DEVELOPMENT OF A \textit{DINOPHYSIS ACUMINATA} BLOOM IN THE RIVER RHINE PLUME (NORTH SEA)

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ABSTRACT

The northwestern coastal zone of the Netherlands is influenced hydrographically and chemically by fresh water flowing in from the river Rhine. In the summer of 1994 a bloom of \textit{Dinophysis acuminata} was observed in this area. At a representative monitoring station 10 km offshore, cell numbers increased rapidly after a sudden increase of water column stability and a rise in water temperature to values above 19°C. In an area of 3000 km\textsuperscript{2}, considered to be the river Rhine plume, the abundance of \textit{D. acuminata} was significantly related to stratification. Termination of the bloom started when water temperature dropped below 20°C, despite a rise in inorganic nutrient concentrations. From the peak of the bloom onwards, small cells were observed; these may have been \textit{D. acuminata} gametes.

INTRODUCTION

Blooms of DSP producing species of the dinoflagellate genus \textit{Dinophysis} are a recurring problem in several parts of the world [1]. Since they cannot be cultured, ecological investigations are restricted to field measurements. In The Netherlands \textit{Dinophysis acuminata} may appear in late summer at water temperatures of 15-19°C and salinities of 30-33 [2]. Calm sunny weather with low wind speed seems to favour \textit{D. acuminata} proliferation [2]. In autumn, cell concentrations decline when water temperatures drop below 14°C while mussel toxicity increases simultaneously [3]. Generally, the high turbulence in the mixed Dutch coastal zone does not conduct dinoflagellate growth. Potentially toxic dinoflagellates are normally found only in the thermally stratified part of the central North Sea [4].

A sudden increase of freshwater run-off in coastal areas may result in temporary salinity stratification and reduced turbulence. The resulting water column stability can be favourable to dinoflagellate growth. In Irish estuaries, however, thermal stratification rather than salinity stratification has been found to lead to dinoflagellate accumulation and dominance [5]. Thermal stratification and its positive effect on \textit{D. acuminata} growth has been described [6,7,8]. So far, stratification and its effect on toxic phytoplankton blooms in the Dutch coastal zone has not been investigated. In this paper we describe the wax and wane of a \textit{D. acuminata} bloom in the southern Bight of the North Sea under direct influence of the river Rhine plume.

Fig. 1. Map of study area. Sample stations are 2 to 30 km offshore; the residual water current is to the northeast.
METHODS

At monitoring station NW10 (Fig. 1) weekly CTD casts (salinity, temperature) and water samples for nutrients (dissolved inorganic nitrogen (DIN) and phosphorus (DIP) were taken at the surface (-1 m), at half depth (-10 m) and near the bottom (-17 m) and analysed as described previously [4]. Surface phytoplankton samples were fixed with formaldehyde (0.14% end concentration) and 2 ml subsamples of 10x concentrated samples were counted on an inverted microscope. After detection of D. acuminata along the Dutch coast in week 31 in 1994 (M. Rademaker, personal communication), additional CTD casts and surface phytoplankton samples were collected in weeks 34 and 36 at four transects with stations 2, 10, 20 and 30 km offshore (Fig. 1, total surface area 3000 km²). To measure vertical flagellate distribution the stations 10 km offshore were also sampled at half depth (ca. -10 m) and near the sea bottom in week 36. Stratification strength was calculated as the difference in seawater density between surface and bottom.

RESULTS

Before week 30, water temperatures were below 19°C, nutrient concentrations were low, and stratification was weak (Fig. 2). During a heatwave, surface water temperatures increased ca. 1°C per week to a maximum of 21.5°C at NW10 in week 31, more than 3°C above the normal yearly maximum. Phosphate concentrations reached the analytical detection limit in week 28. In week 30, a decreasing surface salinity and a simultaneously developing temperature difference between surface and bottom caused a large increase in stratification. Meanwhile, D. acuminata started to bloom (Fig. 2). In week 33 highest cell numbers (5x10³ per litre) at NW10 were measured. To the north, highest cell numbers (5x10³ per litre at EG10) were found 1 week later. Further north, in the Marsdiep entrance to the Wadden Sea, the major Dutch shellfish grounds, the highest concentration was 600 per litre in week 32 (Cadée, personal communication).

Highest D. acuminata concentrations occurred at a wide range of salinities, between 29 and 34 (Fig. 3), in accordance with previous findings [2,7,11]. On average, surface samples had twice the D. acuminata cell numbers compared to samples from half depth or the bottom, but differences were not statistically significant (Mann Whitney U-test, P > 0.05). At the peak of the bloom (week 34) a significant (P < 0.05) log-linear relation between cell numbers and stratification strength was found (Fig. 4). In the wane of the bloom (week 36) such a relation was absent, despite considerable saline stratification and

Fig. 2. Development of physical variables, D. acuminata cell numbers and nutrients at NW10 at surface (open symbols) and bottom (closed symbols).
sharply rising nutrient concentrations at NW10 (Fig. 2) and other stations along the Noordwijk transect (not shown). From week 33 onwards, when temperatures had dropped below 20°C (Fig. 2a), small sized cells were observed (Fig. 5).

![Graph](image1.png)

**Fig. 3.** *D. acuminata* concentrations as function of surface salinity in week 34 (●) and week 36 (▲).

![Graph](image2.png)

**Fig. 4.** *D. acuminata* concentration as function of stratification in week 34 (●) and week 36 (▲).

**DISCUSSION**

In previous research on *D. acuminata* in the North Sea the importance of surface state variables such as salinity and temperature has been stressed [2,3]. We have shown here that water column stability induced by salinity stratification also influences the blooming of this dinoflagellate species. This is probably the reason why *D. acuminata* at times is abundant in an area that had been considered to be well mixed. A decrease in wind stress, which will diminish upper layer turbulence, will enhance the growth of dinofla-
gellates such as *D. acuminata* even more [2,8]. At low turbulence, the wax and wane of the bloom seemed to be induced by a threshold temperature of 19°C and not by changes in nutrient concentrations (Fig. 2). Comparably, a *D. acuminata* bloom in the baie de Vilaine in France occurred after a rapid increase in temperature (from 14° to 21°C in 2 weeks) in nutrient-poor thermally homogenous coastal water [9]. Cell numbers fell below 200 litre⁻¹ three months later, despite increased phosphate, when temperatures dropped below 20°C [9], as was the case at NW10 (Fig. 2). However, the wane of a bloom will not only be influenced by lower temperatures, it will also be enhanced by increased turbulence [8]. In the Antifer area (France) the effect of estuarine water outflow was noted, but not correlated with salinity stratification [7]. In waters off the French Atlantic coast the start of a *D. acuminata* bloom was observed in the thermocline after rapid heating of the surface layer from 11.5° to >15° in 3 weeks time [6].

Attempts to correlate the occurrence of *Dinophysis* blooms with environmental factors have been unsuccessful [1]. A conventional *Dinophysis* growth model could not simulate sharp increases in cell concentration [8] while a simple one for *D. fortii*, using threshold values for temperature and salinity, could [7]. A steep linear relation between temperature (10-25°C) and growth rate has also been established for the DSP producing and culturable *Prorocentrum lima* [10]. This *in vitro* relation was inverse for toxin production. Similarly, Kat [3] found increased *D. acuminata*-related mussel toxicity at decreasing temperatures *in situ*.

We propose that in modelling *Dinophysis* blooms and DSP in shellfish, water column stability and water temperature, or the rates of changes in these variables, must be regarded as crucial factors.

*D. acuminata* cells can vary considerably in size and shape [1] as an effect of environmental change [15]. Morphological changes in *D. acuminata* cells have been described when growth ceased during a culture experiment at 17°C [11]. However, these changes were not as pronounced as in the wane of the bloom in the North Sea (Fig. 5). In our samples the decrease in mean cell size seemed gradual on a weekly basis, but combining all data revealed the appearance of small cells as a distinct group from week 33 onwards (not shown). Similar small cells are also found during *D. acuminata* blooms in Portugal, where they are designated *Dinophysis skagii* [M.A. de M. Sampayo, personal communication]. Dodge [17] noted that *D. skagii* may be an aberrant form of *D. acuminata*. Sexual reproduction in the
The genus *Dinophysis* has been implied from the observation of planozygotes [12]. Anisogamous gametes have been described for *Dinophysis tripos*, *D. acuta* [13,14] and *D. sacculus* [18]. It is therefore not unlikely that our small *D. acuminata* cells (presumably *D. skagii*) are gametes. Culture studies of *Dinophysis* species are needed to elucidate this problem.

Fig. 5. Photomicrographs of *D. acuminata* from NW10 in week 33, 1994. a. normal cell, b. small cell (bar = 50 µm).

As long as culturing of *Dinophysis* is not possible, it might be worthwhile to investigate certain aspects of the ecophysiology of *Dinophysis* by using *Prorocentrum* spp. as "model species". All members of the *Prorocentrum* genus can be cultured and some species produce DSP toxins [10]. Most of all *Prorocentrum* spp. and *P. micans* in particular are very often found in considerable concentrations during *Dinophysis* blooms [2,9,10,16], so it is tempting to suggest that they respond to environmental changes in a comparable way.

Acknowledgements. We thank personnel of the North Sea Directorate, master and crew of the m.s. Holland for the extensive sampling. J.A. van de Broeke helped in making the figures. P. Günther corrected the English.

REFERENCES


HARMFUL AND TOXIC ALGAL BLOOMS

- Proceedings of the Seventh International Conference on Toxic Phytoplankton
  Sendai, Japan, 12-16 July 1995

Co-published with
Laboratory of Bioorganic Chemistry, Tohoku University

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For bibliographic purposes, this document should be cited as follows:
Harmful and Toxic Algal Blooms
Yasumoto, T., Oshima, Y and Fukuyo, Y. (Eds)
Intergovernmental Oceanographic Commission of UNESCO 1996
(English only)

Published in 1996
by the United Nations Educational, Scientific and Cultural Organization
7, Place de Fontenoy, 75352 Paris 07 SP

Printed by Sendai Kyodo Printing Co. Ltd.

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Printed in Japan