Harmful Marine Algal Blooms - P. Lassus, G. Arzul, E. Erard, P. Gentien, C. Marcaillou

The German Wadden Sea: A problem area for nuisance blooms?

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Abstract. Mass occurrences of Phaeocystis globosa and Noctiluca scintillans are recurrent phenomena in the German Wadden Sea. In contrast, potentially toxic species of Dinophysis spp. and Alexandrium excavatum only occur at low concentrations. It is suggested that they result from advection from offshore sites stratified in summer, as well as from frontal structures adjacent to the Wadden Sea, where blooms of Dinophysis acuminata at densities over 150 x 10^3 cells/ dm^3 were observed. In addition, semi-enclosed brackish basins situated behind the coast-line are favorable sites for mass developments of various nuisance forms. The cyst flora of the Wadden Sea is in concords with the low abundance of motile cells. Cyst numbers are dominated by Scrippsiella spp., with a species composition very similar to that of the open German Bight. There is no evidence of cyst accumulation in Wadden sediments.

1. Introduction

The German North Sea coast is entirely bordered by the Wadden Sea, which is a very sensitive area from the ecological point of view and used intensively for tourism and fishery activities. In this context, two aspects of nuisance phytoplankton blooms are of relevance: Esthetic problems of water quality and the danger of shellfish poisoning. Annual revenue from the tourism industry are in the range of \$1.5 x 10^9, with a clientele very sensitive to the appearance of the water. Blue mussel cultures are concentrated especially in the northern and westernmost area, with a production in 1991 and 1992 of about 30 to 50 x 10^3 tons/year, representing an annual turnover of \$10-13 million (Anonymous, 1993).

2. Materials and Methods

Seasonal investigations were carried out in January, May and August between 1989 and 1992 on a fixed grid comprising 80-90 stations. A frontal structure was investigated in August 1984 on 5 stations. Discrete water samples were taken from aboard ship with a 5l-Niskin bottle at a depth of about 1 m. Phytoplankton subsamples were preserved with Lugol's iodine, prior to further analysis under an inverted microscope equipped with phase contrast. For the purpose of additional taxonomical identification, living samples were taken using an Apstein-net (20 µm -mesh size).

Vertical profiles of salinity and water temperature were obtained with an ME-multiprobe.

Mouse bioassays for DSP are practised from extracts of bivalve molluscs by health authorities.

For cyst investigation, sediment cores were sampled at 7 stations between 1991 and 1993, using a hand-held coring device at both northern stations (W1, W2) and at W7 (Fig. 5) and a gravity corer at all other stations. Core sections (0.5 cm or 1cm) were gently sonicated and then passed through 150 µm gauze and retained on 20 µm gauze. The residue on the 20 µm gauze was rinsed from the net and resuspended in 30 ml filtered seawater. Several milliliters of this preparation were counted on Utermöhl slides using an inverted microscope.

3. Results

3.1. Nuisance phytoplankton species in the German Wadden Sea

Recurrent mass occurrences of Phaeocystis spp. and Noctiluca scintillans, with associated foam and mucus production, are a rather common phenomenon in the coastal waters of the German Bight and - with respect to esthetics - the most spectacular events (Fig. 1). Detailed surveys in the Wadden Sea conducted over the last 4 years revealed maximum cell concentrations of Phaeocystis amounting to 7 x 10^7 cells/dm^3 in 1989, with corresponding numbers for subsequent outbreaks in the range of 10^8 cells/dm^3 in 1990, 7 x 10^7 (1991) and 13 x 10^6 cells/dm^3 in 1992, respectively. Scum formation and acrid odour (dimethylsulfide) being most intensive in 1989. Red tides of decaying Noctiluca scintillans have occurred each year in spring and summer, always a rather conspicuous phenomenon to tourists and newspapermen. Major events concerning this species occurred in 1989, with nearshore densities up to 7 x 10^4 cells/dm^3, equaling a biomass of 20 mg C/dm^3. In the inner regions of the Wadden Sea, toxic species of Dinophysis have occurred in low numbers not exceeding 800 cells/dm^3, from late spring to autumn. Usually, important concentrations, culminating in cell densities of about 10^4/dm^3, are observed only at the seaward border of the study area in summer, well away from mussel beds (Fig. 2). However, DSP was recorded in mussel samples in 1986 and 1990 from the East Frisian Wadden Sea and in 1989 and 1992, together with a doubtful record in 1991, in mussel samples from the North Frisian Wadden Sea (Lenz, 1991; H. Schenk, pers. comm.). These cases were due to D. acuminata, which is the dominant form of the ten different Dinophysis species occurring in the area.

At small density inhomogenities deriving from the Elbe front, Dinophysis concentrations of more than 10^5 cells/dm^3 were found during summer 1984 (Fig. 3). As a consequence of strong north winds, large amounts of D. acuminata (2.5 x 10^4 cells/dm^3) were observed in the East Frisian Wadden Sea (Jade bay) in mid August 1990, probably originating from the seaward, thermally stratified, side of the tidal mixing front.

For reasons of precaution, the area was closed for sale of shellfish by the

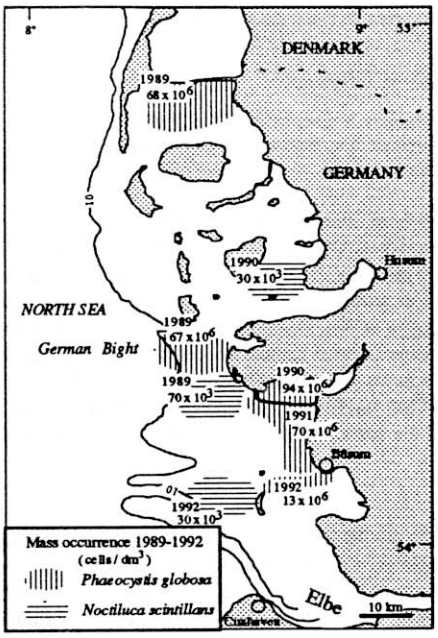


Fig. 1: Mass occurrences of Phaeocystis globosa and Noctiluca scintillans in surface waters of the North Frisian Wadden Sea in the period 1989-1992.

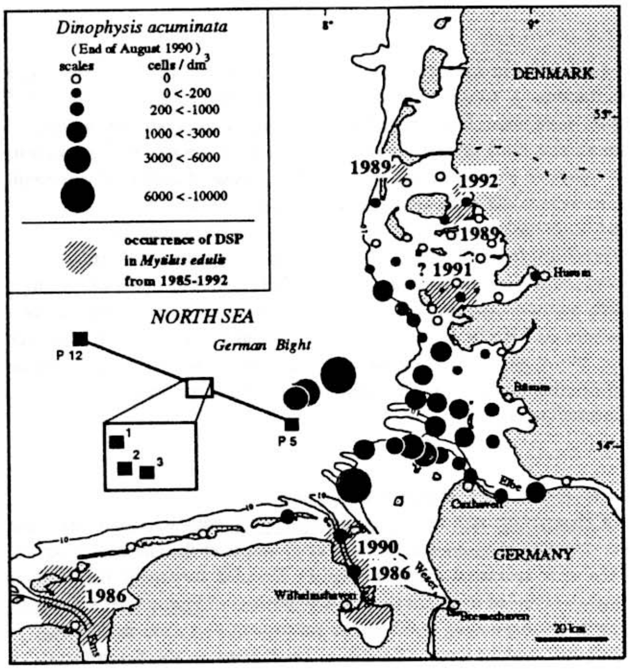


Fig. 2: Distribution of Dinophysis acuminata in surface waters of the German Wadden Sea (27.-31.1990) and occurrence of Diarrhetic Shellfish Poison (DSP) in Mytilus edulis in the period 1985-1992. In addition: Location of stations investigated on a frontal transect in Augsut 1984, as referred to in figure 3.

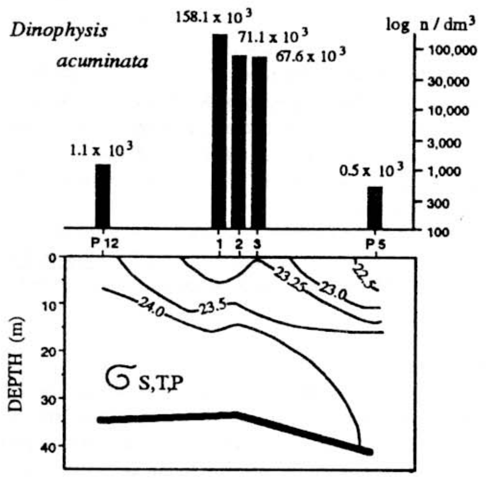


Fig. 3: Mass occurrence of Dinophysis acuminata in surface waters at a frontal structure in the southwestern part of the German Bight in August 1984. For location of stations see figure 2.

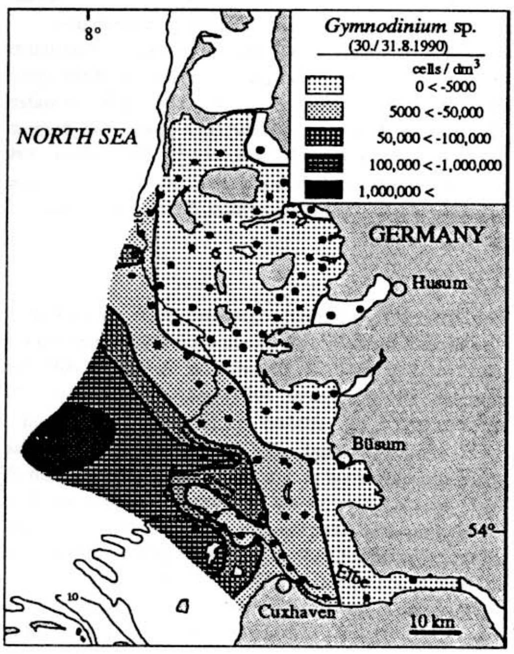


Fig. 4: Mass development of a hitherto unknown green Gymnodinium sp. in surface waters near Heligoland, and the extent of the spread of the bloom into adjacent Wadden Sea.

local Veterinary Office and some days later, Diarrhetic Shellfish poison was detected in Mytilus edulis samples of the region. No intoxications of humans were reported. The distribution of D. acuminata at the end of August 1990 shows highest densities in the outer estuaries of the Elbe and Weser rivers and cells are transported into the Wadden Sea (Fig. 2).

Other potentially toxic forms, such as Gymnodinium cf. sanguineum and Gyrodinium aureolum, only occurred sporadically. Cell counts for Alexandrium excavatum did not exceed 400 cells/dm^3. This is in keeping with the absence of Alexandrium resting cysts in recent sediments of the Wadden Sea (see below) and its scarce occurrence in adjacent regions (Nehring, in press).

In August 1990, an unusual green tide of a still unidentified dinoflagellate, very similar to Lepidodinium viride Watanabe et al., was observed in thermo-halin stratification on one side of the Elbe front near Heligoland, mean concentrations amounting up to 20 x 10^6 cells/dm^3. Part of this bloom was dispersed into the northern Wadden Sea (Fig. 4). It is thought that estuarine circulation was the predominant hydrodynamic mechanism for the observed advection, since among the nearshore sites, highest concentrations of the green dinoflagellate occurred in the Elbe estuary.

As well as stratified waters in the German Bight, semi-enclosed brackish basins situated behind the coast-line appear to be very favorable sites for mass developments of dinoflagellates, as illustrated by the recurrent red tides of Glenodinium foliaceum in some of these ponds (Hesse *et al*, 1992). With each ebb tide, a considerable amount of the blooms streams out into the Wadden Sea. These blooms are associated with intense formation of temporary cysts, divided into as many as 8 daughter cells. This may help to ensure long-term persistence of the population. In the aftermath of blooms, the dense carpet of cysts on the sediments partly serves as a diet for cyclopoid copepods and oligochaete worms. Prymnesium parvum and 3 different species of Chrysochromulina, were observed in some of the brackish basins, the former species in concentrations of up to several millions/dm^3 (A. Haase *et al.*, in prep.). However, since a single event of fish mortality in 1978 (Dietrich & Hesse, 1990), no subsequent harmful effects due to these forms have been reported from the German West Coast. A mass bloom of the toxic cyanophyceae Nodularia spumigena developed in a brackish public bathing lake on the East Frisian coast in August 1990. It caused the death of two dogs, which, after having ingested the water, suffered lethal haemorrhages in the liver related to the potent hepatotoxin Nodularin (Nehring, 1993 a; Jungmann & Nehring, in prep.). In consequence, the municipal authorities closed the bathing lake for several weeks.

There are no records of any nuisance diatom blooms in the German Wadden Sea or adjacent areas up to now. In summer 1992, however, a dense bloom of species belonging to the Pseudonitzschia pungens-group was observed at offshore stations near Heligoland, among them the potentially toxic P. pungens f. multiseries (E. Hagmeier, pers. comm.).

3.2. Dinoflagellate resting cysts in recent Wadden Sea sediments

The Wadden Sea system functions as a trap for particulate material of <100 µm in size, which corresponds with the size spectrum of most dinoflagellate cysts. To date, more than seventy species of marine and more than twenty species of freshwater dinoflagellates produce resting cysts as part of their sexual life cycle (Nehring, 1993 b). The present study reveals that living and empty cysts are widespread throughout the stations investigated (Fig. 5). Altogether 15 different cyst types were identified to species level. At all stations, Scrippsiella trochoidea (Fig. 6C) dominated the cyst assemblages. Other common species were Peridinium dalei, Protoperidinium conicum, S. lachrymosa and Zygabikodinium lenticulatum. Cysts of potentially toxic dinoflagellates were not found. The wide distribution of living and empty cysts of S. lachrymosa (Fig. 6A) as well as the occurrence of S. trifida cysts (Fig. 6B) suggests that both species are common plankton organisms of German coastal waters, although motile individuals have not been officially recorded so far in the region.

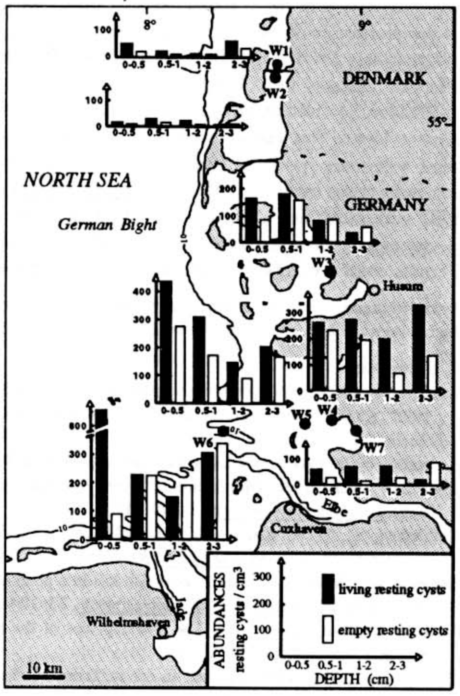
The small-scale vertical distribution of living and empty cysts usually exhibited maximum concentrations well below the sediment surface (Fig. 5). The comparative distribution of the cysts showed a general increase in cyst abundances and diversity from the shallow sites (< 0.5 m water depth during high tide; station W1, W2, W7) to the deeper area in the tidal inlets. The deepest station (W6) at the seaward border of the Wadden Sea was characterized by the highest cyst abundance (859 living and 90 empty cysts/cm^3 in the topmost half centimeter). At most stations the ratio of living to empty cysts of abundant species was >1 in the uppermost 2 cm of the sediment, in contrast to the situation in the deeper layer (2 to 3 cm).

4. Discussion

Plankton blooms that would be considered exceptional on a larger geographical scale, are a more or less regular feature in the open waters of the German Bight. Former bloom events were recorded for Gyrodinium cf. aureolum west of the island of Sylt in 1979 (Doerffer & Amann, 1984), for Ceratium furca along the entire coast in summer 1981 (Gillbricht, 1983) and in late of July 1993 around Heligoland with maximum concentrations of 1×10^6 cells/dm^3 (E. Hagmeier, pers. comm.), for Ceratium fusus in 1986 (Hesse *et al.*, 1989) and for Noctiluca scintillans in 1986 and 1989 near Heligoland, the latter amounting to maximum concentrations of 1×10^6 cells/dm^3 (Schaumann & Hesse, 1990; J. Goebel, pers. comm.). With the exception of the G. aureolum bloom, massive outbursts of potentially toxic forms have not been reported from the area. However, as a consequence of intense Ceratium-blooms, serious oxygen deficiency, accompanied by fish mortality, was observed in vast areas of the deeper German Bight (e.g. Dethlefsen & Westernhagen, 1983).

Hydrographical factors like summer stratification events and frontal structures seem to play a major role in bloom formation in the open German Bight. The very different hydrographic structure in nearshore areas, however, which are from the economical point of view much more sensitive to the impact of nuisance blooms, does not favor the development of most phytoplankton forms hitherto suspected of being toxic. The generally low abundance of dinoflagellates in the Wadden Sea proper is well in accordance with turbulent conditions in this unstable environment. Wyatt (1993) examined

Fig. 5: Horizontal and vertical distribution of living and empty dinoflagellate resting cysts in the uppermost three centimeters of North Frisian Wadden Sea sediments (W1, W2: 21.4.93 / 0.3 m water depth; W3,W7: 19.6.91 / 3 m, 0.3 m; W4, W5,W6: 17.11.92 / 6 m, 7 m, 11 m).



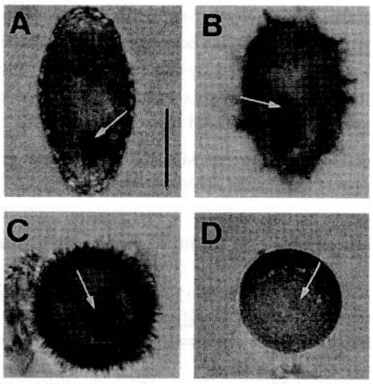


Fig. 6: Dinoflagellate resting cysts isolated from recent North Sea sediments. A) Scrippsiella lachrymosa. B) S. trifida. C) S. trochoidea. D) Gymnodinium catenatum. Arrows: Red accumulation body. Scale bar: 18 µm in (C), 20 µm in (B), 25 µm in (A,D).

the importance of water column stability as a prelude for PSP events in British waters and found a critical current velocity of 1 knot at spring tide as a limit for PSP outbreaks during the last twenty years. Corresponding values in the German Wadden Sea lay in the range of 1 to 3 knots. Therefore it is presumed that the formation of dinoflagellate blooms in the region is prevented by high current speeds and that any appreciable amounts of dinoflagellates in the Wadden Sea are rather the result of advection from adjacent sites of intensive growth, such as the stratified region of the Elbe river plume and, in the warm season, the tidal mixing front off the East-Frisian islands. Onshore surface currents induced by the prevailing westerly winds, eddy transport as well as estuarine circulation and tidal asymmetry seem to be the predominant transport mechanisms for bloom advection (Hesse *et al.*, 1992). In accordance with the conceptual model of Margalef (1978) the phytoplankton development in the German Wadden Sea is dominated all the year round by diatoms (Hesse *et al.*, in press.), with the exception of recurrent bloom events due to Phaeocystis, mostly concentrated in the estuarine regions. Tychopelagic diatoms account for about 30% of total phytoplankton biomass, based on a yearly average. The potential occurrence of toxic diatom species, especially of Amphora coffeaeformis, Pseudonitzschia pungens f. multiseries and P. pseudodelicatissima, forms recorded from adjacent waters of the North Sea, present a risk to the mussel fishery. In the Wadden Sea proper species belonging to P. pungens-group are rather common but their local relevance for mussel toxicity has yet to be established.

The results of dinoflagellate cyst investigations concord with the low abundance of motile cells in the area. There is no evidence of cyst accumulation in German Wadden Sea sediments. It is unlikely that the poor cyst assemblage of the Wadden Sea would initiate substantial bloom formation, but it demonstrates the presence of hitherto undetected species in the water column. The only previous record of dinoflagellate resting cysts in Recent sediments of the German Wadden Sea was given by Chowdhury (1982). His findings revealed only few empty cysts, all with sporopollenin cyst walls. The apparent dominance of calcareous Scrippsiella spp. cysts in Wadden Sea sediments was certainly overlooked in Chowdhury's study because the preparation method did not preserve calcareous

material.
The comparison of the Wadden Sea cyst flora with the corresponding situation in the adjacent area of the North Sea shows close similarities (Nehring, in press), but total cyst abundances increase progressively from the shallow sites of the Wadden Sea to the deeper area and culminate in the offshore region of the North Sea. In spite of the occasional occurrence of Alexandrium excavatum in Wadden Sea waters, no cysts of toxic species were found in the present study. However, there is some evidence that factors such as cyst resuspension and current transport may repeatedly infect areas with toxic species (Cembella *et al.*, 1989). For the area of the North Sea, resting cysts of the non-indigenous toxic chain forming Gymnodinium catenatum (Fig. 6D) has been found since March 1992 with increasing abundance (Nehring, in press) and it was suggested by Nehring (1993 c) that G. catenatum was introduced from the Atlantic coast of the Iberian peninsula to French and then to German coastal waters by increased water influx through the English Channel into the North Sea.

Acknowledgements. Part of this study was supported by a grant of the German Ministry for Research and Technology and by a grant of the Federal Environmental Agency and of the State of Schleswig-Holstein .

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