

## Naked *Dictyocha speculum* – a new type of phytoplankton bloom in the Western Baltic

F. Jochem and B. Babenderd

Institut für Meereskunde an der Universität Kiel, Düsternbrooker Weg 20, D-2300 Kiel, FRG

### Abstract

We report on the bloom incidence of a curious new type of phytoplankton organism: the naked form of the silicoflagellate *Dictyocha speculum*. This special form does not develop the siliceous skeletons which normally characterize the genus *Dictyocha*, its growth is apparently independent of the availability of dissolved silicate. The first massive bloom of this organism was observed in the Kiel Bight area, FRG, in May 1983. Since then, late-spring blooms of this flagellate have become a common phenomenon in the Western Baltic. We suggest that the occurrence of this new type of bloom is related to changes in nutrient conditions due to increased eutrophication.

### Introduction

Since the early 1980's exceptional phytoplankton blooms seem to have increased in number and size in German, Danish and Swedish waters (Anderson et al. 1985). Public concern that increased anthropogenic nutrient inputs may be important in triggering such ecological perturbations has prompted much research on eutrophication and its consequences in the Baltic transitional area and the coastal zones of the southern North Sea (Gerlach 1984).

It is now apparent, from long-term trend analysis, that in both regions, annual inputs of phosphorus and nitrogen have increased by a factor of about three during the past three decades, and that overall biomass production has increased by the same order of magnitude (Babenderd and Zeitzschel 1985, Radach and Berg 1986, Babenderd in press). Nevertheless, it is still uncertain whether there is any direct causative relationship between elevated nutrient inputs and the more frequent occurrence of so-called exceptional phytoplankton blooms. Phytoplankton bloom formation de-

pends not only on the supply of nutrients (although this is the main prerequisite to build up a high biomass), but also on a variety of other environmental factors such as light availability and the absence or the ineffectiveness of grazers.

There can be no doubt that over the past decade blooms of newly reported, undesirable species have increased in the Baltic transitional area, including Kattegat and Skagerrak. Examples are *Gyrodinium aureolum* (Brockmann et al. 1985, Lindahl 1985), *Prorocentrum minimum* (Edler et al. 1982, Tangen 1983), and *Chrysochromulina polylepis* (Dahl et al. in press). In the Kiel Bight, *P. minimum* has formed blooms annually since 1983 during August/September (Kimor et al. 1985, Neuer 1986, Stienen 1986, Jochem 1989) and thus became a normal component of annual phytoplankton succession.

A similar development has taken place with a new type of phytoplankton bloom which is the main subject of this paper: the naked form of the silicoflagellate *Dictyocha speculum* (syn. *Distephanus speculum*). Blooms of this organism first occurred in the Kiel Bight area in May 1983 and have also become common in the species succession of this area.

The first records came from the Danish Alssund where a bloom of naked, previously undescribed flagellates was observed in connection with heavy mortalities of caged fish. It was identified by Moestrup and Thomsen (H. Thomsen, Copenhagen, personal communication) as a naked, (i.e., non-skeleton-forming) modification of *Distephanus speculum* and was confirmed by observations in Kiel Bight, (Neuer 1986, Jochem 1987).

Silicoflagellates of the genus *Dictyocha* are marine chrysophytes bearing a single flagellum and a star-shaped siliceous skeleton composed of tubular elements forming a basal ring and several extruding spines. While *D. fibula* possesses a quadrangular basal ring and four spines, *D. speculum*, which is to be found in the Kiel Bight area, has a hexagonal basal ring and six spines. Ultrastructure and taxonomy of both the naked and skeleton-bearing form of *D. speculum* will be discussed elsewhere by Moestrup and Thomsen (in press).

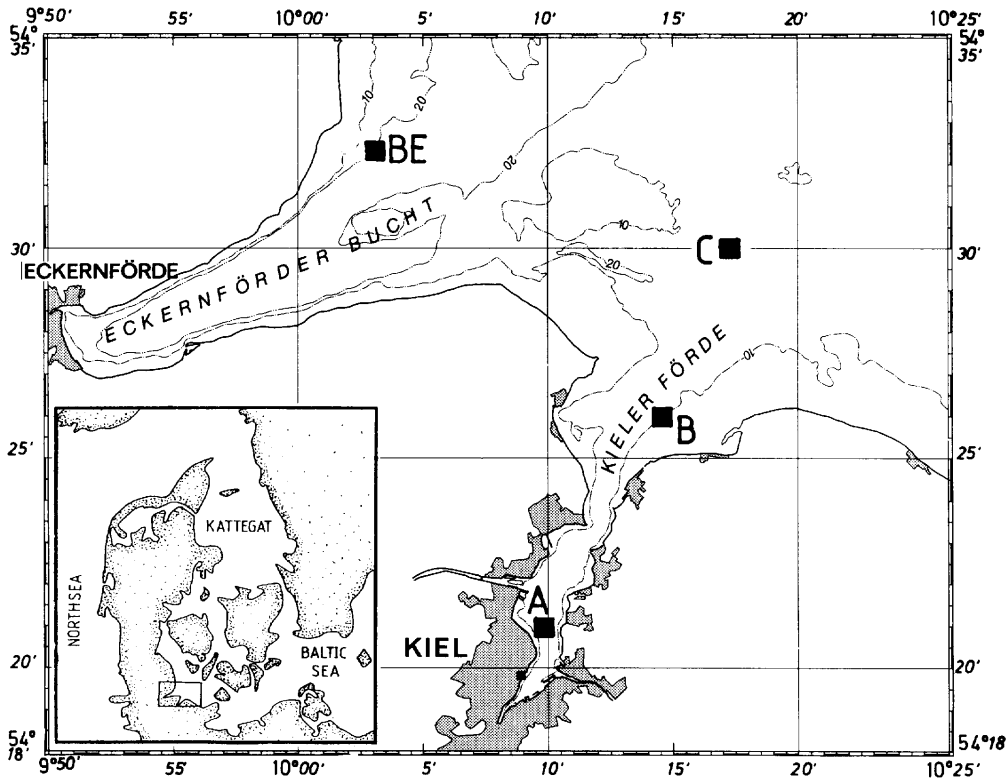


Fig. 1. Sampling stations in Kiel Fjord and Kiel Bight. A: Inner Kiel Fjord; B: outer Kiel Fjord; C: Kiel lighthouse; BE: Boknis Eck

## Material and methods

In May 1986, the occurrence of *Dictyocha speculum*, chlorophyll concentrations and abiotic conditions were recorded at three stations (Stns A, B, C, Fig. 1). In April/May 1988 the development of a bloom of naked *D. speculum* in the inner Kiel Fjord, and the abiotic conditions during this period, including the concentration of inorganic nutrients, were recorded at 4 d intervals.

Water samples were analyzed for cell numbers and phytoplankton composition by the inverted-microscope technique (Utermöhl 1958, Hasle 1978). Phytoplankton carbon biomass was derived from cell numbers and conversion factors given by Strathmann (1967) and Smetacek (1975). Chlorophyll *a* was determined with the trichromatic method (Strickland and Parsons 1972) and concentrations calculated according to Jeffrey and Humphrey (1975). Inorganic nutrients (silicate, nitrate, nitrite, ammonia, phosphate) were measured according to Grasshoff et al. (1983). Temperature and salinity were recorded with a WTW Conductometer LF 191.

## Results and discussion

Naked cells of *Dictyocha speculum* found in Kiel Bight are more or less spherical and ca 20  $\mu\text{m}$  diam. (Fig. 2). They possess one flagellum and ca 25 chloroplasts. The cell surface often appears to be lobed due to plastids and cells are very sensitive to high temperatures and physical stress (e.g.

Table 1. *Dictyocha speculum*. Occurrence of the naked silicoflagellate in Kiel Fjord and Kiel Bight

Observation	Kiel Fjord (cells $\text{l}^{-1}$ )	Kiel Bight (cells $\text{l}^{-1}$ )	Source
10 May 1983	$5.7 \times 10^6$	$2.3 \times 10^6$	Nöthig 1984, Stienen 1986
1984	No conspicuous bloom, but present		Stienen personal communication
22 May 1985	$7.0 \times 10^6$		Neuer 1986
28 May 1986	$6.6 \times 10^6$	$3-5 \times 10^6$	Jochem 1987
1987	No observations		
18 May 1988	$5.5 \times 10^6$		

shaking). In preserved samples, they easily disintegrate after brief storage. Thus, it is not easy to distinguish them from detrital material by means of the inverted-microscope technique, especially when present in low numbers. The flagellum is shed mostly following preservation.

Table 1 summarizes the occurrence of naked *Dictyocha speculum* in Kiel Bight and Kiel Fjord. Nöthig (1984) observed it for the first time in the open Kiel Bight (Stn BE, Fig. 1) on 10 May 1983. The bloom was already declining at that time. Naked *D. speculum* accounted for 80% of the total phytoplankton biomass with an average concentration of  $2.3 \times 10^6$  cells  $\text{l}^{-1}$ . By the end of May, *D. speculum* was still blooming in Kiel Fjord (maximum population density  $5.7 \times 10^6$  cells  $\text{l}^{-1}$ ) and was also observed in open Kiel Bight (Stienen 1986).

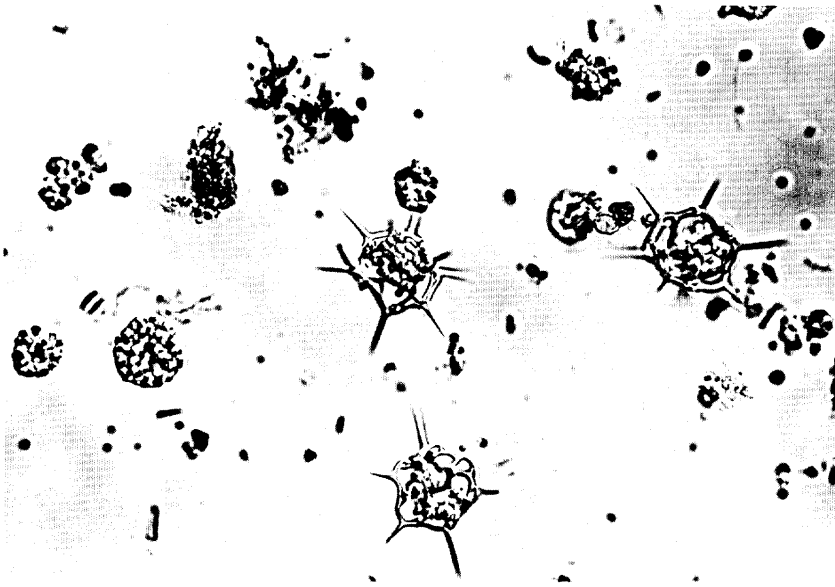


Fig. 2. *Dictyocha speculum*. Naked and skeleton-forming cells preserved in 4% formaldehyde. Magnification  $\times 480$

In 1984, naked *Dictyocha speculum* did not form conspicuous blooms but was present during May in Kiel Bight and Kiel Fjord (C. Stienen personal communication). However, in May 1985, this organism was again seen to form dense blooms in the surface waters of the inner Kiel Fjord. Neuer (1986) reported  $7 \times 10^6$  cells  $l^{-1}$  of naked *D. speculum*, while skeleton-bearing cells achieved concentrations of only 100 cells  $l^{-1}$  on 22 May and  $2.6 \times 10^5$  cells  $l^{-1}$  on 30 May.

During May 1986, naked *Dictyocha speculum* bloomed again in the area. On 28 May population densities of up to  $6.6 \times 10^6$  cells  $l^{-1}$  were found in the inner Kiel Fjord (Stn A, Fig. 1) and 3 to  $5 \times 10^6$  cells  $l^{-1}$  in the outer Kiel Fjord and Kiel Bight (Stns B and C, and Kiel lighthouse, Fig. 1). Phytoplankton carbon biomass reached 5.5 and 2.6 mg C  $l^{-1}$  at the surface of Stns A and B (Fig. 1), respectively. Naked *D. speculum* accounted for 98% of phytoplankton carbon and 96.3 to 99.3% of the total *D. speculum* population. Chlorophyll *a* profiles (Fig. 3a to c) reveal that population maxima occurred in subsurface waters associated with the pycnocline for samples taken at 07.00 to 08.00 hrs. Diurnal vertical migration, however, cannot be excluded (Jochem 1989).

In 1987, no microscopic observations on phytoplankton composition were made, but routine chlorophyll *a* measurements in the inner Kiel Fjord showed high concentrations, during May of up to  $26.9 \mu g l^{-1}$  (22 May 1987). These values indicate some kind of phytoplankton bloom.

Due to unusually high water temperatures in 1988 (Fig. 4), the first occurrence of naked *Dictyocha speculum* was already recorded by mid-April (Fig. 5). The population reached a maximum density of  $5.5 \times 10^6$  cells  $l^{-1}$  on 18 May 1988. *D. speculum* accounted for 97% of phytoplankton carbon on that day. Surface cell numbers were almost equal to, or higher than, those at 5 m depth for samples taken around 11.00 hrs. From field data, a growth rate of 0.4 to 1.1 doublings per day was obtained. Skeleton-forming cells accounted for only 0.3 to 18.5% of the *D. speculum* popula-

tion, with a slightly higher contribution in the 5 m samples. Having reached its maximum, the population declined rapidly and the contribution of skeleton-forming cells increased to 100% within 10 d. No *D. speculum* could be detected by the inverted-microscope technique (sample volume of 20 ml) on 15 June 1988 at which time the diatom *Skeletonema costatum* was the dominant species. Some observations suggest disintegration of naked *D. speculum* cells at temperatures above  $15^\circ C$  (Nival 1965, Travers and Travers 1968, Van Valkenburg and Norris 1970).

There are good reasons to believe that the persistent occurrence of this new late-spring flagellate bloom is related to changed nutrient conditions due to eutrophication, especially the input of inorganic nitrogen compounds.

The annual cycle of phytoplankton succession in the Kiel Bight area starts with a massive diatom bloom in March/April. At least until the mid-1970's this typical diatom spring bloom was terminated by exhaustion of inorganic phosphorus and/or nitrogen compounds down to detection limits, while small amounts of silicate were still available (Bodungen 1975, 1986). Nowadays, however, lack of silicate seems to terminate the diatom spring bloom (Bodungen 1986), and the remaining nitrate and phosphate are apparently sufficient to support considerable blooms of silicate-independent flagellates directly after the diatom bloom.

To verify this hypothesis, we followed the change in nitrate and silicate concentrations in inner Kiel Fjord during spring 1984, 1986 and 1988, i.e., the years characterized by the occurrence of *Dictyocha speculum* (Fig. 6). In each of these years, silicate showed low concentrations at the beginning of the *D. speculum* bloom. In 1984 and 1988 silicate had already dropped below  $10 \mu mol l^{-1}$  in early April. In 1986 and 1988 silicate concentrations at the time of the bloom were below  $5 \mu mol l^{-1}$ , and thus near the lower limit of silicate uptake in some natural waters (Paasche 1980). In Kiel Bight and Kiel Fjord silicate concentrations seldom fell below  $2 \mu mol l^{-1}$ . Nitrate, however, showed high concentra-

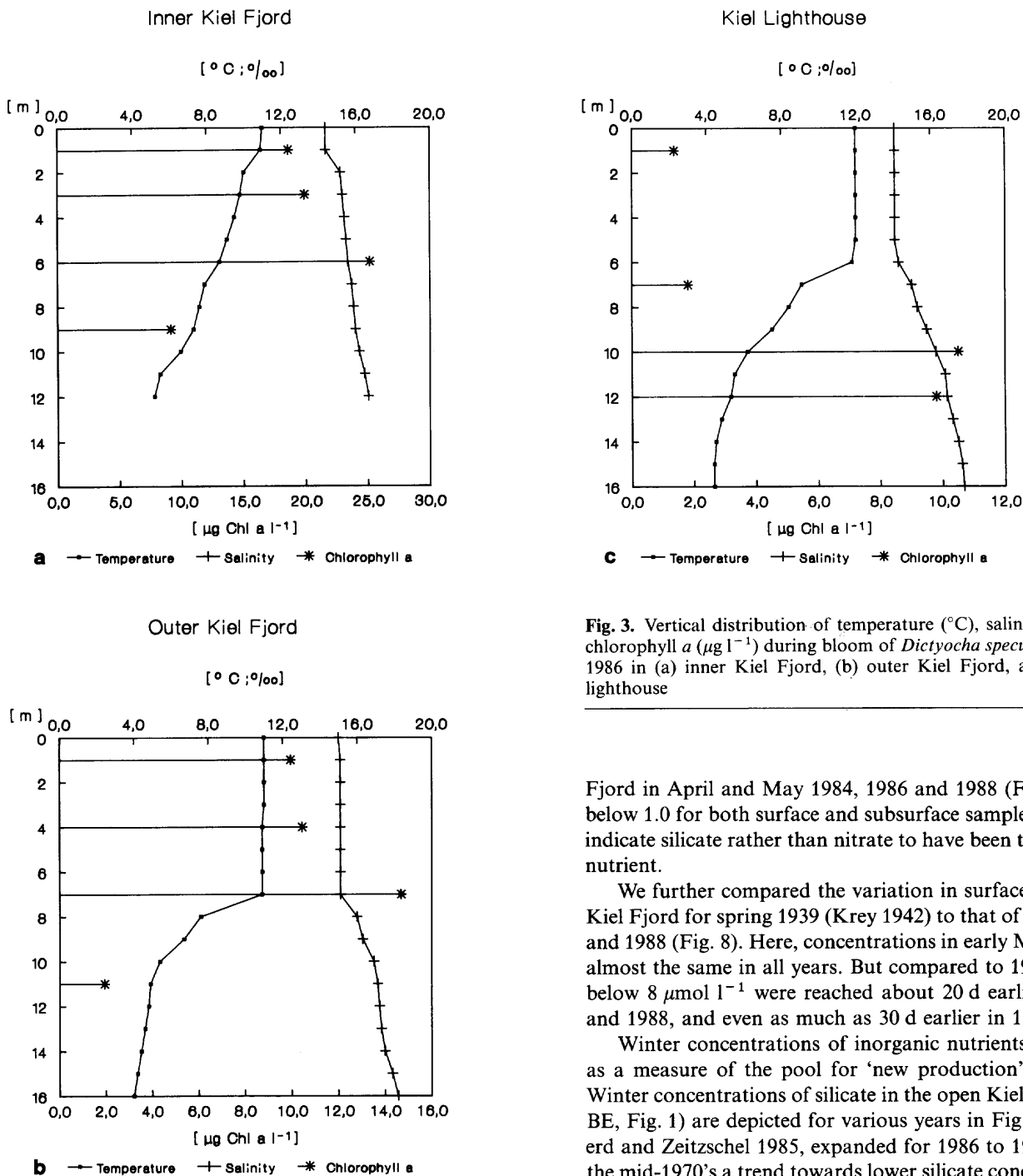


Fig. 3. Vertical distribution of temperature ( $^{\circ}\text{C}$ ), salinity ( $\text{‰}$ ) and chlorophyll *a* ( $\mu\text{g l}^{-1}$ ) during bloom of *Dictyochoa speculum* in May 1986 in (a) inner Kiel Fjord, (b) outer Kiel Fjord, and (c) Kiel lighthouse

tions ( $>20 \mu\text{mol l}^{-1}$  in the inner Kiel Fjord) until 7 May each year. Nitrate is not depleted until the end of May, presumably by the bloom of *D. speculum*. In 1988, the decline of nitrate concentrations seems to have started somewhat earlier than in other years and is associated with the earlier start of the bloom. Although only surface values are depicted in Fig. 6a to c, subsurface values basically showed the same scheme.

From natural water samples Redfield et al. (1963) gave an atomic Si:N ratio of 0.94. Molar Si: $\text{NO}_3$  ratios in Kiel

Fjord in April and May 1984, 1986 and 1988 (Fig. 7) were below 1.0 for both surface and subsurface samples and thus indicate silicate rather than nitrate to have been the limiting nutrient.

We further compared the variation in surface silicate in Kiel Fjord for spring 1939 (Krey 1942) to that of 1984, 1986 and 1988 (Fig. 8). Here, concentrations in early March were almost the same in all years. But compared to 1939, values below  $8 \mu\text{mol l}^{-1}$  were reached about 20 d earlier in 1986 and 1988, and even as much as 30 d earlier in 1984.

Winter concentrations of inorganic nutrients are taken as a measure of the pool for 'new production' in spring. Winter concentrations of silicate in the open Kiel Bight (Stn BE, Fig. 1) are depicted for various years in Fig. 9 (Babenerd and Zeitzschel 1985, expanded for 1986 to 1989). Since the mid-1970's a trend towards lower silicate concentrations can be found ( $r = -0.63$ ,  $p < 0.05$ ,  $n = 17$ ). Consequently, diatom spring blooms should become weaker and, on a long time scale, more severe silicate limitation should lead to a shift in species composition and succession towards organisms independent of silicate, i.e., flagellates. Similar trends of decreasing winter concentrations of silicate have also been found in the adjacent Arkona Sea (Western Baltic, H. Dahlin personal communication), Skagerrak (S. Carlberg personal communication) and German Bight (Radach and Berg 1986). The latter authors also reported a shift towards increasing flagellates and decreasing diatoms in the German Bight. Unfortunately, no long-term studies are available for

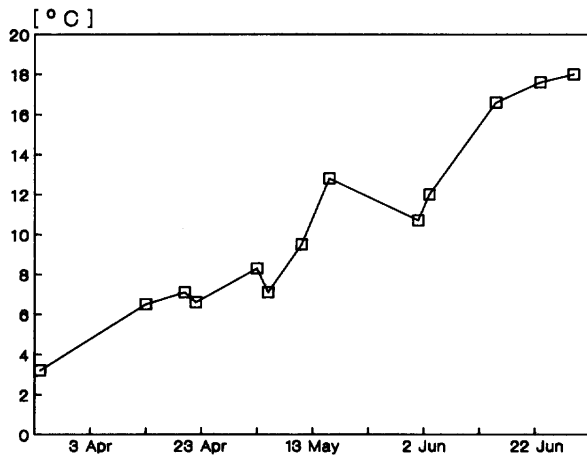


Fig. 4. Surface temperature (°C) in inner Kiel Fjord during spring 1988

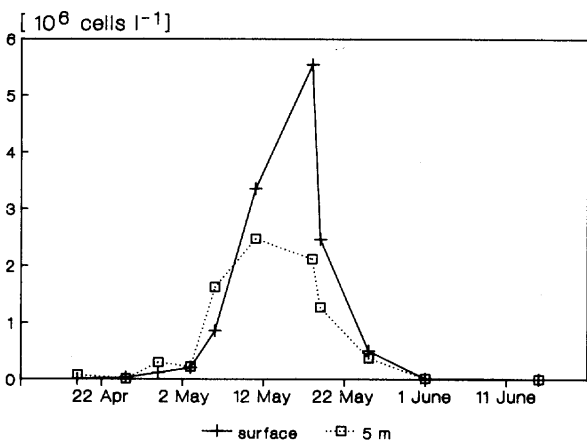


Fig. 5. *Dictyocha speculum*. Cell numbers ( $10^6$  cells  $l^{-1}$ ) at 0 and 5 m depth in inner Kiel Fjord in spring 1988

the inner Kiel Fjord where flagellate blooms were most intense.

In Kiel Bight and Kiel Fjord *Dictyocha speculum* not only demonstrates that an 'exceptional' phytoplankton bloom can become a recurrent event in species succession, but may also be related to the change in environmental conditions due to eutrophication. Apparently, *D. speculum* has found its ecological niche because spring diatoms are no longer able to exhaust the winter nitrate pool due to silicate limitation in April (Bodungen 1986, Jochem 1989). Both decreasing winter concentrations of silicate and the increased input of nitrogen are likely to be reasons for this development. Although known for years to occur in Kiel Bight as a skeleton-forming species, *D. speculum* had never produced blooms in this form. The changed environmental conditions stimulated this species to grow in a yet unknown form, i.e., as a silicoflagellate without its siliceous skeleton, and to form blooms.

*Dictyocha speculum* is not the only example of flagellate blooms in late spring. Late-spring blooms dominated by the nanoflagellates *Gonyaulax catenata*, *Nannochloropsis* sp.

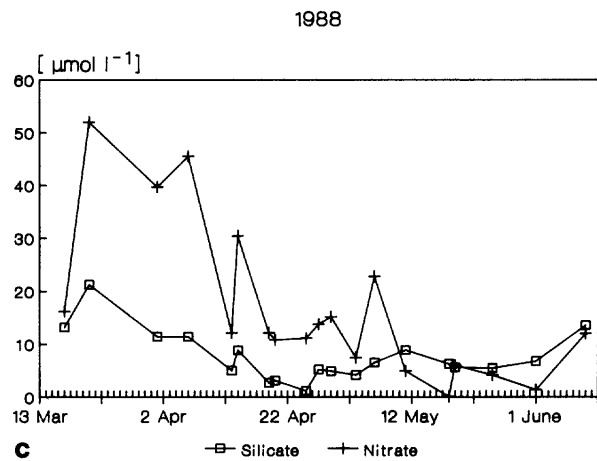
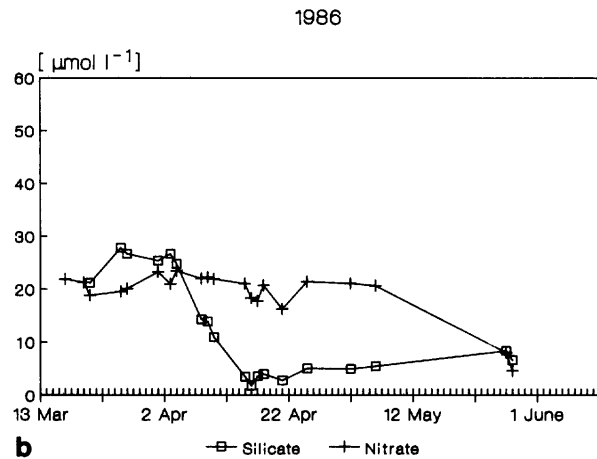
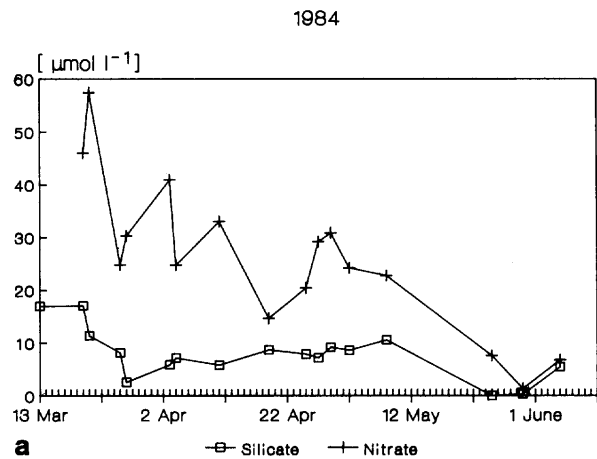


Fig. 6. Surface concentration of silicate and nitrate ( $\mu\text{mol l}^{-1}$ ) in inner Kiel Fjord during spring (a) 1984, (b) 1986, and (c) 1988

and *Cryptomonas* sp. have also been reported from the eastern Baltic (Kuparinen 1987). The toxic bloom of the prymnesiophycean nanoflagellate *Chrysochromulina polylepis* in the Skagerrak/Kattegat area in May 1988, which generated massive public and scientific interest (Dahl et al. in press),

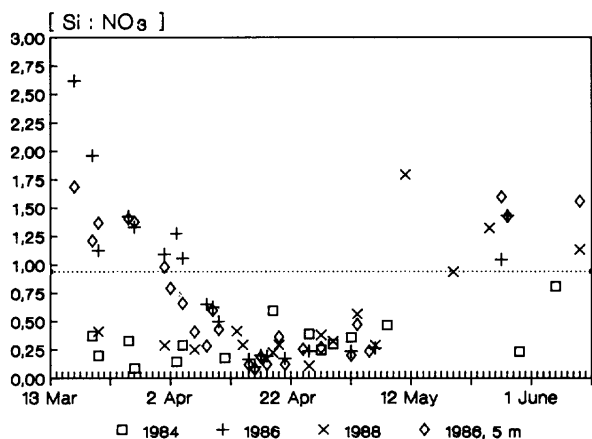


Fig. 7. Molar ratio  $\text{Si}:\text{NO}_3$  in surface and subsurface waters of inner Kiel Fjord during spring 1984, 1986 and 1988

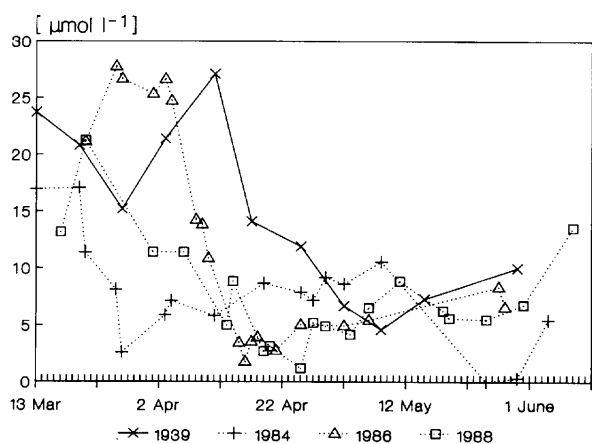


Fig. 8. Surface concentration of silicate ( $\mu\text{mol l}^{-1}$ ) in Kiel Fjord during spring 1939, 1984, 1986, and 1988

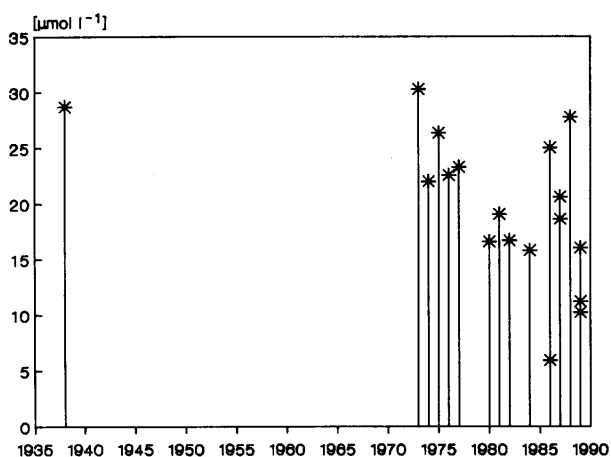


Fig. 9. Winter concentration of silicate ( $\mu\text{mol l}^{-1}$ ) (mean of upper 20 m) in Kiel Bight (Stn BE). For 1986 to 1989 several data were available for each year. Modified after Babenerd and Zeitzschel 1985

showed some resemblance to the *D. speculum* blooms. *C. polylepis* was also known to occur in that area (K. Vagn Hansen personal communication) but had never produced blooms before. As most of the toxic algae are among the nanoflagellates, eutrophication also increases the probability of toxic blooms. Fatal effects would result if a toxic species became part of the natural species succession as *D. speculum* did in Kiel Bight.

The story of *Dictyocha speculum* shows that changes in environmental conditions may change not only the ecological significance of an algal species, but also its morphology and possibly its physiological properties. Therefore, together with good monitoring to record phytoplankton bloom events, intense physiological studies on bloom-forming algae are much required.

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