

Short communication

Establishment of thermophilic phytoplankton species in the North Sea: biological indicators of climatic changes?

Stefan Nehring



Nehring, S. 1998. Short communication: Establishment of thermophilic phytoplankton species in the North Sea: biological indicators of climatic changes? – ICES Journal of Marine Science, 55: 818–823.

Since the beginning of the 20th century, 16 non-indigenous phytoplankton species have become an integrated part of the pelagic system of the North Sea. Among them, 10 thermophilic species were first recorded during the last decade, assumed transported by currents from southern regions. It is suggested that the relatively mild winters during recent years may have been an important factor for their successful establishment. The permanent colonization of the North Sea by species from lower latitudes may be a biological signal of subtle changes in the climate. This issue may be clarified by the analysis of resting stages of plankton organisms in bottom sediments.

© 1998 International Council for the Exploration of the Sea

Key words: climate change, German Bight, immigrants, North Atlantic Oscillation index, North Sea, phytoplankton, temperature.

Stefan Nehring: Bundesanstalt für Gewässerkunde, Kaiserin-Augusta-Anlagen 15–17, 56068 Koblenz, Germany. Tel: +49 261 1306 5474, fax: +49 261 1306 5374, e-mail: nehring@bafg.de

Introduction

The apparent world-wide increase in frequency and dispersion of exceptional phytoplankton blooms may, through the release of toxins, oxygen depletion, and deteriorating bathing water quality, create significant economic losses in aquaculture, fishery, and tourism. High nutrient inputs in coastal waters are held largely responsible for the successful establishment and enhancement of nuisance species (Smayda, 1990). However, other factors may be involved, and the possible effects of global warming are of particular interest.

The inventories of North Sea phytoplankton made over more than 100 years (e.g. Cleve, 1900) indicate that occasionally ‘new’ species have been identified in the area which were previously only known from other regions. This contribution is aimed at a review of newly recorded phytoplankton species and their origin in order to address the question whether, apart from effects of eutrophication, the observed changes may be related to long-term trends in climate.

Results

The appearance of a new species in plankton samples can have different causes and four categories may be distinguished.

(a) *Uncertain taxonomic status:* As long as there is taxonomic uncertainty about the status of a particular form, assessing its ecological status and origin is obviously problematic. In this context, the taxonomic status of *Gymnodinium catenatum* and *Gyrodinium aureolum* in the North Sea is presently under discussion (Nehring, 1995; Partensky *et al.*, 1991).

(b) *Previously overlooked species:* Old records may not have documented the existence of a particular species and are thus incomplete, because sampling methods (mesh size) and preservation techniques (strong fixatives) were inadequate. With the increased interest in plankton monitoring, the scientific community is better equipped and more alert for signs and symptoms of plankton blooms. However, because of increased attention for ‘new’ species, a careful check should be made as to whether a species may have occurred in the

area before. For conspicuous species, this is generally no problem, but inconspicuous species like *Chrysochromulina*, *Pseudo-nitzschia*, or *Scrippsiella* are suspect for having been overlooked (e.g. Nehring, 1994; Hasle *et al.*, 1996; Vrieling *et al.*, 1996). Absolute certainty can only be obtained by re-examining historic samples. However, there is always the possibility that a species has been overlooked because of extremely low abundance.

(c) *Temporary immigrants*: Atlantic species such as *Dinophysis odiosa* and *Rhizosolenia robusta* may be transported irregularly by currents into the North Sea. However, relatively low water temperatures in winter and the absence of particular trace elements, etc., prevent the development of permanent populations. For other species (e.g. *Corymbellus aureus*, Gieskes and Kraay, 1986; *Gonyaulax polyedra*, *Phaeopolykrikos hartmannii*, and *Protoperdinium compressum*, Nehring, 1997), it is not yet clear what their status as immigrants is.

(d) *Permanently established immigrants*: A review of the available literature suggests that 16 non-indigenous phytoplankton species have become permanently established immigrants (Table 1). Of these, 13 have colonized the German Bight, corresponding to an increase of about 1% in the number of phytoplankton species found in this area. A detailed discussion of the likely region of origin and the transport vectors involved is given by Nehring (1998). Newcomers may affect the structure and functioning of the pelagic system, for instance by their nutrient uptake characteristics, edibility, repression of indigenous species, release of toxins, or other properties. So far, only a few studies have addressed the impact of alien species (e.g. Rick and Dürselen, 1995; Hesse *et al.*, 1996). It should be noted that the time span since the establishment of several species in the North Sea is relatively short and therefore the permanent character is still uncertain. For example, mild winters may have enabled *Corethron criophilum* and *Rhizosolenia indica*, also indicators of Atlantic water (e.g., Drebes and Elbrächter, 1976), to colonize coastal areas (Cadée and Hegemann, 1991; Drebes, 1991), although it is questionable whether they will survive a severe winter. The term is used here to indicate that they appear regularly and frequently in samples since their first recordings.

Discussion

The factors enabling alien species to establish permanent populations cannot easily be identified because of the large number of factors determining the ecological niche of a species. Besides chemical factors (e.g., shifts in nutrients), physical factors may be involved which are related to local or global climatic conditions. Changes in the North Atlantic current system may affect temperature and salinity conditions in the North Sea and

changes in wind conditions may influence dispersal of organisms (e.g. Aebischer *et al.*, 1990; Aurich, 1953). However, changes in species composition might reflect potential effects of global warming.

Prognoses of faunal shifts in aquatic systems as a consequence of the greenhouse effect (e.g., a suggested increase by 20–40% in macrozoobenthos species number in the Wadden Sea in response to a 2–4°C increase in temperature; Reise, 1993) still have a hypothetical character. Nevertheless, the establishment of 10 non-indigenous ‘thermophilic’ (i.e., species that are normally found in more southerly and warmer waters) phytoplankton species in the North Sea during recent years coincides with a period of slightly increased sea surface temperature anomalies in the northern oceans (Houghton *et al.*, 1992; Fig. 1). A comprehensive analysis by Becker and Pauly (1996) did not identify a distinct trend in mean temperature in the North Sea, but the mildest winters of the past 50, and perhaps even 130, years in the North Sea area occurred between 1989 and 1994. A time series of water temperature measured in the German Bight shows an overall increase by 1°C over the period 1962–1984 (Radach *et al.*, 1990). However, the observed increases are within the expected natural variability and therefore a warming trend cannot be ascertained. Nevertheless, the establishment of an unusual number of thermophilic phytoplankton species in the North Sea ecosystem may be a sensitive indicator of changes that are not evident in the temperature record. The winters of 1983, 1989, and 1990 were marked by the highest positive values of the North Atlantic Oscillation (NAO) index recorded since 1864 (Hurrell, 1995). A positive NAO index indicates that the wind across the North Atlantic had a strong westerly component, resulting in higher winter temperatures in Europe than normal (Hurrell, 1995).

The increased influx of Atlantic Water through the English Channel in 1989–1991 (Becker and Dooley, 1995), through its effects on initial population abundance, may be a further factor that has contributed to the establishment of non-indigenous plankton species from more southerly regions. In addition, temperatures during the cold season seem a crucial factor for their prolonged presence.

The results confirm that long-term studies of phytoplankton species diversity provide an important contribution to climate impact research (cf. Lange *et al.*, 1992; Robinson and Hunt, 1986), because species composition appears to be a sensitive indicator of subtle changes in the temperature conditions. A climatic indicator function has also been attributed to other key pelagic organisms. In recent years, the thermophilic siphonophore *Muggiaea atlantica* and the cladoceran *Penilia avirostris* have entered the North Sea (Greve *et al.*, 1996). Also, several southern fish species have shown increased abundance in the southern North Sea (Corten and van de Kamp, 1996).

Table 1. Permanently established phytoplankton species with indication of supposed year of settlement in the North Sea (N.S.) and the German Bight (G.B), supposed region of origin, suggested transport vector, and occurrence in the German Bight (†thermophilic; *potentially toxic).

Species	Year	G.B.	Origin	Transport vector	Occurrence G.B.	References ¹
Bacillariophyceae						
<i>Corethron criophilum</i>	? 1990	1990	North Atlantic	Currents	Occasional	Drebes (1991)
<i>Coscinodiscus wailesii</i>	1977/78 ²	1978	Indo-pacific	Aquaculture	Regular with outbreaks	Boalch and Harbour (1977)
<i>Odontella sinensis</i>	1903	1903	Indo-pacific	Ballast water	Frequent	Ostenfeld (1908)
<i>Rhizosolenia indica</i> †	1989	1989	Atlantic	Currents	Frequent	Cadée and Hegeman (1991)
<i>Stephanopyxis palmeriana</i> †	1990	1990	Mediterranean	Currents	Occasional	Drebes (1991)
<i>Thalassiosira hendeyi</i> †	1978	1995	South Atlantic	Currents	Frequent	U. Tillmann (pers. comm.)
<i>Thalassiosira punctigera</i>	1979	1981	Indo-pacific	Aquaculture	Frequent	Kat (1982)
Dinophyceae						
<i>Alexandrium minutum</i> †*	1985/92 ²	1992 ³	Mediterranean	Currents	—	TRIPOS (1993)
<i>Gymnodinium catenatum</i> †* ⁴	1983/91 ²	1991	Northern Spain	Currents	Living cysts only	Nehring (1995)
<i>Gymnodinium chlorophorum</i> †	1990	1990	River Loire estuary	Currents	Outbreak	Nehring <i>et al.</i> (1995)
<i>Gyrodinium aureolum</i> †*	1966	1968	? West Atlantic	Ballast water?	Frequent	Braarud and Heimdahl (1970)
<i>Prorocentrum redfieldii</i>	1961	1992	?	?	Frequent	Kat (1979)
Raphidophyceae						
<i>Chattonella antiqua</i> †*	1991	1991 ³	?	?	—	Peperzak <i>et al.</i> (1996)
<i>Chattonella marina</i> †*	1991	1991 ³	?	?	—	Peperzak <i>et al.</i> (1996)
<i>Fibrocapsa japonica</i> †*	1991	1992	?	?	Occasional	Vrieling <i>et al.</i> (1995b)
<i>Heterosigma akashiwo</i> †*	? 1993	1993	?	?	Frequent	Rademaker <i>et al.</i> (1995)

¹For expanded list of references, see Nehring (1998).

²First year indicates record from the English Channel.

³Years of establishment in the German Bight refer to Dutch waters, directly west of the German Bight.

⁴Taxonomic status uncertain (see text).

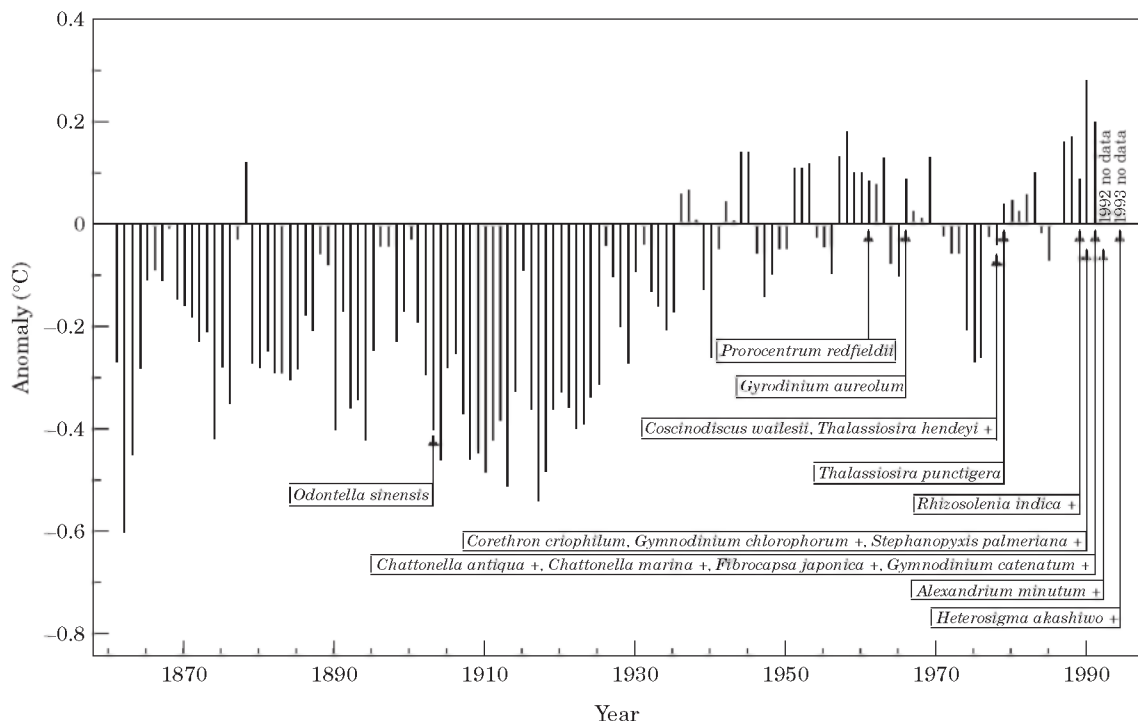


Figure 1. Time series of northern hemisphere sea surface water temperature anomalies (1861–1991) relative to 1951–1980 (after Houghton *et al.*, 1992) with indication of the first year of permanent establishment of non-indigenous phytoplankton species in the North Sea (+ thermophilic).

A better understanding of the impacts of climate on the development of plankton populations and species composition on time scales of some decades to several thousands of years might be gained from the analysis of fossilized resting forms in dated sediment depth cores. Dale *et al.* (1993) found subfossil cysts of *Gymnodinium catenatum* in Kattegat/Skagerrak sediments from a period between ~6000 and 300 BP and suggested that inflow of warmer waters in prehistoric times contributed to the occurrence of 'fossil blooms' of the species. Cooling during the 'Little Ice Age' ~300 BP may have been the cause of its disappearance (Dale and Nordberg, 1993). In recent years, the appearance of living cysts and/or vegetative cells in surveys off Danish, Dutch, French, German, and Swedish coasts (e.g. Nehring, 1995, 1996; Peperzak *et al.*, 1996) suggest that northern European waters have been recolonized.

However, because vegetative cells and also cysts show small morphological variations compared to the organisms from the type locality in northern Spain, the taxonomic status of *G. catenatum* found in the North Sea is uncertain (Nehring, 1995): (i) if it is the same species, its recent establishment is likely due to immigration by current transport from Spanish waters, or (ii) if it is a different species, it is probably a relict that

survived somewhere in areas adjacent to the North Sea from prehistoric times (cf. Dale *et al.*, 1993). In both cases, changed environmental conditions may have enabled this thermophilic species to (re-)colonize the North Sea and adjacent waters.

Partensky *et al.* (1991) questioned the taxonomic identity of *G. aureolum* described from the western North Atlantic by Hulburt (1957) and the species recorded in the eastern Atlantic in 1966 on the SW coast of Norway (Braarud and Heimdal, 1970). The European form appears to have a stronger affinity with *G. mikimotoi* (synonym *G. nagasakiense*), a toxic bloom-forming species from the Pacific (e.g. Takayama and Adachi, 1984), than with the original description of *G. aureolum* by Hulburt (Steidinger and Tangen, 1996). Immunochemical studies show that the European form and *G. mikimotoi* cannot be distinguished (Vrieling *et al.*, 1995a), but other results suggest that the American and European forms might be different morphotypes of the same species (Blasco *et al.*, 1996).

Acknowledgements

Comments by K.-J. Hesse are greatly appreciated.

References

- Aebischer, N. J., Coulson, J. C., and Colebrook, J. M. 1990. Parallel long-term trends across four marine trophic levels and weather. *Nature*, 347: 753–755.
- Aurich, H. J. 1953. Verbreitung und Laichverhältnisse von Sardelle und Sardine in der südöstlichen Nordsee und ihre Veränderung als Folge der Klimaänderung. *Helgoländer wissenschaftliche Meeresuntersuchungen*, 4: 175–204.
- Becker, G. A., and Dooley, H. D. 1995. The 1989/91 high salinity anomaly in the North Sea and adjacent areas. *Ocean Challenge*, 6: 3–4.
- Becker, G. A., and Pauly, M. 1996. Sea surface temperature changes in the North Sea and their causes. *ICES Journal of Marine Science*, 53: 887–898.
- Blasco, D., Bérard-Therriault, L., Levasseur, M., and Vrieling, E. G. 1996. Temporal and spatial distribution of the ichthyotoxic dinoflagellate *Gyrodinium aureolum* Hulburt in the St Lawrence, Canada. *Journal of Plankton Research*, 18: 1917–1930.
- Boalch, G. T., and Harbour, D. S. 1977. Unusual diatom off the coast of south-west England and its effect on fishing. *Nature*, 269: 687–688.
- Braarud, T., and Heimdal, B. R. 1970. Brown water on the Norwegian coast in autumn 1966. *Nytt Magasin for Botanikk*, 17: 91–97.
- Cadée, G. C., and Hegeman, J. 1991. Phytoplankton and primary production, chlorophyll and species composition, organic carbon and turbidity in the Marsdiep in 1990, compared with foregoing years. *Hydrobiological Bulletin*, 25: 29–35.
- Cleve, P. T. 1900. The plankton of the North Sea, the English Channel and the Skagerrak. *Kongliga Svenska Vetenskaps-Akademiens Handlingar*, 32(8): 1–53.
- Corten, A., and van de Kamp, G. 1996. Variation in the abundance of southern fish species in the southern North Sea in relation to hydrography and wind. *ICES Journal of Marine Science*, 53: 1113–1119.
- Dale, B., Madsen, A., Nordberg, K., and Thorsen, T. A. 1993. Evidence for prehistoric and historic “blooms” of the toxic dinoflagellate *Gymnodinium catenatum* in the Kattegat-Skagerrak region of Scandinavia. In *Toxic phytoplankton blooms in the sea. Developments in marine biology*, 3, pp. 47–52. Ed. by T. J. Smayda and Y. Shimizu. Elsevier, Amsterdam.
- Dale, B., and Nordberg, K. 1993. Possible environmental factors regulating prehistoric and historic “blooms” of the toxic dinoflagellate *Gymnodinium catenatum* in the Kattegat/Skagerrak region of Scandinavia. In *Toxic phytoplankton blooms in the sea. Developments in marine biology*, 3, pp. 53–57. Ed. by T. J. Smayda and Y. Shimizu. Elsevier, Amsterdam.
- Drebes, G. 1991. Neue Planktondiatomeen im Sylter Wattenmeer. *Jahresbericht der Biologischen Anstalt Helgoland*, 1990: 29–30.
- Drebes, G., and Elbrächter, M. 1976. A checklist of planktonic diatoms and dinoflagellates from Helgoland and List (Sylt), German Bight. *Botanica Marina*, 19: 75–83.
- Gieskes, W. W. C., and Kraay, G. W. 1986. Analysis of phytoplankton pigments by HPLC before, during and after mass occurrence of the microflagellate *Corymbellus aureus* during the spring bloom in the open northern North Sea in 1983. *Marine Biology*, 92: 45–52.
- Greve, W., Reinert, F., and Nast, J. 1996. Biocoenotic changes of the zooplankton in the German Bight: the possible effects of eutrophication and climate. *ICES Journal of Marine Science*, 53: 951–956.
- Hasle, G. R., Lange, C. B., and Syvertsen, E. E. 1996. A review of *Pseudo-nitzschia*, with special reference to the Skagerrak, North Atlantic, and adjacent waters. *Helgoländer Meeresuntersuchungen*, 50: 131–175.
- Hesse, K.-J., Tillmann, U., Nehring, S., and Brockmann, U. 1996. Specific factors controlling phytoplankton distribution in coastal waters of the German Bight (North Sea). In *Biology and ecology of shallow coastal waters*, pp. 11–22. Ed. by A. Eleftheriou, A. D. Ansell, and C. J. Smith. Olsen & Olsen, Fredensborg, Denmark.
- Houghton, J. T., Callander, B. A., and Varney, S. K. (Eds.) 1992. Climate change 1992: The supplementary report to the IPCC scientific assessment. Intergovernmental Panel on Climate Change. Cambridge University Press. 200 pp.
- Hulburt, E. M. 1957. The taxonomy of unarmored Dinophyceae of shallow embayments on Cape Cod, Massachusetts. *Biological Bulletin (Woods Hole)*, 112: 196–219.
- Hurrell, J. W. 1995. Decadal trends in the North Atlantic Oscillation: regional temperatures and precipitation. *Science*, 269: 676–679.
- Kat, M. 1979. The occurrence of *Prorocentrum* species and coincidental gastrointestinal illness of mussel consumers. In *Toxic dinoflagellate blooms*, pp. 215–220. Ed. by D. L. Taylor and H. H. Seliger. Elsevier, Amsterdam.
- Kat, M. 1982. Effects of fluctuating salinities on the development of *Thalassiosira angustii*, a diatom not observed before in the Dutch coastal area. *Journal of the Marine Biological Association of the United Kingdom*, 62: 483–484.
- Lange, C. B., Hasle, G. R., and Syvertsen, E. E. 1992. Seasonal cycle of diatoms in the Skagerrak, North Atlantic, with emphasis on the period 1980–1990. *Sarsia*, 77: 173–187.
- Nehring, S. 1994. *Scrippsiella* spp. resting cysts from the German Bight (North Sea): A tool for more complete check-lists of dinoflagellates. *Netherlands Journal of Sea Research*, 33: 57–63.
- Nehring, S. 1995. *Gymnodinium catenatum* Graham (Dinophyceae) in Europe: A growing problem? *Journal of Plankton Research*, 17: 85–102.
- Nehring, S. 1996. Recruitment of planktonic dinoflagellates: importance of benthic resting cysts and resuspension events. *Internationale Revue der gesamten Hydrobiologie*, 81: 513–527.
- Nehring, S. 1997. Dinoflagellate resting cysts from Recent German coastal sediments. *Botanica Marina*, 40: 307–324.
- Nehring, S. 1998. Non-indigenous phytoplankton species in the North Sea: supposed region of origin and possible transport vector. *Archive of Fishery and Marine Research* (in press).
- Nehring, S., Hesse, K.-J., and Tillmann, U. 1995. The German Wadden Sea: A problem area for nuisance blooms? In *Harmful Marine Algal Blooms*, pp. 199–204. Ed. by P. Lassus, G. Arzul, E. Erard, P. Gentien, and C. Marcaillou. Lavoisier, Paris.
- Ostenfeld, C. H. 1908. On the immigration of *Biddulphia sinensis* Grev. and its occurrence in the North Sea during 1903–1907 and on its use for the study of the direction and rate of flow of the currents. *Meddelelser fra Kommissionen for Havundersgelser, Serie Plankton*, 1(6): 1–44.
- Partensky, F., Gentien, P., and Sournia, A. 1991. *Gymnodinium* cf. *nagasakiense*=*Gyrodinium* cf. *aureolum* (Dinophycées). In *Le phytoplankton nuisible des côtes de France, de la biologie à la prévention*, pp. 63–82. Ed. by A. Sournia. IFREMER, Brest, France.
- Peperzak, L., Verreussel, R., Zonneveld, K. A. F., Zevenboom, W., and Dijkema, R. 1996. The distribution of flagellate cysts on the Dutch continental shelf (North Sea) with emphasis on

- Alexandrium* spp. and *Gymnodinium catenatum*. In Harmful and toxic algal blooms, pp. 169–172. Ed. by T. Yasumoto, Y. Oshima, and Y. Fukuyo. UNESCO, Paris.
- Radach, G., Berg, J., and Hagmeier, E. 1990. Long-term changes of the annual cycles of meteorological, hydrographic, nutrient and phytoplankton time series at Helgoland and at LV ELBE 1 in the German Bight. *Continental Shelf Research*, 10: 305–328.
- Rademaker, M., Janmaat, L., Zevenboom, W., and de Jong, B. 1995. Potentially toxic algae along the Dutch coast in 1994. *Harmful Algae News*, UNESCO IOC Newsletter, 10/11: 2.
- Reise, K. 1993. Die verschwommene Zukunft der Nordseewatten. In *Klimaänderung und Küste – Einblick ins Treibhaus*, pp. 223–229. Ed. by H. J. Schellnhuber and H. Sterr. Springer-Verlag, Berlin.
- Rick, H.-J., and Dürselen, C.-D. 1995. Importance and abundance of the recently established species *Coscinodiscus wailesii* Gran & Angst in the German Bight. *Helgoländer Meeresuntersuchungen*, 49: 355–374.
- Robinson, G. A., and Hunt, H. G. 1986. Continuous plankton records: annual fluctuations of the plankton in the western English Channel, 1958–83. *Journal of the Marine Biological Association of the United Kingdom*, 66: 791–802.
- Smayda, T. J. 1990. Novel and nuisance phytoplankton blooms in the sea: evidence for a global epidemic. In *Toxic marine phytoplankton*, pp. 29–40. Ed. by E. Granéli, B. Sundström, L. Edler, and D. M. Anderson. Elsevier, Amsterdam.
- Steidinger, K. A., and Tangen, K. 1996. Dinoflagellates. In *Identifying marine diatoms and dinoflagellates*, pp. 387–570. Ed. by C. R. Tomas. Academic Press, London.
- Takayama, H., and Adachi, R. 1984. *Gymnodinium nagasakiense* sp. nov., a red tide forming dinophyte in the adjacent waters of Japan. *Bulletin of the Plankton Society of Japan*, 31: 7–14.
- TRIPOS 1993. Biomonitoring van fytoplankton in de Nederlandse zoute en brakke wateren 1992. Rijkswaterstaat Dienst Getijdewateren, Rapport 1992. 123 pp.
- Vrieling, E. G., Gieskes, W. W. C., Rademaker, T. W. M., Vriezekolk, G., Peperzak, L., and Veenhuis, M. 1995a. Flow cytometric identification of the ichthyotoxic dinoflagellate *Gyrodinium aureolum* in the central North Sea. In *Harmful marine algal blooms*, pp. 743–748. Ed. by P. Lassus, G. Arzul, E. Erard, P. Gentien, and C. Marcaillou. Lavoisier, Paris.
- Vrieling, E. G., Koeman, R. P. T., Nagasaki, K., Ishida, Y., Peperzak, L., Gieskes, W. W. C., and Veenhuis, M. 1995b. *Chattonella* und *Fibrocapsa* (Raphidophyceae): First observation of potentially harmful, red tide organisms in Dutch coastal waters. *Netherlands Journal of Sea Research*, 33: 183–191.
- Vrieling, E. G., Koeman, R. P. T., Peperzak, L., Veenhuis, M., Scheerman, P., and Gieskes, W. W. C. 1996. *Pseudo-nitzschia pungens* forma *multiseries* and other *Pseudo-nitzschia* species in the Dutch Wadden Sea. In *Harmful and toxic algal blooms*, pp. 139–142. Ed. by T. Yasumoto, Y. Oshima, and Y. Fukuyo. UNESCO, Paris.