

Eutrophication and recent changes in macrophytic vegetation in the Western Baltic (Kiel Bay)

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Abstract

Important growth of seaweeds and oxygen depletions were observed since 1970. During this time, budget in N and P remained rather unchanged in spite of increasing arrival of nutrients especially nitrogen. Among the compensatory responses of the environment, many changes in the macroalgae pattern and biomass can be observed, such as the appearance of "opportunistic" seaweeds and progressive disappearance of algae of the genera *Furcellaria* or *Fucus*.

Introduction

Kiel bay, the westernmost area of the Western Baltic covers 1571 km². Together with the Belt Sea it is part of the transition zone between the Central Baltic and the North Sea, which is characterized by pronounced fluctuations of salinity, temperature and nutrient levels (Fig. 1).

Since the 70ths, in Kiel Bay like in many other parts of the Baltic, some changes were observed, which were suspected to be a result of eutrophication processes :

1) Increasing mass development or blooms of finely branched seaweeds.

2) Repeated and increasing oxygen depletion in the deeper areas of the Western Baltic. In 1981, oxygen depletion and H₂S development was observed in Kiel Bay and Mecklenburg Bay, devastating major portions of the bottom fauna (Ehrhard & Wenck 1984, Weigelt & Rumohr 1986).

Because of these alarming signs, in 1983 an interdisciplinary research project was initiated to study from different point of views the eutrophication situation and processes in the German waters of the Baltic (UBA Wasser N° 10204215 : Eutrophication of the Baltic and the North Sea).

In the study presented here, possible effects of eutrophication on the benthic vegetation, and the role of benthic macrophytes in eutrophication processes in Kiel Bay were investigated.

Evolution of nutrient concentration in Kiel Bay

To characterize the nutrient situation in Kiel Bay, it must be taken into account that strong fluctuations of nutrients are typical for the Baltic due to seasonal variation of primary production and remineralisation processes. In summer, nutrients in the water column become depleted nearly to detection limits as a result of the activity of primary producers.

Therefore, for long-term trend analyses, nutrient concentrations are only comparable during the winter months, when the water column is well mixed and no plankton blooms occur.

Long-term observations in Kiel Bay, the earliest beginning in the late 50ths, are only available for a nearshore station (Boknis) in the inner western part (Krey *et al.* 1978, Bodungen 1986) and for the northern Fehmarn belt area (Aertebjerg-Nielsen 1985).

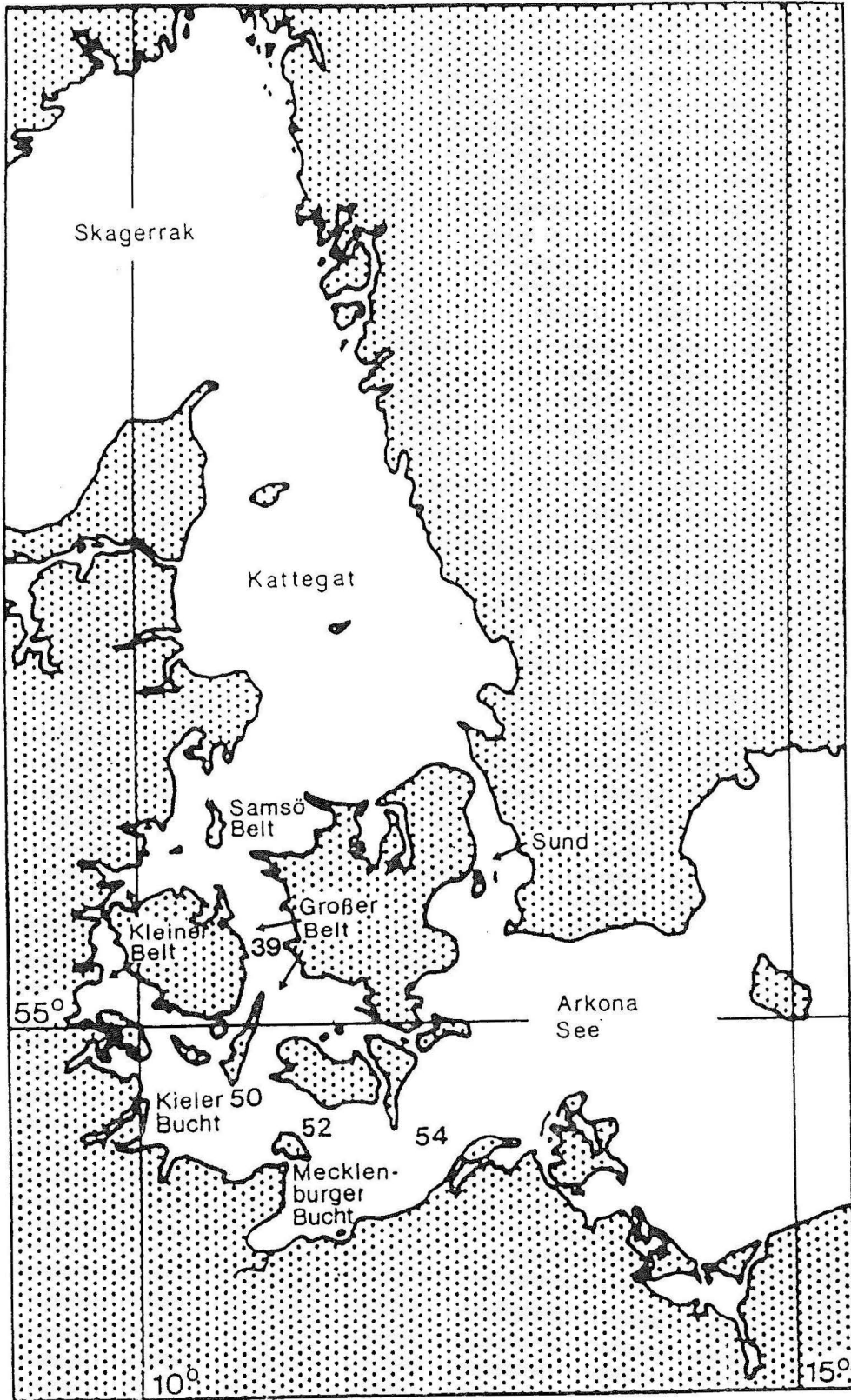


Fig. 1. Investigation area Kiel Bay (Western Baltic Sea).

Significant increase in total P by ca $0.1 \mu\text{mol dm}^{-3} \text{ year}^{-1}$ and in dissolved inorganic N by $0.4 \mu\text{mol dm}^{-3} \text{ year}^{-1}$, respectively, was observed in the Fehmarn area from 1975-1984. In contrast, in the inner Kiel bay (Station Boknis), inorganic N in January/February was on average $12.7 \mu\text{mol dm}^{-3}$ without significant changes. At this station, also total P remained unchanged at a mean concentration of $1.23 \mu\text{mol dm}^{-3}$ during 1958-75, despite of increasing land run-off as a result of growing use of fertilizers and abolition of septic tanks. In 1980-84, on the other hand, mean total P concentration in the winter water increased to $1.94 \mu\text{mol dm}^{-3}$, although the input of anthropogenic P was significantly reduced as a result of increasing waste water treatment with P precipitation during this period.

One of the major causes for the observed increasing nutrient concentration may be the inflow of nutrient rich water from the Central Baltic, where nutrient concentration in the winter water has threefold increased during the period from 1969-80 (Nehring 1984). On the basis of various model calculations (e.g. Aertebjerg-Nielsen *et al.* 1981), Gerlach (1986, 1990) estimates a daily inflow of 5 t inorganic P or 25 t N. From 1969 to 1983 this daily load has increased by 1.5 t P or 4.5 t N, respectively. Nutrient input into Kiel Bay from land run-off has been estimated as on average 4 t P/day and 35 t P/day (Gerlach 1990, based on Brandt 1974, Baltic Environment protection Commission 1987). In addition, approximately 14 t N/day enter Kiel bay as outfall from the polluted atmosphere. Compared to the 1430 t P and 5900 t N contained in the 42 km^3 winterwater of the 1571 km^2 large Kiel Bay in 1975, the estimated annual total input of 17800 t N from land and from the atmosphere should be significant, whereas the additional 1500 t of P per year may be of lesser importance.

The considerable inputs on the one side, and the somehow contradictory observed trends of nutrient concentrations during the past two decades on the other side, have been discussed by Gerlach (1986, 1990). He concludes that several elimination processes may be effective. Based on data by Balzer & Kähler (1989), it can be calculated that through denitrification about 3451 t N, and through accumulation in the sediments 1443 t N and 367 t P are removed from the system per year.

As total elimination through denitrification and sedimentation ($\approx 5000 \text{ t N}$, $\approx 370 \text{ t P}$) cannot balance the input from land and atmosphere ($\approx 18000 \text{ t N}$, $\approx 1500 \text{ t P}$), Gerlach assumes that the excess input may be exported with the current passing through Kiel Bay.

All in all, however, we do not yet fully understand the mechanisms, which lead to the rather constant winter equilibrium between input and output. Not yet clear is also the summer situation. Despite of the considerable nutrient inputs, N and P levels did not increase in summer, in fact, they are still near the detection level. Here, most probably primary producers, which first of all should react on additional nutrient supply, play an important role.

Changes of macroalgae pattern and biomass in Kiel Bay

Unfortunately, little information is available on long-term trends of primary production in Kiel Bay. There is some indication that phytoplankton biomass as well as production has doubled during the period from the early 50ths to the late 70ths (Babenard & Zeitzschel 1985). No data are available for benthic microphytes. For macroalgal vegetation a semiquantitative survey was carried out in 1962-64 (Schwenke 1964, 1969). In the framework of our investigations on the role of macrobenthic primary producers in eutrophication processes, in 1965-88 a large scale survey of the benthic vegetation of the Kiel Bay was made by analysis of underwater television observations and samples obtained by divers or by dredging (Schramm 1988). During the past two decades, distinct changes in biomass as well as in species composition have occurred in Kiel Bay. Between 6 and 20 m water depth, biomass has increased above the 12 m level, and has decreased below 12 m depth (Fig. 2). The lower boundary of the vegetation has probably slightly moved upward from 20 to 18 m depth. Species composition and dominance has changed (Table 1). The red alga *Furcellaria lumbricalis*, previously being an important component of the vegetation below 6 m depth, has been replaced almost completely by the red algae *Phyllophora truncata* and *Phycodrys rubens* (Breuer & Schramm 1988). Also in the shallower water from 2-6 m

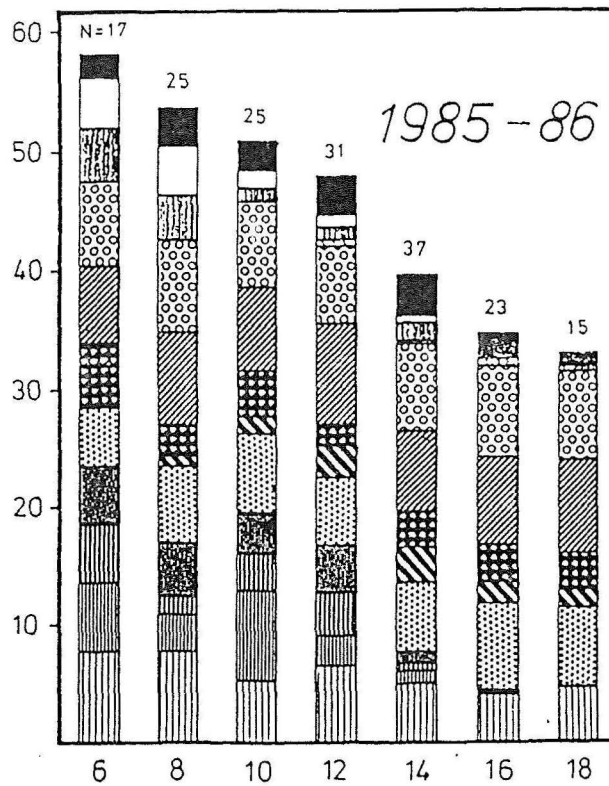
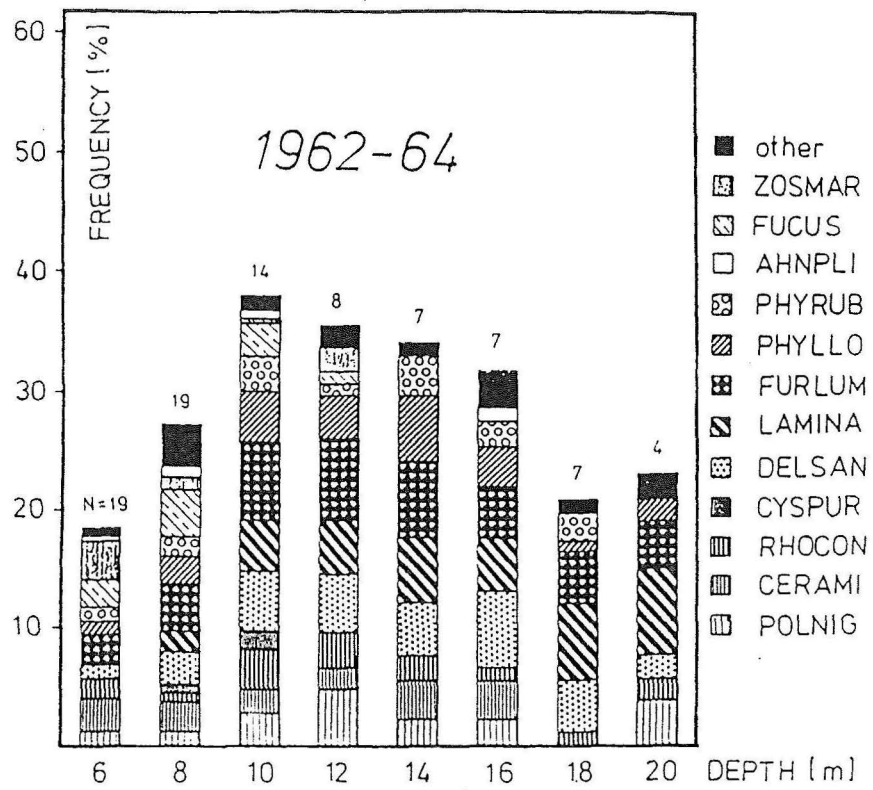


Fig. 2. Kiel Bay (Western Baltic). Biomass and distribution of seaweeds in depths between 6-20m in 1962-64 and 1985-86.

depth, these two red algae together with other finely branched red and brown seaweeds (*Polysiphonia*, *Ceramium*, *Pilayella*, *Ectocarpus*), have spread and replaced *Furcellaria*, in particular *Fucus vesiculosus* and *F. serratus*, formerly being the most important community forming species in this depth range. Whereas *Fucus* was still frequent at depth below 2 m down to 13m in the 70ths (Black 1978), during our investigation *Fucus* was not found in water depths greater than 2 m. Schwenke (1965) used his own observations and Hoffmann's data (Hoffmann 1952) to calculate a total standing crop of nearly 40 000 t wet weight *Fucus* in Kiel Bay in the early 50ths. This amount has decreased to only 2400 t wet weight (*i.e.* 6%) in 1987/88 (Vogt & Schramm 1991, Fig. 3).

Table 1. Dominant seaweed species, at various water depths between 6 and 20 m, in 1962-64 and 1985-86, in Kiel Bay (Western Baltic Sea).

depth	Species	
	1962-64	1985-86
6 m	<i>Zostera marina</i> <i>Fucus serratus</i> <i>Furcellaria lumbricalis</i>	<i>Polysiphonia nigrescens</i> <i>Phyllophora truncata</i>
8 m	<i>Furcellaria lumbricalis</i> <i>Fucus serratus</i> <i>Ceramium</i> spp.	<i>Phyllophora truncata</i> <i>Phycodrys rubens</i> <i>Polysiphonia nigrescens</i>
10 m	<i>Furcellaria lumbricalis</i> <i>Laminaria saccharina</i> <i>Phyllophora truncata</i>	<i>Phycodrys rubens</i> <i>Ceramium</i> spp.
12 m	<i>Furcellaria lumbricalis</i> <i>Polysiphonia nigrescens</i> <i>Rhodomela confervoides</i> <i>Delesseria sanguinea</i>	<i>Phycodrys rubens</i> <i>Polysiphonia nigrescens</i> <i>Phyllophora truncata</i>
14 m	<i>Furcellaria lumbricalis</i> <i>Delesseria sanguinea</i> <i>Laminaria digitata</i> <i>Laminaria saccharina</i>	<i>Phycodrys rubens</i> <i>Phyllophora truncata</i> <i>Delesseria sanguinea</i>
16 m	<i>Furcellaria lumbricalis</i> <i>Laminaria saccharina</i>	<i>Phycodrys rubens</i> <i>Phyllophora truncata</i>
18 m	<i>Laminaria saccharina</i> <i>Phyllophora truncata</i>	<i>Phycodrys rubens</i>
20 m	<i>Furcellaria lumbricalis</i>	

Causes of the changes in macroalgae pattern

The possible causes for the observed changes have been discussed in detail by Schramm (1988), Breuer & Schramm (1988), Vogt & Schramm (1991). Among the more important factors may be changes in substrate conditions (increasing cliff erosion, sand deposition, so-called "stone-fishing") and eutrophication, in particular. A direct response to increased nutrient supply may be seen in the spread of finely branched forms, as also described for Finnish and Swedish coasts (Kangas *et al.* 1982, Wachenfeldt 1986). Most of these "opportunistic" annual forms are characterized by high nutrient uptake rates and nutrient saturation levels as well as by fast growth which may be of competitive advantage over less active species such as *Fucus*. We have therefore investigated the nutrient uptake kinetics and productivity (growth) of the two competing community forming seaweeds *Fucus* and *Phycodrys* in relation to seasonal nutrient conditions in their respective habitats (Schramm *et al.* 1988). Nutrient concentration of the "interalgal water" are significantly higher, than in the surface water of the open Kiel Bay, probably as a result of internal remineralization and recycling within the algal beds (Fig. 4).

Under this conditions, *Fucus* was obviously most of the time able to maintain its internal nutrient content at levels that nutrients were not limiting to optimal growth, whereas growth in *Phycodrys* was limited by P in early spring and by N in summer (Fig. 5).

Additional nutrient supply during periods would probably enhance growth of *Phycodrys*, and possibly also of *Fucus* in early summer.

To understand more about the possible direct effects of eutrophication on the benthic vegetation, further studies of competitive nutrient requirements, particularly of the finely branched "nutrient opportunists" are certainly necessary.

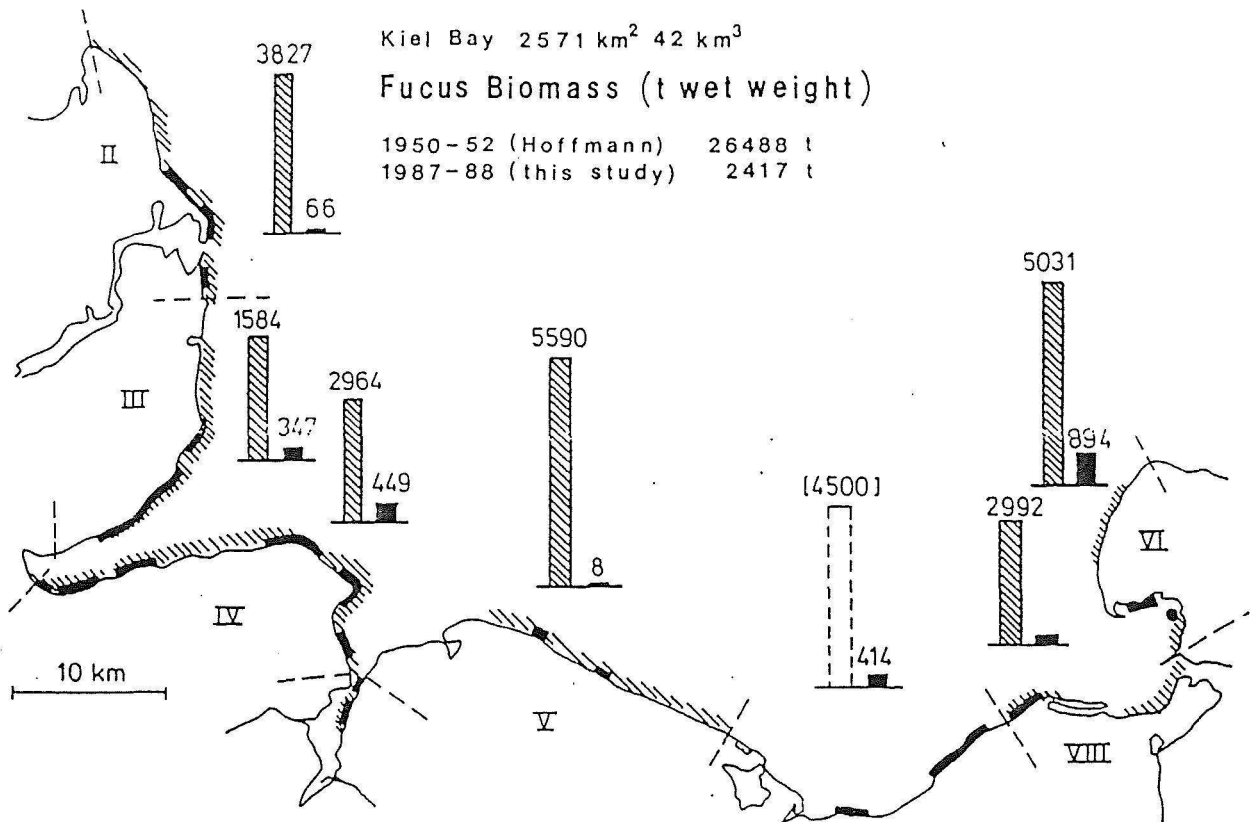


Fig.3. *Fucus* spp. biomass (t wet weight) and distribution in different areas of Kiel Bay as determined by Hoffmann between 1950 and 1952 (hatched bars and areas) and by Vogt and Schramm between 1987 and 1988 (solid bars and areas).

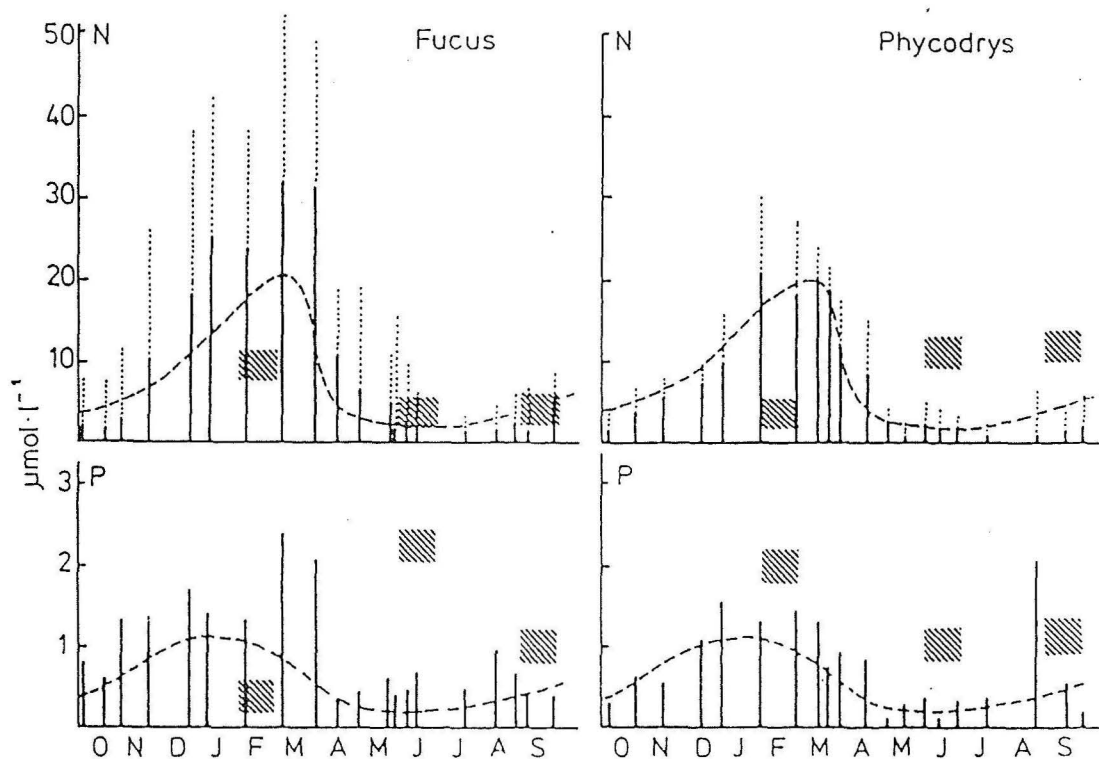


Fig. 4. Seasonal variation of inorganic nitrogen (solid bars : NO_2/NO_3 , dotted bars : NH_4) and phosphorus (PO_4) concentration in the interalgal seawater of a *Fucus* and a *Phycodrys* community. The hatched areas indicate growth saturating nutrient concentrations during different times of the year.

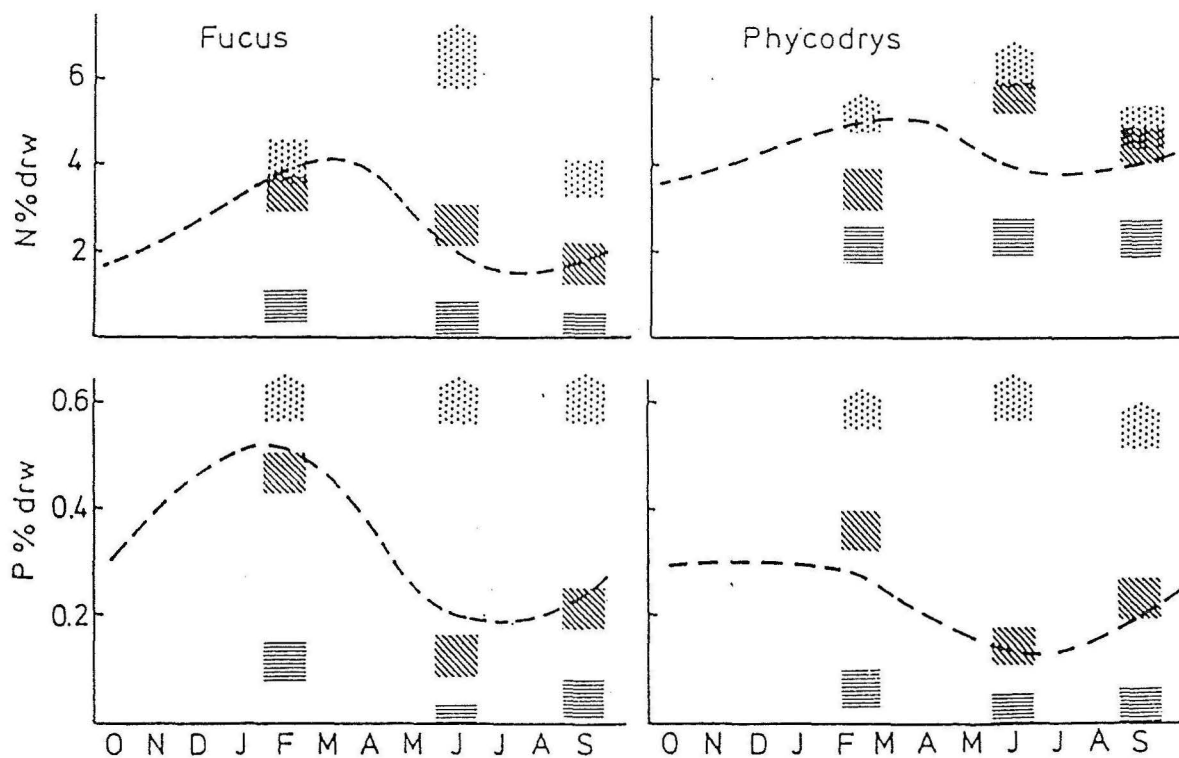


Fig. 5. Seasonal variation of N and P content in the tissue of *Fucus* and *Phycodrys* (broken curves) in relation to saturated nutrient contents (dotted areas), and to nutrient contents at which growth is saturated (diagonal hatching) or where growth ceases (horizontal hatching).

More important however, are probably the indirect effects of eutrophication on the vegetation through changes of the light climate.

Unfortunately, there are no long-term light or transmission measurements for the nearshore waters of Kiel Bay. However, there are some indications that, as a result of increasing nutrient input and plankton density, the turbidity has increased and penetration of light has decreased. In addition, overshadowing through mass development of epiphytic, filamentous or folious "nutrient opportunists" may further reduce the light intensity, so that light may become limiting to strong-light adapted forms like *Fucus* in competition with low-light adapted algae, as for example the red algae *Phycodrys*, *Phyllophora*, or *Polysiphonia*.

References

- Aertebjerg-Nielsen G. 1985. Aarsager til iltsvind i kategatt og Baelthavet. *Vand og Miljø* 2: 59-62.
- Aertebjerg-Nielsen G., Jacobson T.S., Gargas E. & Buch E. 1981. The Belt Project. *National Agency of Environmental Protection*, Denmark, pp. 122.
- Babenerd B. & Zeitzschel B. 1985. Trends für eintragsrelevante Faktoren und die Nährsalzkonzentration im Wasser der Kieler Bucht. *Ber. Inst. Meereskunde*, Kiel 148: 1-45.
- Balzer W. & Kähler P. 1989. Natürlicher Entfernung von Stickstoff durch Denitrifikation aus dem System Kieler Bucht. *Abschlußbericht UBA Proj. Wasser 102 04 215*, pp 22.
- Black H.J. 1978. Vegetationsdynamische Untersuchungen an epilithischen Algengemeinschaften im Sublitoral der Westlichen Ostsee unter Berücksichtigung der produktionsbiologischen Bestandsabschätzung. *Rep. Sonderforschungsbereich 95*, Univ. Kiel, 44: 1-44.
- Breuer G. & Schramm W. 1988. Changes in the macroalgal vegetation of Kiel Bight (Western Baltic Sea) during the past 20 years. *Kieler Meeresforsch.* 6: 241-255.
- Bodungen B. v. 1986. Annual cycles of nutrients in a shallow inshore area, Kiel Bight - variability and trends. *Ophelia* 26: 91-107.
- Ehrhardt M. & Wenck A. 1984. Wind pattern and hydrogen sulfide in shallow waters of the Western Baltic Sea, a cause and effect relationship? *Meeresforsch.* 30: 101-110.
- Gerlach S. 1986. Landfristige Trends bei den Nährstoff-Konzentrationen im Winterwasser und Daten für die Bilanzierung der Nährstoffe in der Kieler Bucht. *Meeresforsch.* 31: 153-174.
- Gerlach S. 1990. Stickstoff, Phosphor, Plakton and Sauerstoffmangel in der Deutschen Bucht und in der Kieler Bucht. *Ber. Umweltbundesamt 4/90*: 1-357, Appendix.
- Kangas P., Autio H., Hällfors G., Luther H., Niemi H. & Salemaa H. 1982. A general model of the decline of *Fucus vesiculosus* at Tvärminne, south coast of Finland in 1977-1981. *Acta Bot. Fennica* 118: 1-27.
- Krey J., Babenerd B. & Lenz J. 1978. Beobachtungen zur Produktionbiologie des Planktons in der Kieler Bucht, 1957-1975. *Ber. Inst. Meereskunde*, Kiel. 54: 1-113.
- Nehring 1984. The further development of the nutrient situation in the Baltic proper. *Ophelia suppl.* 3: 167-179.
- Schramm W. 1988. *Untersuchungen zur Rolle benthischer Primärproduzenten im organischen Stoffhaushalt der Kieler Bucht*. Abschlußbericht Umweltbundesamt Proj. Wasser 102 04 215, Appendix. 34 pp.
- Schramm W., Abele D. & Breuer G. 1988. Nitrogen and phosphorus nutrition and productivity of two community-forming seaweeds (*Fucus vesiculosus*, *Phycodrys rubens*) from the Western Baltic (Kiel Bight) in the light of eutrophication processes. *Kieler Meeresforsch.* 6: 221-240.
- Schwenke H. 1964. Vegetation und Vegetationsbedingungen in der Westlichen Ostsee (Kieler Bucht). *Kieler Meeresforsch.* 20: 157-168.
- Schwenke H. 1965. Beiträge zur angewandten Vegetationskunde der westlichen Ostsee (Kieler Bucht). *Kieler Meeresforsch.* 21: 14-152.
- Schwenke H. 1969. Meeresbotanische Untersuchungen in der Westlichen Ostsee als Beitrag zu einer marinen Vegetationskunde. *Int. Rev. ges. Hydrobiol.* 54: 35-94.
- Vogt H. & Schramm W. 1991. Conspicuous decline of *Fucus* in Kiel Bay (Western Baltic) : What are the causes? *Mar. Ecol. Prog. Ser.* 69: 189-194.
- Wachenfeldt T. von, Waldemarson S. & Kangas P. 1986. Changes in the littoral communities along the Baltic coasts. *Baltic Environm. Proc.* 19: 394-403.
- Weigelt & Rumohr H. 1986. Effects of wide range oxygen depletion on benthic fauna and demersal fish in Kiel Bay 1981-1983. *Meeresforsch.* 31: 124-136.