureolum and the blooms of Chrysochromulina polylepis and Chrysochrotnulina leadbeateri have occurred in water masses which are not expected to be overloaded with nutrients from anffiropogenic sources.

VI. RESULTS

Major toxic blooms:

A large number of potentially harmful algal blooms were recorded by the SEAWATCH Europe buoy system in 1993. All potential toxic species were detect in Norway, except Glenodinitim foliaceum (dinoflagellate), and Nodularia spumigenti (Cyanobacteria).

1. April - June :

Two blooms of Pseudonitzschia pseudodehfcatissima

- April - June (Bloom I) : 0.5-5 mill/L in mid-Norway after the regular spring bloom.
- August - Nov: Max conc. early Sept. In the More district (2.8 mill/L) + late Sept. In Trondheimsfjord (2.5 mill/L).
- Both blooms lasted about 1.5-2 months.
- From spring to fall: Bloom conc. Obs.in samples along the coast (incl.Fjords) from the Swedish west coast to Tromso.
- No ASP toxin (domoic acid) detected along the Norwegian cost (large number oftoxin analyses performed by the Norwegian College for Veterinary Medicine

2. Phaeocystis cf. globosa in Dutch waters, May 1993:

- Indication of-eutrophication i Southern North Sea.
- Netherlands II buoy: End of April (2mill/L)-12May(>40miliAL)
- Phaeo-blooms usually extend to the German Bight and Danish west coast.

3. Extensive bloom of Emiliania huxleyi May-Sept-93:

- Bloom along Norw coast and offshore waters
- Last half of April: Started in Osterfjorder/Sorfjorden, NE of Bergen (>I mill/L), obs below the brackish layer.
- May - early June: 1-5 mill/L from Oslofjord to Mid-Norway.
- Middle of June: Bloom spread to Haltenbanken, 200 km off Mid-Norway.
- End of June: >I mill/L obs from the Oslofjord to the Polar circle.
- July: Bloom started to decline at the south and wast coast, but continued northwards to Vesteralen (69N, 20 July)
- August: Bloom reached Tromso area (70N, 10 August)
- September: Undocumented obs of milky waters in the Barents Sea (fishermen)
- Upwelling situations i the southwest and west coast during early summer mixed nutrient rich deep water into the surface water above the pycnocline

4. Skeletonema costatum :
   - The dominating species during the spring bloom and later local blooms from the Oslofjord to Finnmark (71^0N), sometimes associated with reduced appetite.
   - Skeletonema bloom in Skagerrak in May.
   - Rhizosolenia spp. were recorded frequently but did not induce mucus production in the gill tissues (danger of suffocation in caged fish).

5. June-July : Prymnesium parvum and P. Patelliferum bloomoriginated (as usual in Hylsfjorden)
   - Site:Hyls-andSandsfjorden in Ryfylke(Rogaland).
   - July:Bloom started in beginning of July with max cell countofl.7milll/L(end of July). - August : Surface water from these two fjords flushed out into the Boknafjord causing fish kills in fish farms (5 tons of salmon)

6. Aug - Sept, Gyrodiniuin aureoluyn
   - G. aereolum detected in the Skagerrak area, but did not reach bloom proportions in 1993.
   - Gymnodinium galaatheanum was abs together with G. aureolum in Aug-Sept and sporadically from the Oslorjord to Mid-Norway.

7. September: Ceratium furca
   - Obs. in bloom proportions at the west coast of Norway during Sep. - Increased in outer Oslofjord i Aug and early Sept.
   - Also reported at the Swedish west coast and Norwegian south coast (Flodevigen).
   - Typical annual occurence of C.furca in North Eur. waters.
   - Up to 30 mill cells per liter.
   - The bloom of C furca on the west coast seemed to be associated with the advection of the Norwegian Coastal Current water masses from the Skagerrak during a large outflow observed in the middle of September.

8. Dinophysiv spp. blooms autumn-winter 1993 (DSP)
   - Discolored water ohs (patchiness, brownis/red, > 0. I mill/L obs, i.e. bloom proportions) recorded from Skagerrak to Slad (62N)
   - North of Stad Cer(tritim.fi4rca dominated, on the Norw Skagerrak coast Ceratium lineatum occurred in rel high cell numbers while C furca bloom was still increasing on the west coast.
   - D. norvegica (most abundant) with D. acuta (2nd) were abundant during the Ceratium furca bloom on the west coast in Aug-Sept.
   - D. rotundata were abundant in some branches of Tr. heimsfjord during summer + scattered obs along the coast up to 69'N.
   - May-fall : DSP detected in very high concentrations in mussels of south and west Norway -associated with the three Dinophysis species.

9. Alexandrium (PSP)

A excavatum (most common, reg. blooms not recorded in 1993, scattered obs. through the year, especially Mid-Norway. A. minutun, A ostenfendii: scattered obs.

- Highest PSP- value recorded from the Molde area(1622MU/100g)in early May.
- Rel.high [PSP] detected in other localities in Mid-Norway(900MU/I(X)g).
- PSP was associated with moderate number of Alexandrium excavatum.
- During summer A.excavalum spread north wards (Tromso) with only traces of PSP north of 67^0N

I0. Prorocentrum miabnum

- Fairly abundant in the outer Oslofjord area (Singlefjorden) in summer-fall.

11.Chrysochromutina polylepis and C leadbeateri

- Both species obs during spring-summer.
- C polylepis in mixed flagellate community associated with some mortality in a salmon farm north of Bergen (Oster and Sorfjorden, April-May), in addition to C polylepis, ce& of Heterosigma akashiwo and Gymnodinium galatheanum were identified (EM microscopy - Marine Botany, Oslo; toxin detection - Defence Research Establishement of Norway). 50 tons, mairdy rainbow trout were killed.
- C polylepis were also found sporadically in Mid-Norway and Skagerrak coast during summer.
- C. leadbeateri occurred in trace amounts in the Vestfjorden area (June, massive fish kills in 1991).
- Chryvochromtilina spp.: March - April, fish kills in March in Masfjorden (rainbow trout and salmon) the cells accumulated under the brackish layer. Cells found.: Chrysochromulina species (0.5 mill/L) and Emiliania huxleyi (5 mill/L)..

12.Fall 1993, the silicoflagellate Dietyocha speculum:

- Abundant in net hauls from Mid-North Norway.

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