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Algal blooms in the North Sea: *the Good, the Bad and the Ugly*

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Abstract

Algal blooms have received a good deal of negative publicity in recent years in that their occurrence is often associated with the loss of revenues from tourism, fish kills and/or toxicity of shellfish or bathing waters. Journalists often link such blooms to pollution and, indeed, it is becoming increasingly apparent that man can stimulate algal blooms through the addition of nutrient-containing waste water to the oceans. However, it is still the minority of algal blooms that are caused by pollution. Algal blooms – even the toxic ones – can have a perfectly natural cause and, in many cases, they play an important role in the ecology of marine systems. Unfortunately, it is often difficult or impossible to identify whether a particular algal bloom is 'natural' or 'man-made'. In this lecture, the phenomenon 'algal bloom' is defined and discussed both in an ecological and historical perspective. Emphasis is placed on algal blooms in the North Sea and their consequences. Finally, the evidence for 'man-made' algal blooms in the North Sea is examined.

Introduction

In the popular press, an algal bloom is treated as being just about as welcome as a swarm of locusts in a grain field and, in much the same way that locusts in the Bible form one of the seven plagues, environmentalists (and journalists) repeatedly suggest that algal blooms are the oceans' way of seeking revenge for the ways in which man mistreats them. In such a climate, it is easy to forget that most algal blooms are a perfectly natural and important part of marine ecosystem dynamics and, in fact, that the blooms that we read and hear so much about actually comprise only a very small percentage of the blooms occurring in the oceans.

Here we will examine the North Sea in an attempt to identify the 'good' and 'bad' algal blooms that occur there. Before doing so, it is necessary to define some of the terms we will use. An 'algal bloom' is simply an outburst of the growth of phytoplankton (microscopic plants (algae) drifting in the water mass) which results in a high biomass of these organisms. What we read about in the papers can be referred to as 'exceptional algal blooms' which we define as algal growths that are noticeable (particularly to the general public) either directly or indirectly through their effects. A 'Red tide' where a high algal biomass results in an obvious change in seawater colour is an example of such an exceptional bloom. Often 'exceptional blooms' are not blooms at all in the true sense of the word. The mere presence of a toxic alga, for example, is usually popularly referred to as a bloom irregardless of whether or not a high biomass is achieved.

The occurrence of exceptional algal blooms is often linked in the media to pollution. In fact, a better term than pollution is 'eutrophication' which means enhanced nourishment and refers to the stimulation of algal growth by enrichment of the aquatic environment with mineral nutrients. Phytoplankton in the sea can be considered to be analogous to grass on land and, just as for a lawn, the growth of phytoplankton is stimulated by the addition of fertilizers (especially those containing nitrogen (N) and phosporus (P)). There is a considerable anthropogenic input of N and P to the North Sea: river inputs of phosphorus and nitrogen to the North Sea south of 56°N have been estimated to be 127 $\times 10^3$ tons per year and 1100 $\times 10^3$ tons per year, respectively (Gerlach, 1988; see also Portman, this volume). Clearly, these nutrients will stimulate the growth of algae and even give rise to exceptional algal blooms. The problem, however, is identifying to what extent blooms (exceptional or otherwise) can be attributed to anthropogenic and 'natural' nutrient sources.

The role of algal blooms in marine ecosystem dynamics

Solar energy is used to drive most aquatic ecosystems and it is converted to usable energy via photosynthesis carried out by phytoplankton. From phytoplankton, this energy is transferred through the different trophic levels via a complicated web of feeding interactions involving all marine organisms from bacteria to whales. As the amount of phytoplankton controls the amount of energy entering this food web, a bloom of phytoplankton can, in some cases, result in more energy being transferred through the system and, thus, end in a greater yield or production from the system (more fish, for example).

The North Sea, by virtue of its depth, tidal currents and temperate latitude is essentially mixed from top to bottom during the winter months. This allows nutrients (N, P) to be thoroughly mixed in the water column. Phytoplankton activity is at a minimum at this time as these organisms are also mixed throughout the water column and, thus, are not exposed to a light climate which is sufficient to support high rates of photosynthesis. As winter storm activity decreases and solar heating of the surface water increases during the early spring, the water column stratifies and a relatively warm surface layer forms. Phytoplankton found in the surface layer are no longer mixed to the bottom and, as a result, are exposed to a much higher average light climate. There are ample nutrients in the surface water as a result of the winter mixing and this, combined with the high light levels, gives rise to a spring phytoplankton bloom (Fig. 1). This bloom is followed by a bloom of zooplankton (microscopic animals) which feed on phytoplankton. Zooplankton are eaten by small fish and, thus, the spring bloom stimulates increased production by the system as a whole.

During the spring/summer months, inorganic nutrients become bound in phyto- and zooplankton and sink out of the surface waters. At this time, phytoplankton have ample light but are limited by nutrient availability. Localized blooms of phytoplankton can, however, occur when nutrients are introduced to the surface water. This can happen, for example, as a result of stormy weather where bottom water is

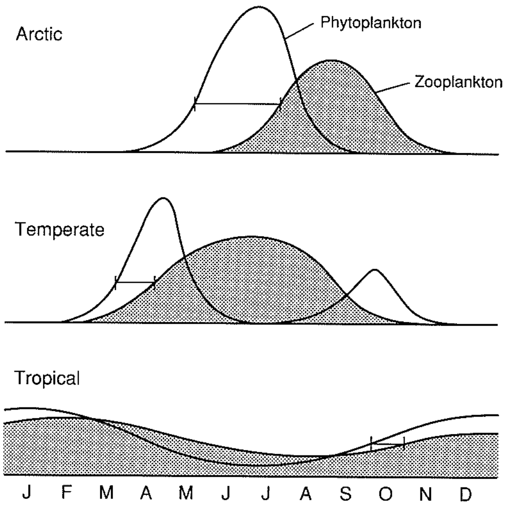

Fig. 1. Seasonal distributions in the biomass of phytoplankton and zooplankton at different latitudes.
(After Cushing, 1959; figure 3).

mixed to the surface or where the juxtaposition of stratified waters and coastal currents create mixing regions where nutrients are transported into surface waters. In most cases, phytoplankton blooms resulting from such mixing processes will give rise to increased zooplankton and, ultimately, fish production.

However, this is not *always* the case and the easiest way to understand why not is to use a terrestrial example. Consider a field with grazing cows. As long as the animals are food limited, increasing the amount of grass available will stimulate meat production from the field. When the cows become satiated, however, continued fertilization of the grass will only give more grass. In another example, we can put our hungry cows in a field of cacti. Irrespective of the number of plants available, the meat production from the field will not increase. A similar scenario occurs in the sea. Some algae because of their shape, size, taste, etc. are not suitable food items for zooplankton and are, thus, analogous to cacti in the above example. The lack of grazing on such blooms may be a contributing factor to their size and this may also be part of the reason why noxious or toxic species are often implicated in exceptional algal blooms. This was, for example, probably the case with the *Chrysochromulina polylepis* bloom in the Kattegat and Skagerrak in 1988 (cf. Nielsen & Richardson, 1988) and may also be a factor in the formation of *Gyrodinium aureolum* blooms in the Skagerrak (Richardson & Kullenberg, 1987).

History of exceptional algal blooms

Exceptional algal blooms are not a new phenomenon. It is believed that the first written reference to such a bloom appears in the Bible (Exodus 7: 20-21):

'... all the waters that were in the river were turned to blood. And the fish that was in the river died; and the river stank, and the Egyptians could not drink of the water of the river'.

There is also fossil evidence suggesting mass death of mussels as a result of an algal bloom that occurred 140 million years ago in what is now the Baltic Sea (Surlyk & Noe-Nygaard, 1988) and it is known that the Indians along the west coast of North America practiced a form of public health administration with respect to algal blooms before Europeans reached the shore. These Indians realized that when mussels were toxic, there was bioluminescence in the water (the most common toxic algal species in this region exhibits bioluminescence) (Seliger & Holligan, 1985). When there was bioluminescence present, the Indians ceased shellfish collection and consumption. Of course, other non-toxic species are also bioluminescent so there were undoubtedly periods in which the Indians closed non-toxic shellfish grounds but, apparently, then, as now, it was better to be 'safe than sorry' in public health matters.

If the Bible citation does refer to an algal bloom, then it was one that was occurring near a concentration of human populations and eutrophication may, thus, have played a role in its formation. However, it is hard to imagine how eutrophication could be implicated in a bloom occurring in the Baltic in prehistoric times or in the Pacific before white man had laid eyes on this ocean! It is, thus, not possible to relate- ed exceptional algal blooms or the presence of toxic species directly to anthropogenic nutrient input to the sea.

Exceptional algal blooms in the North Sea

What, then, is the problem and why are we so concerned about the North Sea? The answer lies in the fact that there is a good deal of evidence to suggest that exceptional algal blooms in the North Sea are becoming more frequent and more intense. Dramatic blooms of the alga *Phaeocystis* occur, for example, more or less annually along the southern and southeastern coasts of the North Sea (Lancelot *et al.*, 1987). This alga excretes a proteinous substance which becomes whipped to a stiff foam by wave action and can be deposited in a thick layer along the beaches in the Southern Bight – much to the detriment of tourism in this area! In a study covering the years 1973-1985, it has been shown that both the number of *Phaeocystis* cells in the water column and the duration of blooms have increased dramatically during this period (Cadée & Hegeman, 1986). *Phaeocystis* is however, not the only alga forming exceptional blooms in the North Sea. Other implicated species are *Mesodinium rubrum* (Gieskes & Kraay, 1983), *Ceratium* sp., *Noctiluca scintillens*, *Prorocentrum* sp. and the toxic species *Gonyaulax* sp. (Armstrong *et al.*, 1978) and *Gyrodinium aureolum* (cf. Richardson & Kullenberg, 1987).

Most of the exceptional blooms recorded in the North Sea occur in coastal waters in the southern North Sea and along the Danish west coast (see Lancelot *et al.* 1987 for distribution of observed *Phaeocystis* blooms). It is also these regions that exhibit the highest inorganic nutrient concentrations (Brockmann *et al.*, 1988) and which one, from oceanographic considerations, would expect to be most influenced by river inputs to the North Sea (Hainbucher *et al.*, 1987). Thus, it is tempting to relate the apparent increase in exceptional algal blooms in the North Sea to anthropogenic input of nutrients to the coastal regions of the North Sea and, indeed, Berg & Radach (1985) have examined variations in phytoplankton carbon and inorganic nutrient at Helgoland Reed and in the German Bight from 1962 to 1984 and conclude that there has been an upward trend in phytoplankton C, nitrate N and phosphate P especially in the Elbe influenced water during this period.

That the highest inorganic nutrient concentrations in the southeastern North Sea can be found in the relatively low salinity water associated with river input can clearly be seen from hydrographic data collected along the Danish west coast during February, 1987 (Fig. 2a and b). This nutrient-rich band of cold (Fig. 2c) low salinity water can be followed along the Danish coast to approximately Hanstholm. At this time, phytoplankton blooms were occurring both in the coastal waters and in the south/central North Sea (on the Dogger Bank). This can be seen from the distribution of the plant pigment, chlorophyll, illustrated in Fig. 2d where it should be noted that the highest chlorophyll concentrations were found in coastal waters.

There is one very important difference between these two algal blooms, however, and that is temperature. The zooplankton that graze on phytoplankton are very temperature sensitive and in the cold coastal waters, at this time, the zooplankton were temperature rather than food limited. Thus, essentially no grazing took place on the coastal phytoplankton bloom and, going back to our analogy of satiated cows in a pasture, more and more 'grass' was able to accumulate. In the south/central North Sea where temperatures were several degrees warmer than along the coast, there were actively grazing zooplankton and, here, the phytoplankton bloom led to increased production through the food web. Of course, not all the phytoplankton in the south/central North Sea could be grazed by zooplankton and some of the algae produced during the spring bloom in this region ends up sedimenting to the bottom where it is presumably consumed by bottom dwelling organisms or resuspended and consumed in the water column (Nielsen & Richardson, 1989).

In the cold coastal waters, essentially all of the phytoplankton produced in this February bloom end up sedimenting to the bottom. This sedimentation of organic material provides a rich food supply to bottom dwelling animals. However, bottom dwelling animals – just like zooplankton – can be likened to cows in a pasture and there comes a point when these bottom communities are not able to consume more food.

In areas in which there are repeated algal blooms such as in the nutrient-rich waters of the North Sea (and in the Kattegat), the bottom-living organisms are simply not able to consume the large amounts of organic material (dead phytoplankton) that are transferred to them throughout the year. The result is that this organic material accumulates on the bottom – in some cases smothering the bottom-living animals – and begins to decompose. The decomposition process is carried out by bacteria and other microorganisms and requires oxygen. Thus, in relatively stable water masses where repeated phytoplankton blooms occur, oxygen depletion of bottom waters can occur.

This, of course, is what has happened in the Kattegat and the consequences – dead lobsters and other bottom dwelling animals as well as a decrease in the fisheries of demersal species – are well known.

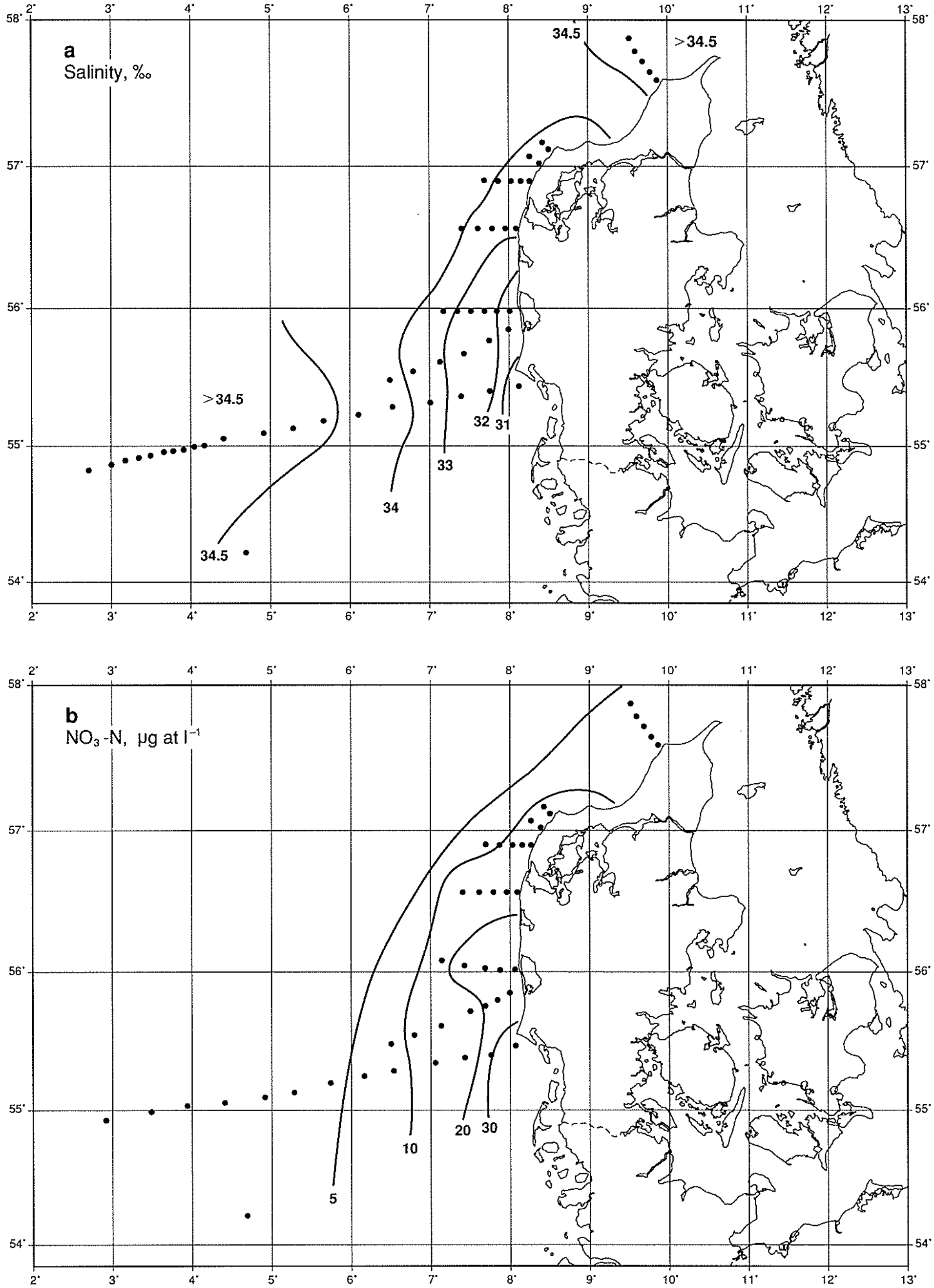

Fig. 2. a: Surface salinity ‰; b: Surface NO_3-N, μg at l^{-1}.
Data collected by Danish Institute for Fisheries and Marine Research 24 February-2 March 1987.
Dots represent sampling stations (From Richardson & Olsen, 1987).

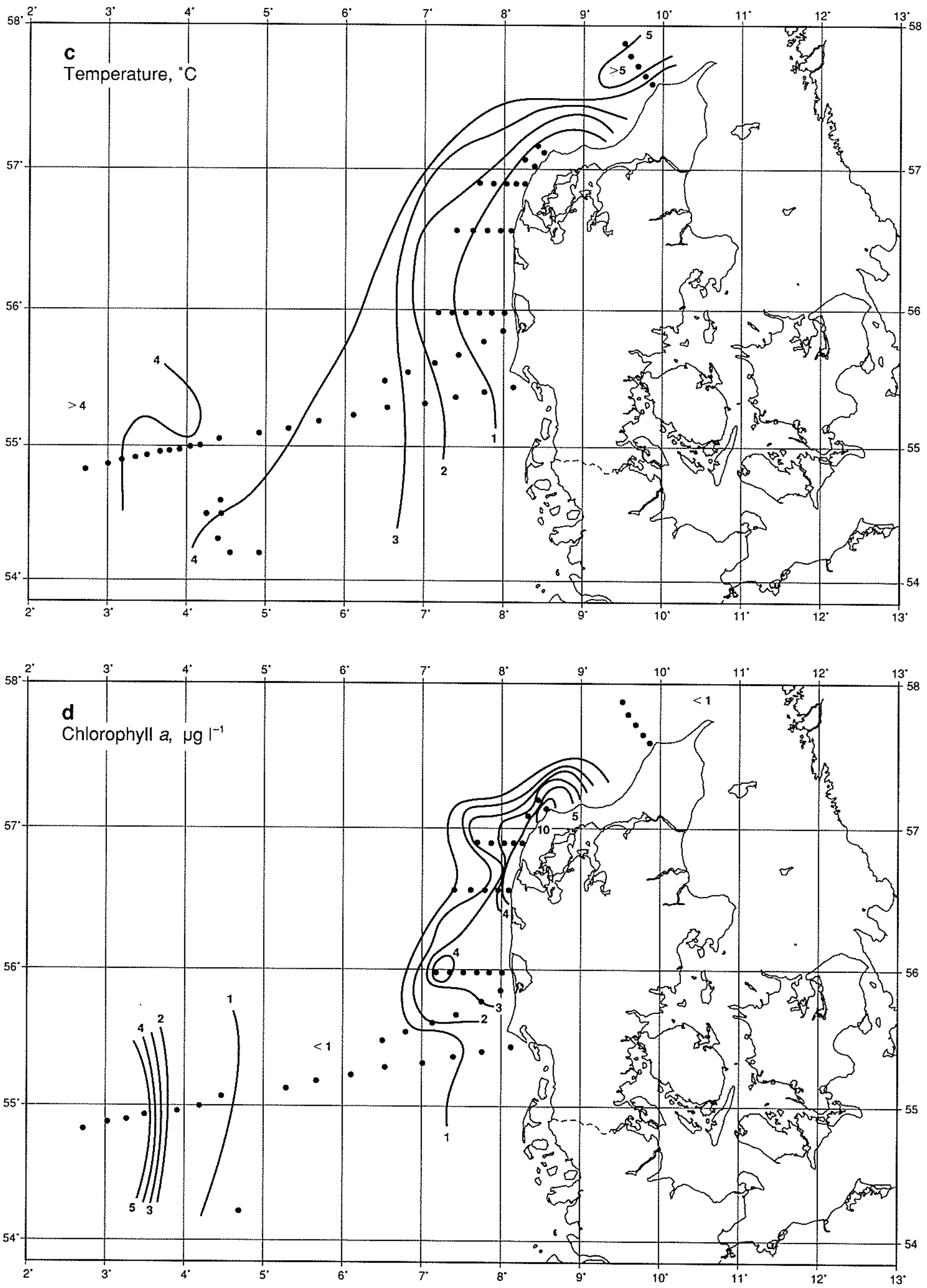

Fig. 2. c: Surface temperature, °C; d: Surface chlorophyll a, $\mu g\ l^{-1}$.
Data collected by Danish Institute for Fisheries and Marine Research 24 February-2 March 1987.
Dots represent sampling stations (From Richardson & Olsen, 1987).

Oxygen depletion events in the North Sea

What is less often appreciated is that oxygen depletion events have also occurred in the North Sea in the coastal waters off the Danish coast. These events were recorded in 1981, 1982 and 1983 (Fig. 3) before the Danish press became aware of the phenomenon and we heard rather less about these oxygen depletion events than we have about those in the Kattegat. Repeated oxygen depletion events, however, would be just as serious in the North Sea as they are in the Kattegat and the region which has been seen to be affected by oxygen depletion is an important spawning, juvenile and/or fishing ground for a number of commercially important fish species including cod, whiting, plaice, sole, turbot, herring, sprat, and sandeel.

Fish, themselves, are seldom directly killed by oxygen depletion (unless they are retained in the affected area by a net or cage). However, those fish that feed primarily on bottom dwelling organisms (i.e. plaice, dab, sole) can be severely affected in that the organisms they feed upon are killed. In addition, the stress incurred by fish from, for example, experiencing low oxygen tensions or starvation following oxygen depletion is believed to be a contributing factor to the development of disease in these fish and, indeed, the areas off the Danish west coast that experienced oxygen depletion in the early 80's are regions where high disease frequencies have been observed compared to regions where oxygen depletion has not been recorded (Fig. 4).

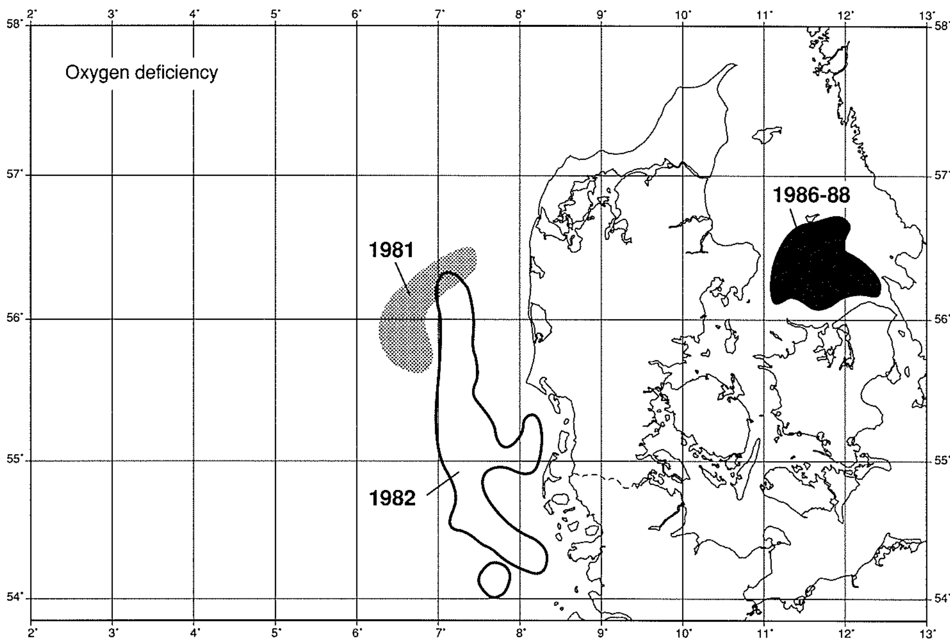

Fig. 3. Marine areas around Denmark affected by oxygen depletion. The oxygen depletion recorded in 1983 in the eastern North Sea is included within the area affected by oxygen depletion in 1982 shown on the map. (From Nielsen & Mellergaard, 1989).

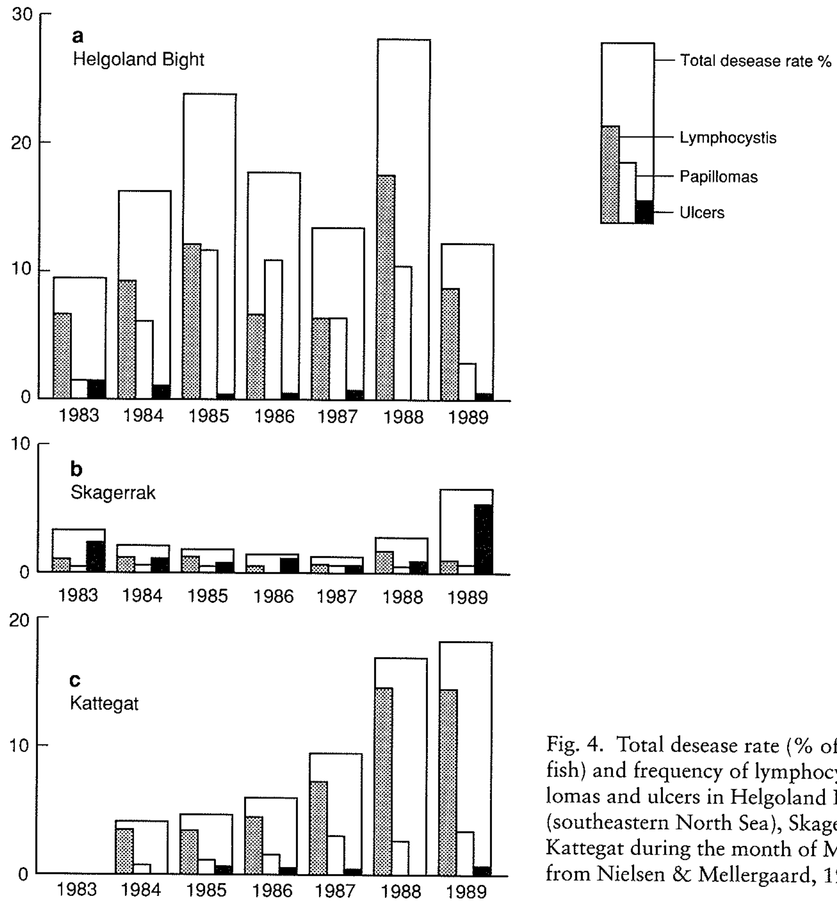

Fig. 4. Total desease rate (% of affected fish) and frequency of lymphocystis, papillomas and ulcers in Helgoland Bight (southeastern North Sea), Skagerrak and Kattegat during the month of May. (Data from Nielsen & Mellergaard, 1989).

Although oxygen depletion events in the North Sea have apparently not been recorded since 1983, the fact that they have occurred is evidence that they can develop and, in the coastal regions of the North Sea where nutrient concentrations due to anthropogenic influences are high and phytoplankton blooms frequent, we must expect oxygen depletion events to occur more and more often and with serious consequences for the fish populations that inhabit these regions. Thus, although man can reasonably argue that the North Sea *as a whole* is only slightly affected by eutrophication and the associated algal blooms and oxygen depletion events, there is every good reason for a fishing nation to be alarmed and express concern over the continued fertilization of the coastal waters of the North Sea!

Other effects of eutrophication on the environment

In addition to increasing the intensity and frequency of exceptional algal blooms and oxygen depletion events, it has been suggested that an increase in nutrient concentrations in the marine environment will cause a shift in the species comprising the algal community (cf. Brockmann *et al.*, 1988). This shift should be in the direction of decreased species diversity and an increase in importance of flagellates in the population as a whole. As flagellates tend to be smaller than many other algal groups, this shift will have consequences in the size structure of the community and it is not inconceivable that the food web as it exists today can be altered so that the preferred food items for some fish species are not able to survive. Thus, a change in algal species composition can, in theory, have drastic consequences throughout the food web.

It has also been suggested that the increase in phytoplankton biomass and, hence, photosynthesis in the North Sea has led to a significant increase in the air pollution which leads to acid rain in that sulphur containing compounds are given off by phytoplankton (Pearce, 1988). Others (Laane *et al.*, 1989) have calculated that the increase in sulphur production (4%) from plankton production in the North Sea is probably unimportant compared with increases in sulphur dioxide production from terrestrial sources. Nevertheless, the message is clear: seemingly small changes in the marine environment can have far reaching and unexpected consequences.

Conclusions

Toxic blooms (both of toxic and non-toxic species) are a perfectly natural and important part of the ecosystem in the North Sea. However, eutrophication (enrichment of the aquatic environment with mineral nutrients) from anthropogenic sources has apparently given rise to an increase in the intensity and frequency of algal blooms in coastal regions of the North Sea. Such an increase in bloom activity can increase the frequency of oxygen depletion events and, thus, have serious consequences for those fish resources in the North Sea that utilize coastal regions for their spawning and feeding grounds. For the protection of the North Sea fisheries and ecology, the eutrophication of North Sea coastal waters must not be allowed to continue unchecked.

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