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INTRODUCTION

The eutrophication of Norwegian inland waters is a prime pollutional problem of practical concern (Ref. 1). The obvious cause of the difficulties is the ever increasing load with plant nutrients, even though other environmental factors are involved. The progressive eutrophication of rivers and lakes is closely reflected in the changing fertility of the water leading to prolific development of aquatic plants, especially planktonic and benthic algal vegetation.

The observations and collections reported in this paper are made in the part of Norway shown on the map in Fig. 1. The sampling stations in lakes and water courses are given. The research area includes the most urbanized part of the country. This part of east Norway covers five per cent of Norway's total land area and has one third of its population. Of 1.6 million inhabitants 51.5 per cent are settled in towns, 9.4 per cent in townlike agglomerations and 39.1 per cent in rural areas (Ref. 2). One of the causes of the variation in population density is the degree of industrialization in the different part of East Norway. The fact that industry and high population density follow each other makes the problem of water pollution more severe. Urban drainage, including sewage and storm-water runoff, is a main factor in eutrophication and cause severe water quality problems.

Human activities result in extensive and striking fertility changes in the oligotrophic conditions of the waters. Waste disposal and agriculture cause a rapid progress of eutrophication in the region. Among the several undesirable consequences are mass growth of algae and change in type of algal vegetation (Ref. 3, 4). The base of the normal food chain in lakes and rivers is upset. Obnoxious effects (e.g. unsatisfactory taste and odour) on water used for supply of drinking water are generated (Ref. 5). Rotting of algal masses is followed by depletion of oxygen in stagnant waters. A main aid for eutrophication control is to understand what factors govern the growth of algae, the nutriient relationships and the fertility of inland waters.

Oligotrophic waters react sensitively when they receive plant nutrients in excess of the natural supply. When there is a slight rise in the con-

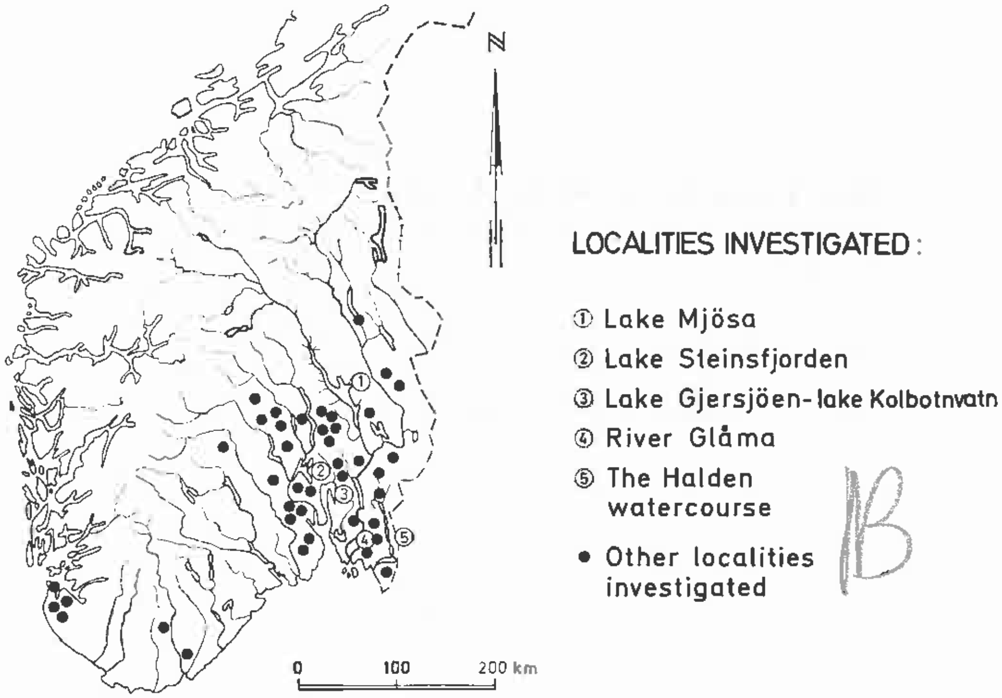


Fig. 1 Area of investigation - east Norway

centration of plant nutrients in the water the natural algal vegetation is stimulated, and the vegetation becomes more abundant. If the supply of fertilizing agents is increased, further community changes of the phytoplankton take place and the biomass of algae is enlarged. This change in flora includes blooms of blue-green algae. Oligotrophic lakes in East Norway vary considerably as to the contents of planktonic blue-green algae. Often they are almost absent, but sometimes the blue-green algae may be prominent with respect to richness of species and their abundance (Ref. 6, 3). Phytoplankton investigations have shown that nutrient enrichment leads to an increase in the size of the blue-green algal vegetation and gives changes in the blue-green algal species composition (Ref. 7, 8).

TROPHIC NATURE OF INLAND WATERS

Most catchment areas of East Norway provide original relatively infertile water, and algal growths seldom develop to such an extent that the human use of the water is affected adversely. The utilization of land for agricultural purposes and human settlement soon leads to an enrichment of water, stimulating algal growth. There is evidence to show that the fertility of these waters may be influenced by relatively small amounts of nutritive substances which would hardly give a detectable change in the chemical composition (Ref. 7).

The bedrock has a strong influence on the composition of inland waters (Ref. 9, 10). The calcium and magnesium content of the rocks in the catchment area of a watercourse is of special importance for the total amount of electrolytes in its waters (Fig. 2). In areas with Cambro-Silurian sedimentary rocks for example, relatively high specific conductivity and calcium contents have been found. The chemical composition of water is to a large extent dependent on soil properties. In East Norway it is extensive areas with relatively thick morainic material and glacifluvial deposits. The presence of these relatively large deposits of soil material below the marine limit (200 metres above the present sea level) is related to the fact that glaciers and water from ice have come from an extensive area during the last glaciation. Wide forests grow on rather infertile moraine derived from rocks such as gneisses and sandstones. They have been uncultivated because the cover of soil material has been too scattered and thin. Comparatively large fields of cultivated soils are present on low-lying land surface and where there are quarternary deposits of fairly fine-grained soil material (Ref. 11).

The inland waters of East Norway belong to several categories with regard to their trophic types. They vary from a distinct oligotrophic-dystrophic type to an extreme eutrophic type. Results of bioassay determinations of inland water fertility using *Selenastrum capricornutum* Printz as test alga are presented in Fig. 3. The predominant type of watershed is classified in three categories based on land use. The bioassay determinations of fertility show a wide range with respect to the waters possibilities of supporting algal growth. The effect of human activities on water fertility is different and varies greatly.

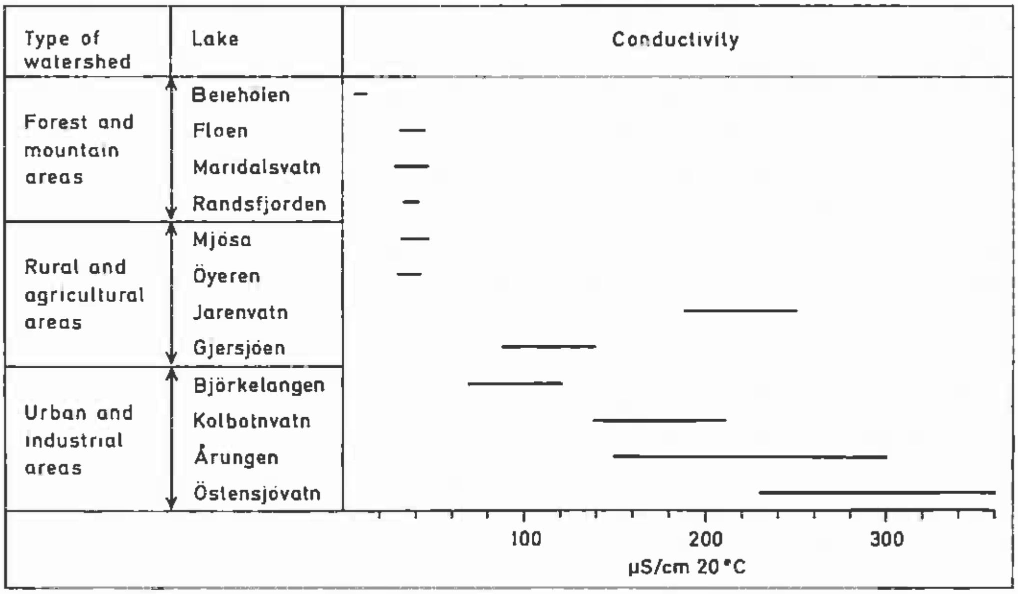


Fig. 2 Content of electrolytes

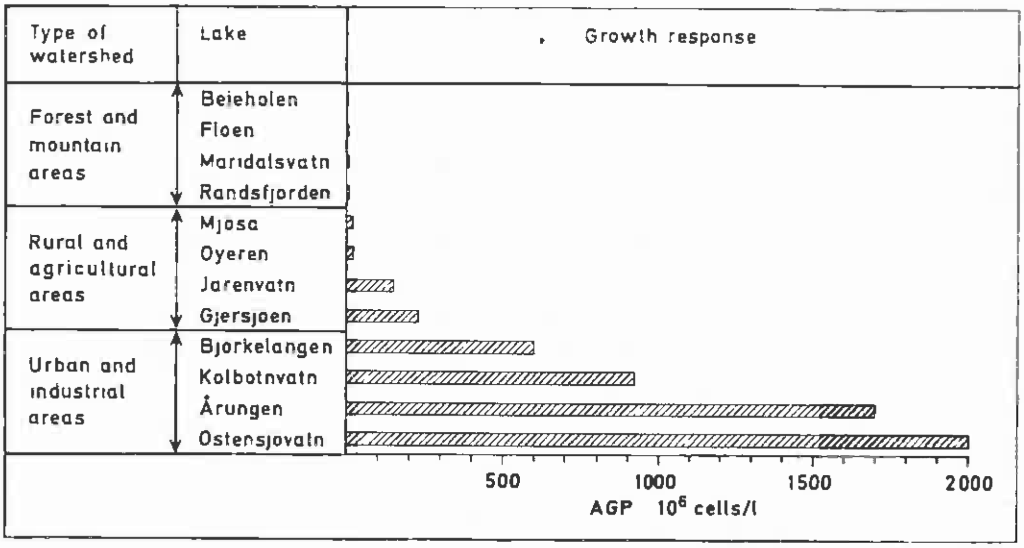


Fig. 3 Bioassay determination of inland water fertility

VEGETATION OF PLANKTONIC ALGAE

During 1880 Wille (Ref. 12) published his paper "A contribution to the knowledge about Norway's freshwater algae". This was in many respects the introduction to the somewhat more systematic investigations of algal vegetation in Norwegian inland waters. Although the regional investigations of algal vegetation have long traditions, still the knowledge on algal distribution, affinities and seasonal variations are provisional. The experience - so far - from the investigations of phytoplankton in the lakes of Norway is the demonstration of the regionally uniform distribution of species over the whole country. That means: Lakes with similar conditions of chemical water quality potentially have the same selection of euplanktic algae developing, without regard to geographical location. Comparative observations from lakes in Norway show that the same algae can proliferate in the widely remote localities with different conditions of climate and geologic substrate (Ref. 13, 14).

The transition from oligotrophy to eutrophy involves community changes of the phytoplankton. It is generally found that oligotrophic lakes have a sparse phytoplankton composed of desmids, diatoms and flagellates. As eutrophication takes place there is an increase of the amount of phytoplankton, and a vegetation with blue green algae as the major component appears. Blue green algae may become so abundant at some seasons as to from water blooms. The vegetation of blue green algae of inland waters thus gives indications on the state of lake succession.

Results from the extensive investigation by Brettum (Ref. 15) give instructive information about the composition of phytoplankton communities related to increasing water fertility (Fig. 4). During September 1973 sampling of phytoplankton was made in 100 lakes distributed all over South Norway. The water samples were taken from the epilimnion (depth 1 m), preserved, and the plankton analyses were performed using an inverted microscope, according

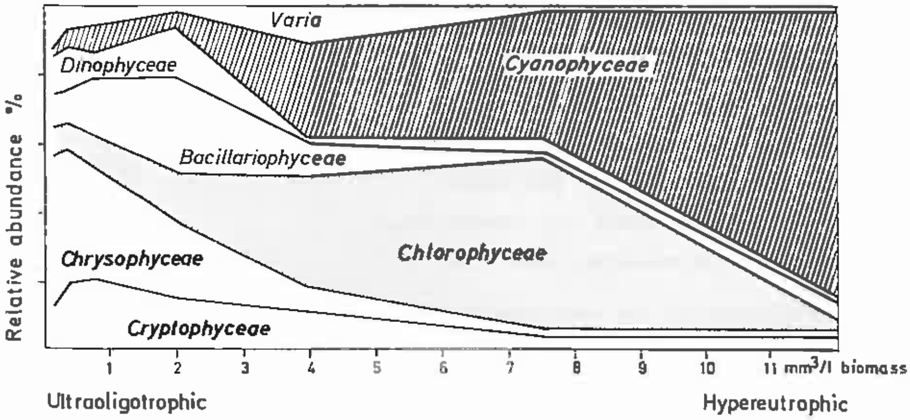


Fig. 4 Composition of phytoplankton and algal biomass expressed by volume in relation to increasing lake fertility. (After Brettum 1978, Ref. 15.)

to Utermöhl (Ref. 16, 17). The increasing dominance by blue-green algae in autumnal planktonic vegetation with increasing lake fertility is obvious. It is important to note that when the algal biomass is high, the blue-green algae have a large share in the phytoplankton.

BLOOM-FORMING, EUPLANKTIC BLUE-GREEN ALGAE

An account of the distribution and abundance of blue-green algae in Norwegian inland waters is given in previous papers (Ref. 18, 10, 20). Only a few remarks will be included here about bloom-forming euplanktic species of interest for this presentation.

Experience shows that algal blooms caused by species of *Hormogonales* are more regionally distributed than blooms of *Chroococcales*. Among the filamentous genera causing algal blooms *Anabaena*, *Aphanizomenon* and *Oscillatoria* are predominating. The species most frequently reported is *Anabaena flos-aquae* (Lyngb.) Bréb. The abundance of heterocystous algae in a particular vegetation generally indicates that this special vegetation is potentially capable of fixing gaseous nitrogen. The following species are typical examples of algae with heterocysts and regional wide distribution:

Anabaena circinalis Rabenh.

Anabaena elliptica Lemm.

Anabaena flos-aquae (Lyngb.) Bréb.

Anabaena planctonica Brunnth.

Anabaena spiroides Klebahn

Anabaena spiroides var. crassa Lemm.

Aphanizomenon flos-aquae (L.) Ralfs

The formation of water blooms by species of *Oscillatoria* is closely associated with lake progression from oligotrophic to eutrophic conditions. While about 15 species of *Oscillatoria* up to now have been observed in lake plankton in East Norway (Ref. 20), a few of them only can be said to be common and are developing algal blooms:

Oscillatoria agardhii Gom.

Oscillatoria agardhii var. isothrix Skuja

Oscillatoria agardhii Gom. var.

Oscillatoria bornetii f. tenuis Skuja

Oscillatoria rubescens DC. var.

Several lakes belonging to the mesotrophic and partly oligotrophic types have algal vegetation dominated by species of *Chroococcales*. Among algae of this category it is worth noticing:

Coelosphaerium naegelianum Unger

Gomphosphaeria lacustris Chodat

Gomphosphaeria lacustris var. compacta Lemm.

The generalization that *Cyanophyceae* play an insignificant role in the freshwater plankton of arctic and alpine lakes (Ref. 21) needs modification. An interesting case is the species *Merismopedia tenuissima* Lemm. which develop dense populations and is a characteristic inhabitant of oligotrophic lakes (Ref. 14). In a few eutrophic lakes *Microcystis aeruginosa* Kütz. and *Aphanocapsa delicatissima* W. & G.S. West are reported with mass development.

ALGAL EVIDENCE OF TROPHIC CHANGES

The great Norwegian fjord lakes can be characterized as fundamentally oligotrophic (Ref. 22, 23). The influence of civilization has a strong eutrophication effect. Lake Mjøsa belongs to the lakes which are under this influence (Ref. 24, 25). But already the investigations during the 1920's pointed out (Ref. 26) that Lake Mjøsa was not so oligotrophic as other comparable fjord lakes in Norway.

The phytoplankton investigations of Lake Mjøsa reveal a fairly well defined seasonal periodicity of the diatom vegetation. During winter there is no appreciable growth. The rapid increase in cell numbers begins during May and follows a more or less exponential course for several weeks. The peak is followed by an almost equally steep decline. The seasonal amplitude in diatom numbers is great - approximately one thousandfold. This pattern of development is repeated by the individual species of diatoms scattered throughout the vegetation period.

Diatoms make up a considerable part of the phytoplankton during the whole vegetation period. The diatoms *Asterionalla formosa* Hass., *Fragilaria crotonensis* Kitton, *Diatoma elongatum* (Lyngb.) G.A. Ag., *Tabellaria fenestrata* var. *aterionelloides* Grun., *Rhizosolenia eriensis* H.L. Smith and *Melosira italica subsp. subarctica* O. Müll. are the dominant species (Ref. 27).

By comparing the results of earlier phytoplankton investigations with observations from today, it is possible to evaluate to what extent conditions of plankton vegetation in Lake Mjøsa have changed over the past years. There are several difficulties for a comparison of this type.

used. The sampling techniques and periods of observations are varying. Taxonomic problems are involved. But nevertheless it is reasonable to obtain valuable information through such a procedure.

The conclusions from such a comparative study (Ref. 27, 28) were that diatoms still are the major components of the phytoplankton. But several new species now develop large populations in Lake Mjøsa. Of these *Fragilaria crotonensis, Diatoma elongatum* and *Rhizosolenia eriensis* are conspicuous in the plankton community. Among the invaders *Fragilaria crotonensis* is prominent by its mass development during late summer - distributed in the epilimnion of the whole lake - with population numbers of more than 4.10^6 cells/l.

During the period 1958 - 1959 *Fragilaria crotonensis* was observed in the plankton, but represented with insignificant quantities. Since 1961 and onwards this species has become a dominant diatom of the plankton with maximum abundance during August (Ref. 28).

During August and September 1976 the first bloom of *Oscillatoria bornetii* f. *tenuis* Skuja took place in the water system Lake Mjøsa - River Glåma (Fig. 5). During August the vegetation was dominated by diatoms, but the population of *Oscillatoria bornetii* f. *tenuis* increased. At the end of September the biomass was considerable (Lake Mjøsa, approximately 2 g/m^3). During late autumn (October - December) however, the blue-green algae dominated the planktonic vegetation. The composition of the plankton community was now influenced by the approaching winter. But an important fraction of *Oscillatoria bornetii* f. *tenuis* was able to continue development (Ref. 20).

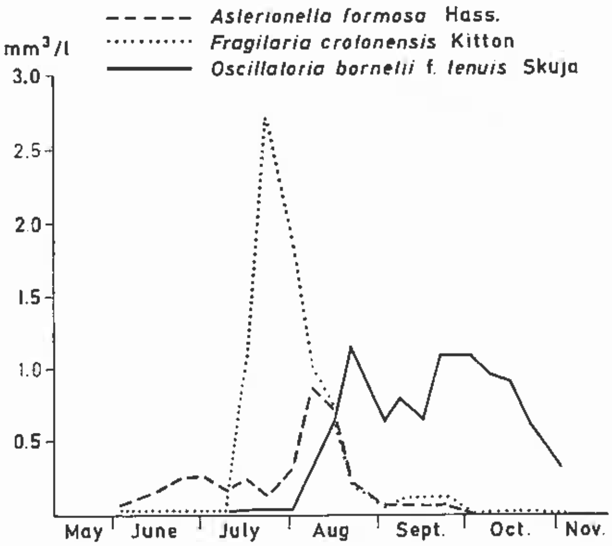


Fig. 5 Variations of the major components of phytoplankton. May-november 1976. River Glåma.

Blue-green algae have earlier been of minor importance in Lake Mjøsa, except in local areas. It should, however, be mentioned that episodes with mass development of e.g. *Anabaena flos-aquae* has occasionally been reported in limited areas of the lake (Ref. 26).

Retrospective investigations based on preserved samples have revealed that *Oscillatoria bornetii* f. *tenuis* was present in Lake Mjøsa plankton at least from 1961 and onwards. But the population has represented small quantities only.

The investigations carried out during recent years have shown that the algal plankton in Lake Mjøsa is transported with the water masses into River Vorma, River Glåma, Lake Øyeren, and River Glåma's estuary and out into the region of the Hvaler archipelago. There is a striking similarity in the periodicity and biomass at different sampling stations in the lake-river system (Fig. 6). The phytoplankton is in a continuous stage of development. This indicates the significance of introducted populations for the composition and development of plankton.

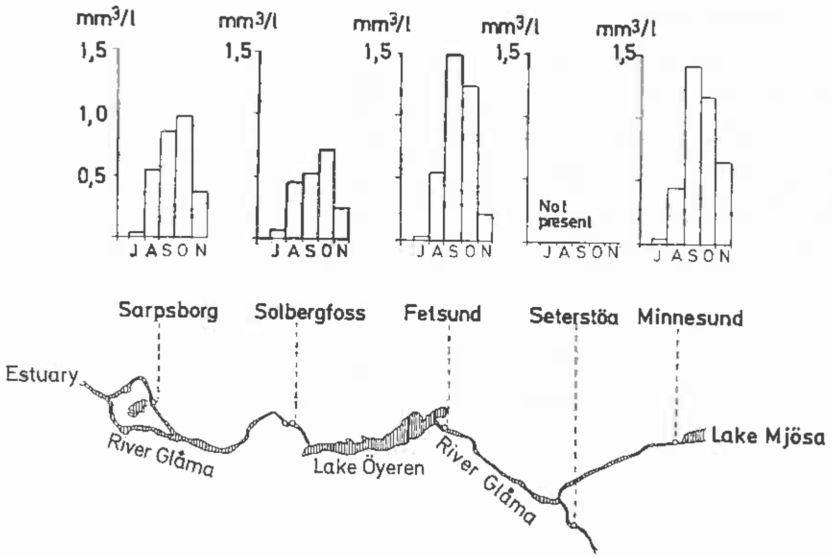


Fig. 6 Biomass of Oscillatoria bornetii f. tenuis Skuja. Lake Mjøsa - lake Øyeren - river Glåma. July-november 1976.

THE INVADER SPECIES OF *OSCILLATORIA*

The progress of eutrophication in South Norway have been associated with invasions of planktonic species of *Oscillatoria* capable of developing dense populations in lakes and slowflowing rivers. Among the successful invaders three species of red-coloured *Oscillatoria* are remarkable.

Oscillatoria rubescens DC. is among the species which have acquired much attention in connection with the evolution of lakes from oligotrophic to eutrophic conditions (Ref. 29, 30). The experience from biological investigations in East Norway point out that two other red-coloured species - *Oscillatoria agardhii* Gom. var. and *Oscillatoria bornetii* f. *tenuis* Skuja - possess similar possibilities of developing large populations in water layers near the thermocline in stratified lakes. In a parallel manner these species have ecologial properties making them successful invaders of lakes and with impetuous consequences for the futher eutrophication prosess.

A taxonomic interpretation of the invader species is presented in a previous paper (Ref. 20). An important question is what make the red-coloured species of *Oscillatoria* successful invaders. Experimental studies indicate that the actual organisms have an efficient regulation of pigment synthesis such as to have an optimum pigment content under several environmental conditions. The presence of accessory photosynthetic pigments may give a considerable ecological advantage to the actual algae under low light intensities.

The carotenoid composition has been investigated (Ref. 31). The results are compiled in Table 1 together with data for *Oscillatoria limosa*. The carotenoids are found - simultaneously with other photosynthetic pigments - in the periphercal region of the protoplast and occur in the structural undefined photosynthetic system of chromatoplasma. The principal carotenoids are involved in the transfer of energy to chlorophyll, and the utilization of light absorbed by carotenoids in photosynthesis has been demonstrated in algae (Ref. 32).

In conclusion the carotenoid composition of *Oscillatoria bornetii* f. *tenuis* resembles much that of *Oscillatoria limosa*, but differs clearly from that of *Oscillatoria rubescens* which produces carotenoid rhamnosides and not O-methyl-methylpentosides.

The mass development of the population of *Oscillatoria bornetii* f. *tenuis* resulted in obnoxious and abnormal taste and odour of the water in the lake-river system. Investigations have made it evident that algae are involved, either directly or indirectly, in the establishment of conditions leading to taste and odour problems in the waterworks using Lake Mjøsa - River Glåma as raw water supply. The substances involved in connection with the blooms of *Oscillatoria* was geosmin, trans-1.10 dimenthyl-trans-9-decalol (Fig. 7) giving the water a very distinct and offending flavour (Ref. 5). From studies with laboratory cultures of *Oscillatoria bornetii* f. *tenuis* it was learned that the alga is almost certainly responsible for the acute production of the spesific aromatic properties of the water. Other microorganisms - including actinomycetes - appear to play a secondary role. The experience with the laboratory cultures was among others that it was possible to isolate from the natural population of *Oscillatoria bornetii* f. *tenuis* clones with more or less prominent production of geosmin. Taste and odour problems in the potable water appear in this case to be determined by the degree of dominance by geosmin - producing strains of *Oscillatoria bornetii* f. *tenuis*. It is reasonable to think that the experience from the investigations of the taste - and odour - problems connected with *Oscillatoria* will give importent information about metabolic products of blue-green algae with great ecological significance.

OSCILLATORIA IN WINTER PLANKTON

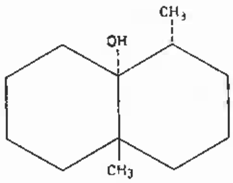
The red-coloured species of *Oscillatoria* illustrate behaviour of unique physiological and ecological interest in their response to the natural environment. Their physiological properties that render possible the overwintering of algal populations under ice-cower belong to the important problems to study in this connection.

A distinct periodicity in the biomass of *Oscillatoria* is observed in the biotopes considered. In contrast to most other phytoplankton algae, their

Table 1. Carotenoid composition of four species of *Oscillatoria* - in percent of total carotenoids. (After Hallenstvedt et al. 1978, Ref. 31.)

Substance		*Oscillatoria rubescens*	*Oscillatoria agardhii*	*Oscillatoria limosa*	*Oscillatoria bornetii f. tenuis*
CAROTENE	β-carotene	29	35	17	39
FURANOID	Mutatochrome	-	1	-	-
XANTHO-PHYLLS	Cryptoxanthin	4	4	1	2
	Zeaxanthin	8	9	22	12
	Echinenone	19	8	23	15
	Canthaxanthin	-	-	7	1
	4-keto-3´-hydroxy-β-carotene	1	1	-	-
GLYCOSIDES	Myxoxanthophyll	30	33	-	-
	Myxol-2´-*o*-methyl-methylpentoside	-	-	27	25
	4-keto-myxol-2´-methylpentoside	-	-	1	-
	Oscillaxanthin	10	10	-	-
	Oscillol-2,2´-di(*o*-methyl)-methyl-pentoside	-	-	9	3
	Unidentified	-	-	-	2

Trans - 1 10 dimethyl - trans - 9 - decalol



C_{12} H_{22} O

Molecular weight (Mol wt)	182
Boiling point (b p)	270 °C
Threshold Odour Concentration (TOC)	0,05 μg/l

Fig. 7 Geosmin.

growth is not greatly reduced or negligible during the winter period of low light and temperatures. Seasonal changes of water temperature tend to lay behind corresponding changes in illumination (Fig. 8). A combination of light and temperature tolerances has been suggested to determine seasonal occurence of algae. The characteristic period with prolific development of *Oscillatoria* is late summer and autumn. The prevailing climatic conditions are influenced by decreasing global radiation and corresponding decreasing water temperature. With respect to the chemical composition of the water the important plant nutrients most likely are to some extent depleted by algal growth. At the same time increasing precipitation take place. This will bring supply of nutrients to the receiving waters. During late autumn (October - December) the blue-green algae dominated the planktonic vegetation influenced by the approaching winter.

Among the red-coloured forms of *Oscillatoria* capable of building up dense deep-water planktonic populations *Oscillatoria agardhii* Gom.var. in the Lake Gjersjøen-system has acquired attention (Ref. 20). The invasion of this alga has been associated with a marked eutrophication due to pollution from sewage effluents. Since the invasion in 1971 the red coloured *Oscillatoria agardhii* var. has become a dominant alga throughout the year with maximum abundance during the autumn months. While the blue-green coloured species of *Oscillatoria* decreased in numbers towards the winter, the red coloured species maintains a prominent overwintering population. Examples of the occurrence of populations of *Oscillatoria agardhii* var. in Lake Gjersjøen are presented in Figure 9 including observations of summer and winter distribution of the alga.

The population of winter algae under ice of the Lake Steinsfjord is dominated by *Oscillatoria rubescens* DC var. Allthough the biomass of *Oscillatoria* during winter usually is low (Figure 10) it represents a significant portion of the total annual standing stock of algae. Growth occurs when photosynthesis exceeds respiration, that is, above the compensation

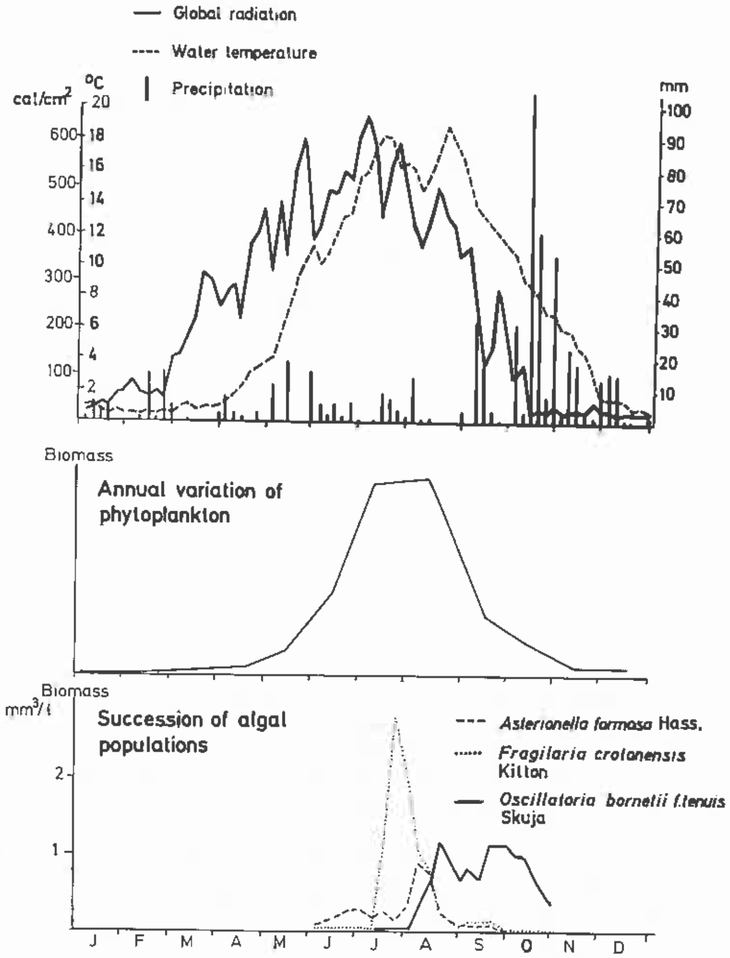


Fig. 8 Climatic conditions and phytoplankton development. 1976, river Glåma, Østfold.

point. It is generally found that compensation occurs at lower light intensities at low temperatures. It is resonable to surmise that the ability of *Oscillatoria rubescens* var. to grow in Lake Steinsfjord at low temperatures and low light intensities is, at least partially, due to this effect.

The winter population of *Oscillatoria* demonstrates a typical clumped distribution. In this case phytoplankton investigations require carefully planned sample techniques in order is obtain representative observations. The concentration of red-coloured algae under the ice and as flocs in the ice have significant consequences for the process of ice melting. Clumps of blue-green algae moves slowly through solid ice by absorbing solar radiation and influence the melting of the ice cover.

The red-coloured species of *Oscillatoria* that are well-developed under

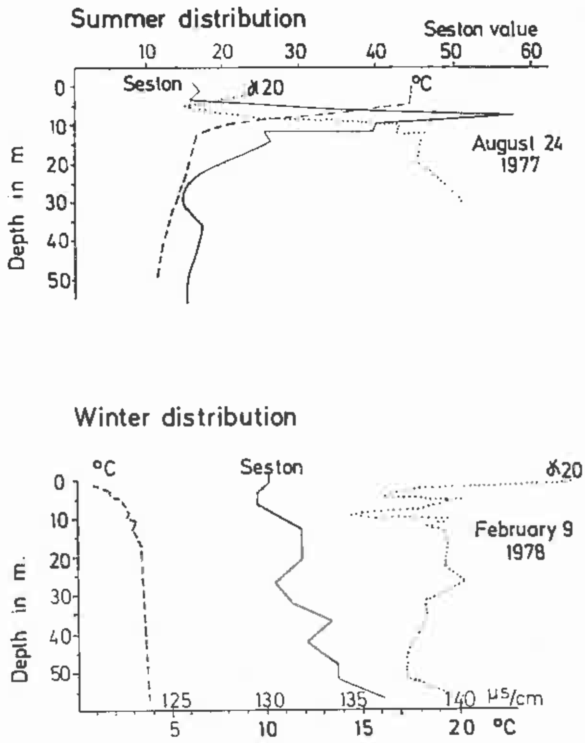


Fig. 9 Observations of seston dominated by Oscillatoria agardhii Gom.var. Lake Gjersjøen.

winter conditions are limited severly during late spring. Masses of blue-green algae concentrate in the surface waters of the lakes and are transported to the shore or to the outlet. During circulation of the water the algal masses are partly resuspended in the lake. This period represent a situation with effective dispersion of *Oscillatoria*.

The winter populations of the red-coloured species of *Oscillatoria* varies in the different lakes with regard to size and state (Figure 11). Being perennial organisms, and as their population numbers do not decrease to very low levels, they can reinoculate the plankton community when growth conditions improve. In case of eutrophic waters the oscillatorians in this way can expel other algae to a great extent (e.g. Lake Gjersjøen).

BIOGEOGRAPHICAL INTERPRETATION OF INVASIONS BY RUDERAL BLUE-GREEN ALGAE

The environmental factors permitting the growth and prolonged maintenance of massive populations of blue-green algae are not properly understood. Algal blooms commonly arise in waters with high fertility - rich in inorganic phosphorus and nitrogen. But the concentrations of phosphates and nitrates may be low by the time the bloom arise. Investigations with algal cultures suggests that e.g. *Oscillatoria* grow as vigorously in purely inorganic media, apart from the need for chelating agents, as in

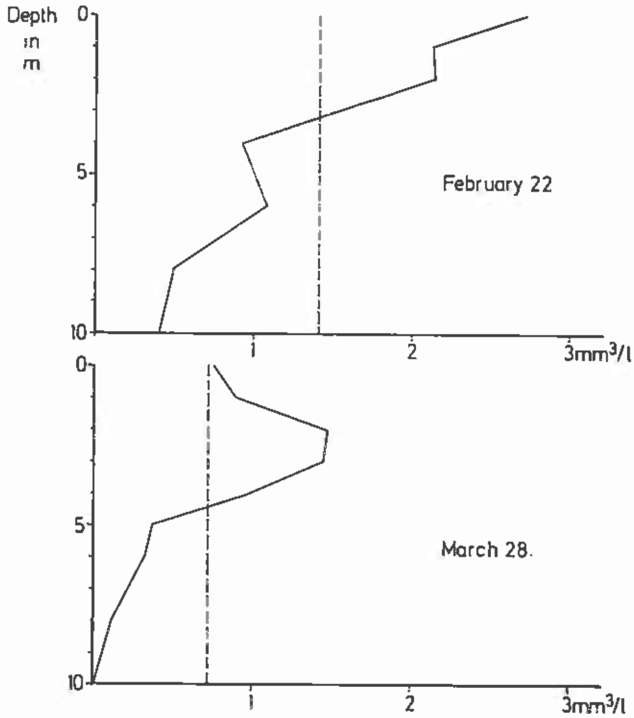


Fig. 10 Winter observations of Oscillatoria rubescens var. Lake Steinsfjorden 1978.

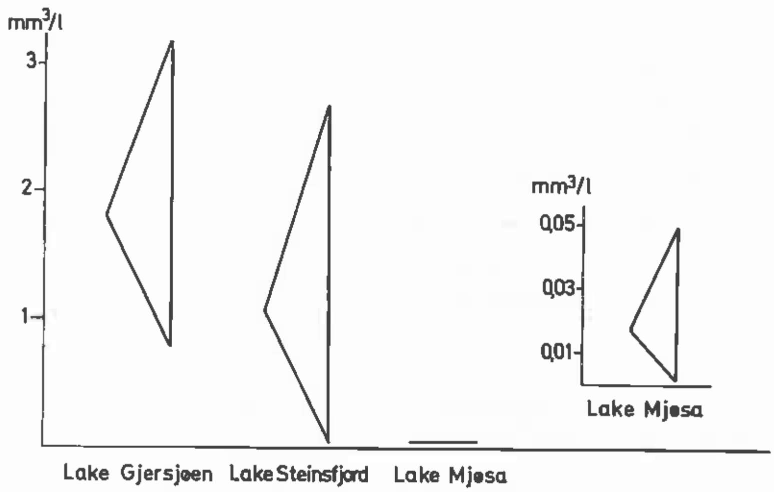


Fig. 11 Determination of Oscillatoria - biomass during winter conditions 1978. Maximum, minimum and arithmetical means of algal volume.

media enriched with organic compounds (Ref. 33). But it is also evident that other factors than increase in nutrient contents of waters are involved causing the phenomena of eutrophication. Biotic interrelations in the inland waters as a water-quality factor have to be considered (Ref. 34). The study of invasions by blue-green algae in water systems will throw light upon the processes in action. Experience from a regional investigation of a lake-river system will be briefly outlined to illustrate this.

The Halden watercourse (Figure 12) is used by the Norwegian Institute for Water Research as a survey area for hydrobiological phenomena related to eutrophication. Water from several oligotrophic-dystrophic lakes flows southward through a complex of lakes with short river reaches in between. The water is receiving sewage from municipalities and runoff from agricultural areas. A considerable eutrophication is experienced with damage done to water quality and public health.

Determination of algal growth potentials has been carried out to assess the fertilizing influence of pollution. The results of the survey show that little growth only was supported in water from the upper reaches of the watercourse. As soon as the water flows into areas with agriculture and settlements substantial growth is experienced, and the water is changing to an extreme eutrophic type. Due to dilution effects by tributaries of oligotrophic nature and selfpurification processes the water quality is gradually changing to a type with relative low algal growth potential.

Observations of blue-green algae in the Halden watercourse during 1961-1977 have given knowledge about regional distribution and occurrence of important species of *Oscillatoria* (Ref. 35). More than 100 species of algae were identified in the plankton. Of these 20 species belongs to CYANOPHYCEAE, 40 species to CHLOROPHYCEAE and 23 to BACILLARIOPHYCEAE and 18 species to different classes of flagellates. The genus *Oscillatoria* was represented by 5 species (*Oscillatoria agardhii* var. *isothrix* Skuja, *Oscillatoria limnetica* Lemm., *Oscillatoria limosa* Ag., *Oscillatoria splendida* Grev. and *Oscillatoria tenuis* Ag.), of these only, *Oscillatoria agardhii* var. *isothrix* Skuja has been a major contributor to the phytoplankton with maxima in population density during late summer and early autumn. The invasion of *Oscillatoria agardhii* var. *isothrix* took place in 1973, and this species has retained the dominance the subsequent years in the most eutrophic part of the watercourse.

Oscillatoria agardhii var. *isothrix* belong to the ubiquitous blue-green algae which can be referred to as ruderal. As an introduced species in a water system it develops dense populations under ecological disturbed conditions. The Halden watercourse is unduly modified from its original conditions by human activities and vegetation with ruderal algae is established.

The following course of events is likely (Figure 13). Agricultural development and urbanization involve amelioration of local areas in the water shed. The vegetation of soil algae is altered. The soil algae have no unique physiological and biochemical features. Phosphorus and nitrogen are most frequently cited as the main elements whose addition will stimulate increased growth of algae in soil. The blue-green algae predominate on neutral and fertile agricultural areas. Waterlogging produces semiaquatic conditions and communities. An environmental conditioning takes place defined as a modification of the effective environment by microbiological activities (biotic interrelations). Ponds, wetland areas and small lakes become eutro-

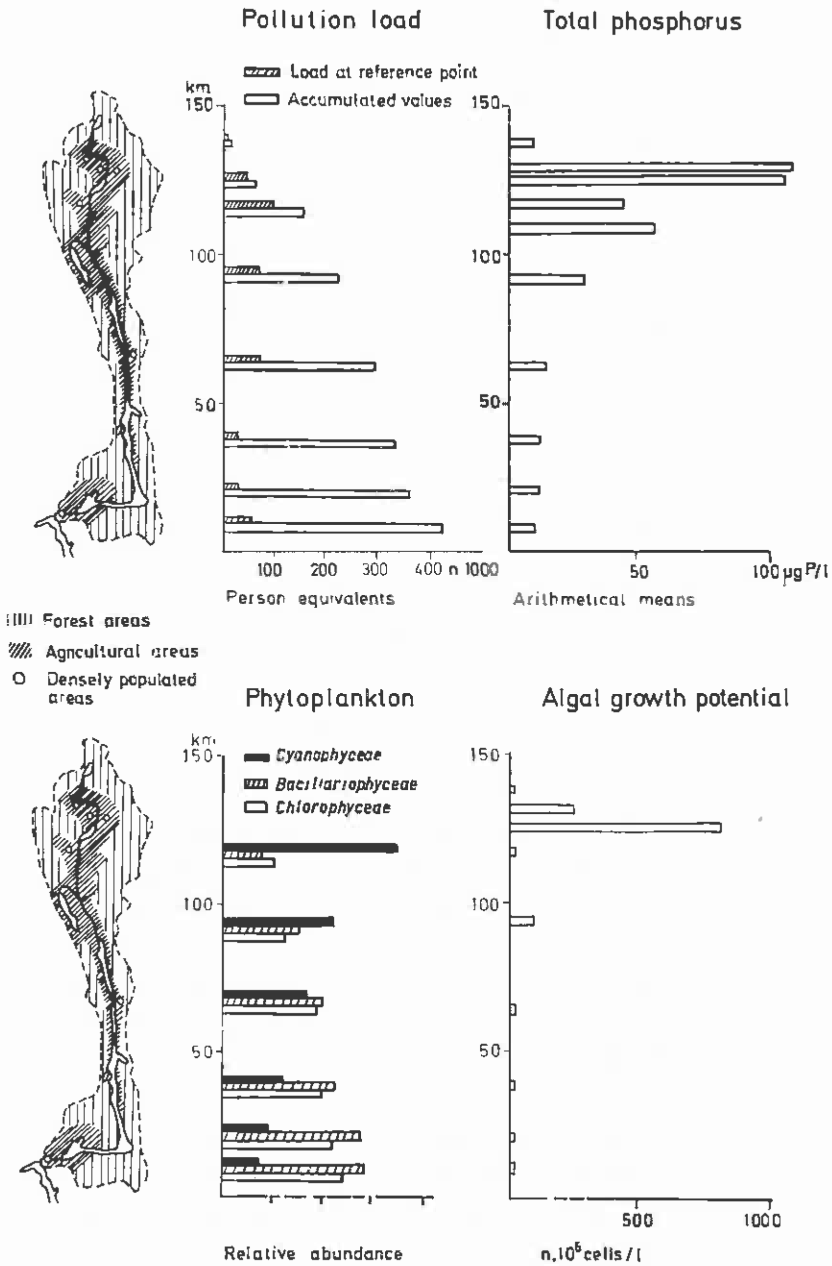


Fig. 12. Regional survey of the Halden watercourse.

phic and develop to reservoirs with vegetation of blue-green algae. Continuous dispersal of blue-green algae to receiving waters is effected. By these mechanisms inoculation of the watercourse is secured and the introducted populations have significant consequences for the further development of algal vegetation. The conditions for an invasion of ruderal blue-green

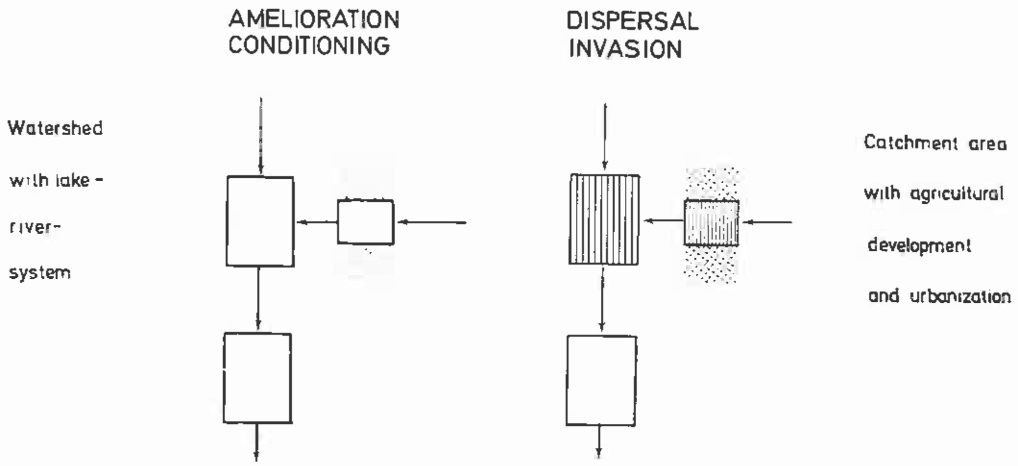


Fig. 13 Biogeographical interpretation of invasions by ruderal blue-green algae.

algae is present. A combination of biotic and abiotic factors will then determine whether the invasion will take place or not.

Some conclusions with implications for further research appear from this interpretation:

1. An algal invasion is a sudden and enormous increase in numbers of some species which are new for the water system or previously only have had insignificant occurrence there.

2. Under disturbed ecological conditions mass development of blue-green algae takes place. In connection with eutrophication of inland waters invasions of ruderal blue-green algae e.g. *Oscillatoria* are common.

3. The process of eutrophication include a sequence of events resulting in mass development of vegetation with blue-green algae. Intensive farming and urbanization involve amelioration, and eutrophic terrestrial and aquatic local areas come into existence. An increase of vigorous vegetation by blue-green algae is experienced. Reservoirs with ruderal species are established. Dispersal and inoculation of water systems take place.

4. The process of eutrophication of terrestrial and aquatic biotopes is a coherent and continuous phenomenon. By changing soil properties through culture and enrichment with plant nutrients changes of microbiota is resulting. A conditioning of runoff water favouring growth of blue-green algae will take place. This process brings with its manifold undersidable effects in the receiving waters and may result in invasion with blue-green algae.

5. The solution of inland water eutrofication problems has to include the identification of local blue-green algae reservoirs - "algal reactors" - and to control the development of ruderal species there by practical measures.

This symposium has given several conclusions of conciderable interest for the further planning of research on Eutrophication of Deep Lakes. I would like to stress the following ones:

1. The experience from Switzerland on the importance of systematic and continuous limnological observations of inland waters should stimulate to include similar programmes in other countries (e.g. Norway).

2. In the further research on nutrient loading models of lakes, it will be necessary to intensify the studies of the time aspect of the processes involved. Much more attention must be paied to the biological availability of the actual substances concerned. Experimental investigations with algal cultures should be carried out in this connection.

3. The consequences of amelioration of rural and agricultural areas for the conditioning (biotic interrelation) of runoff water for the development of blue-green algal vegetation should be investigated. The importance of "local algal reactors" for the dispersion and invasions of planktonic algae should be stressed.

4. As a continuation on the OECD-programme on eutrophication comparative investigations in reference areas selected within different geographic regions and based on experimental field methods should be performed.

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