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Pollution effects on littoral algal communities in the inner Oslofjord, with special reference to *Ascophyllum nodosum*

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KURZFASSUNG: **Verunreinigungseffekte auf litorale Algengemeinschaften im inneren Oslofjord unter besonderer Berücksichtigung von *Ascophyllum nodosum*.** In dem verunreinigten inneren Oslofjord tritt die Braunalge *Ascophyllum nodosum* (L.) LE JOL. nicht mehr auf. Mit der vorliegenden Untersuchung sollte geklärt werden, ob das verunreinigte Fjordwasser einen unmittelbar hemmenden Effekt auf die Entwicklung dieser Alge ausübt oder ob ein indirekter Einfluß vorliegt, indem bestehende biotische Faktoren eine ungünstige Konkurrenzsituation für diese Art bedingen. Zur Klärung dieser Frage wurden 3 Versuchsareale von Algenvegetation reingeschabt; anschließend wurden Wiederbesiedelung und Artensukzessionen über einen Zeitraum von 16 Monaten verfolgt. Das eine Versuchsgebiet lag bei Dröbak (30 km von Oslo entfernt), wo *Fucus vesiculosus* und *Ascophyllum nodosum* in der litoralen Vegetation dominieren. Die beiden anderen Versuchsgebiete befanden sich in dem verunreinigten inneren Teil des Oslofjords, wo einjährige Grünalgen vorherrschen. Exemplare von *Ascophyllum nodosum* wurden von Dröbak in die im inneren Fjord gelegenen Versuchsgebiete transplantiert, um Wachstum und Entwicklung der Algen mit der Population bei Dröbak vergleichen zu können. Es wurde festgestellt, daß keine wesentlichen Unterschiede hinsichtlich des vegetativen Wachstums und der Reifung von Rezeptakeln auftraten. Eine kritische Phase stellt die Entwicklung der Keimpflanzen auf dem Substrat dar. Als Folge der Eutrophierung bildet sich innerhalb weniger Wochen ein dichter Bewuchs von *Enteromorpha* spp. Es zeigte sich, daß die Konkurrenz um das Substrat und die reduzierte Lichtzufuhr durch den *Enteromorpha*-Bewuchs sich als entscheidend für das Fehlen von *Ascophyllum nodosum* erweisen.

INTRODUCTION

The inner Oslofjord has several advantages to offer for the study of pollution effects on littoral algae. Firstly there exist data, regrettably not numerical data, from surveys carried out by GRAN 1897, SUNDENE 1953, GRENAGER 1957, KLAVESTAD 1967. Furthermore in the inner Oslofjord, in contrast to many other Norwegian fjords, surface salinity gradients are small, due to the fact that the largest rivers (river Glåma and river Drams) have their outlets in the outer fjord. Salinity is, therefore, of little importance for horizontal distribution of the littoral algae within the inner fjord.

More detailed investigations in the innermost part of the fjord were carried out from 1943 to 1946 by GRENAGER (1957) and from 1962 to 1965 by KLAVESTAD

(1967). In these investigations, vegetation was recorded in a great number of localities at varying distances from the main discharge of sewage. The inner boundaries of species were recorded and discussed according to the ability of the various species to withstand pollution. The interval between GRENAGER's and KLAVESTAD's observations was a period in which there was a very marked increase in sewage load. KLAVESTAD's investigations revealed that 23 species had their inner boundaries moved inwards, and only 9 had moved in the opposite direction. Natural variations, e.g. in summer temperatures, rather than in increased pollution, were supposed to be of importance in explaining the differences observed from year to year (KLAVESTAD 1967).

According to KLAVESTAD (1967), *Capsosiphon fulvescens* (C. AG.) SETCH. et GARDN., which formed dense growths in many of the most polluted localities where this species had not been observed earlier, was taken as indicator of increased pollution. It is probable that quantitative plant sociological methods would have revealed more changes in vegetation during the 20-year period which elapsed between the two investigations, than on the basis of the qualitative data available.

Comparing present floristical data with what is known from the earliest collections of algae from the inner Oslofjord (GRAN 1897), qualitative changes are obvious. Many easily recognizable species have disappeared or become very rare in the inner Oslofjord (e.g. *Rhodochorton purpureum, Phyllophora brodiaei, Ptilota plumosa, Spermothamnion repens, Spermatochnus paradoxus, Asperococcus turneri, Ascophyllum nodosum).* A few species have migrated to the Oslofjord since the first investigation: *Gracilaria verrucosa, Trailliella intricata* and *Fucus distichus* ssp. *edentatus.* The last mentioned was recorded for the first time in South Norway in Drøbak at the end of last century (SIMMONS 1898), but is today the commonest fucoid in the inner basin.

According to GRAN (1897), *Ascophyllum nodosum* was common and abundant in the inner Oslofjord. During GRENAGER's investigation, the species was recorded in only three of 57 localities (GRENAGER 1957). He claimed that the disappearance of the species was probably due to increased pollution. KLAVESTAD's survey (1967), twenty years later, showed that the species had been forced further outwards; it was recorded only in a few localities, and then rarely or very rarely. Today I have not been able to find *A. nodosum* in any of the localities inside Nesoddtangen mentioned in previous reports.

Assuming that pollution is the decisive ecological factor for the inability of *Ascophyllum nodosum* to exist in the inner part of the Oslofjord, two causal categories may be operating: (1) Polluted water exerts a direct unfavourable effect on growth and development of the alga (autecological effect). (2) Polluted water has no direct unfavourable effect on growth and development of the alga, but in polluted localities indirect biotic factors lead to an unfavourable competitive situation for the species (synecological effect).

MATERIAL AND METHODS

Three localities were chosen, one in the Drøbak area (Storskjær) where the phaeophyceans *Fucus vesiculosus* and *Ascophyllum nodosum* dominated the littoral

zone, and two localities in the inner basin (Hovedøya and Katten) where annual and ephemeral species were predominant (Fig. 1). At these three localities, strips, 2 m wide and extending about 0.5 m below mean sea level, were cleared by means of gas flame and steel brush. The regrowth on the denuded rocks was observed and the vegetation in the undisturbed neighbourhood was registered every fortnight or every month.

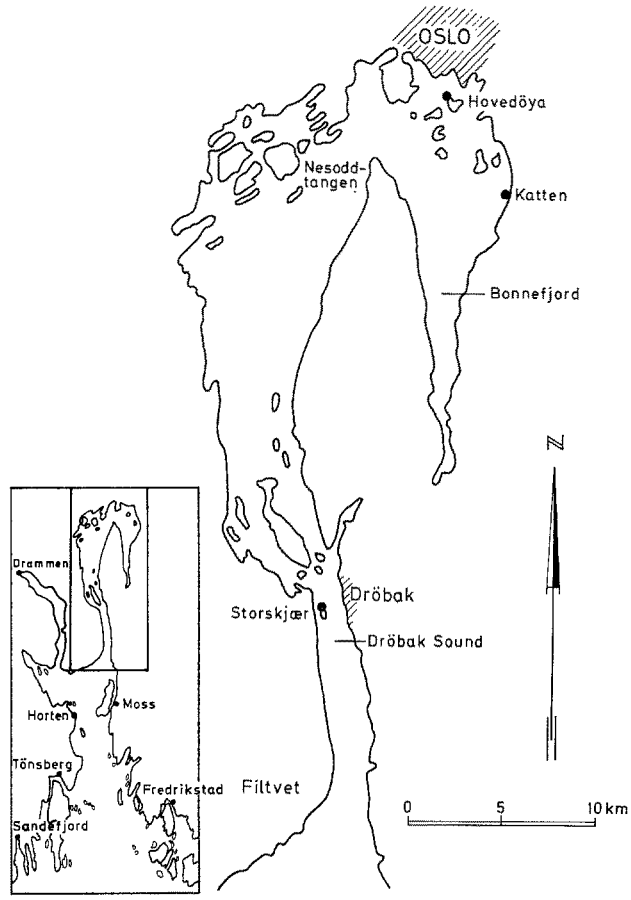

Fig. 1: Inner Oslofjord and Drøbak Sound. Localities investigated are indicated

Fucus vesiculosus and *Ascophyllum nodosum* were not growing near the localities in the inner basin; therefore, in order to enhance the chances for zygotes and germlings to establish themselves on the substrate, fertile material of both species was collected in Drøbak (12 May) and placed in net bags on the cleared strips. Unfortunately, these did not remain undisturbed for more than about a week.

On 5 June and 13 August three large stones from Drøbak bearing several well-grown specimens of *Ascophyllum nodosum* were each time transferred and placed at the two localities in the inner basin. The stones were laid in a firm position.

In order to record the increase in length, a number of shoots were measured from the apical end of the last bladder to the apex. Likewise a number of lateral shoots were measured each month or more often. The growth of the transplanted specimens and of specimens in a native population in the Drøbak area was compared.

Growth and development of *Fucus distichus* ssp. *edentatus*, which is the most successful fucoid in the polluted part of the inner Oslofjord, were followed in a population at one locality (Katten) from the state of germlings to fertility.

RESULTS AND DISCUSSION

Regrowth and succession on the three localities

H o v e d ø y a. This locality faces north and is situated near the city of Oslo; it is the most heavily polluted of the two localities in the inner basin.

The most characteristic alga before clearing was *Fucus spiralis* forming an association in a belt 20 cm broad in the upper part of the strip. For the rest, annual and ephemeral algae predominated (*Blidingia minima, Enteromorpha* spp., *Ulothrix* spp., *Ulva lactuca, Urospora penicilliformis, Scytosiphon lomentaria*, etc.).

Regrowth appeared faster on this locality than on the other two. The dominating organism was *Enteromorpha compressa*, attaining a length of about 10 cm after one month; it was 20–30 cm long in September, 4 months after clearing. The largest specimens were recorded in the lower part of the cleared strip where regrowth was especially good. In the upper part, at the level of the *Fucus spiralis* association, only slight regrowth appeared after one month (*Calothrix scopulorum, Gloeocapsa crepidinum, Plectonema* sp., *Blidingia minima, Enteromorpha* sp., *Ulothrix* sp., *Urospora penicilliformis*).

At the end of July, two and a half months after clearing, some *Fucus* germlings were recorded in the middle and lower part of the strip. They were up to 1 cm in length. *Fucus spiralis* had just initiated the period of fertility, while germlings of *Fucus distichus* ssp. *edentatus* at the same time measured 3–4 cm at the locality Katten. Most probably these germlings belonged to *Fucus vesiculosus*, and many have been derived from the plants placed on the strip in the middle of May. Further development of the *Fucus* germlings was poor, and ten months later only a few 1–5 cm high plantlets were seen. At this time, however, *Fucus spiralis* germlings occurred in the upper part of the strip, the largest plants being 10 cm. No *Ascophyllum* germlings were recorded.

The number of species was higher on the strip than outside. Some species, usually preferring a different habitat, as for instance *Percursaria percursa* and *Rhizoclonium riparium*, were rather common in the lower part of the strip. Several species appeared for only a short period: *Ceramium strictum* (late summer), *Acrosiphonia centralis* (spring), *Scytosiphon lomentaria, Petalonia fascia, Urospora penicilliformis* (winter and spring).

K a t t e n. This locality has a western exposure. *Fucus* spp. were lacking on the strip. Only *Fucus distichus* ssp. *edentatus* occurred in the vicinity, growing mainly in the sublittoral.

While the vegetation resembled that on Hovedøya, *Enteromorpha* spp. were less abundant and benthic diatoms and the encrusting algae *Hildenbrandia* and *Ralfsia,* as well as the snail *Littorina littorea,* were prominent.

Recolonization proceeded more slowly than on Hovedøya, the regrowth pattern and the species appearing being about the same, with *Enteromorpha compressa* predominating. The following species were recorded on the strip of this locality only: *Polysiphonia nigrescens, Petalonia zosterifolia, Cladophora* cf. *dalmatica.* No germlings of *Ascophyllum nodosum* or *Fucus* were recorded.

Storskjær (Drøbak area). The vegetation in this locality is markedly different from the localities in the inner basin because the perennial algae *Fucus vesiculosus* and *Ascophyllum nodosum* constitute the main littoral vegetation, with a number of accompanying algae playing a subordinate part (*Hildenbrandia prototypus, Ectocarpus siliculosus, Elachista fucicola, Pilayella littoralis, Sphacelaria* spp., *Cladophora rupestris, Cladophora* sp., *Enteromorpha* spp., *Ulothrix* spp.). The repopulation on the cleared strip also differed from that observed at the localities in the inner basin. Regrowth proceeded more slowly and green algae were less predominant.

Two months after clearing, only a sparse growth of *Blidingia minima, Enteromorpha* spp., *Ulothrix* sp., and cyanophyceans had repopulated the area. At the end of July, three months after clearing, a dense stand of *Porphyra purpurea* had appeared, forming a belt 5–10 cm in width at the *Fucus vesiculosus* level. This stand of *Porphyra purpurea* was maintained throughout a year. Outside the strip, this species was only recorded sparsely on stones and shells in shallow water, and not on rocks among fucoids.

Gradually other species were also observed on the strip, the number of species becoming greater than in the localities in the inner basin. The following species occurred on this strip but not on the other two: *Ceramium rubrum, Polysiphonia urceolata, Chordaria flagelliformis, Elachista fucicola, Sphacelaria cirossa, Sphacelaria* sp., *Bryopsis plumosa, Cladophora rupestris, Cladophora sericea.*

First in the lower part of the strip, later at higher levels, *Fucus vesiculosus* gradually developed. After three months the largest specimens were 8 cm high, after six months (October) the largest plants measured 14 cm, and after one year up to 20 cm. Some of these then bore receptacles and a pair of bladders. Most *Fucus vesiculosus* plants did not, however, become fertile or have bladders after one year. It is probable that the *Fucus vesiculosus* population on the strip consisted of a mixture of plants partly derived from zygotes of the last summer, partly of plants developed adventitiously from basal parts which had survived the clearing of substrate. The latter kind becomes fertile and develops bladders after one year, according to PRINTZ (personal communication).

One specimen of *Fucus distichus* ssp. *edentatus* also occurred on the strip, and became fertile after one year. No *Ascophyllum* plants were recorded on the cleared area.

Growth and development of transplanted *Ascophyllum nodosum*, compared with native plants in the Drøbak area

Of the transplanted *Ascophyllum* plants only one at Hovedøya was lost, and that was due to rope and other driftage which tore it away.

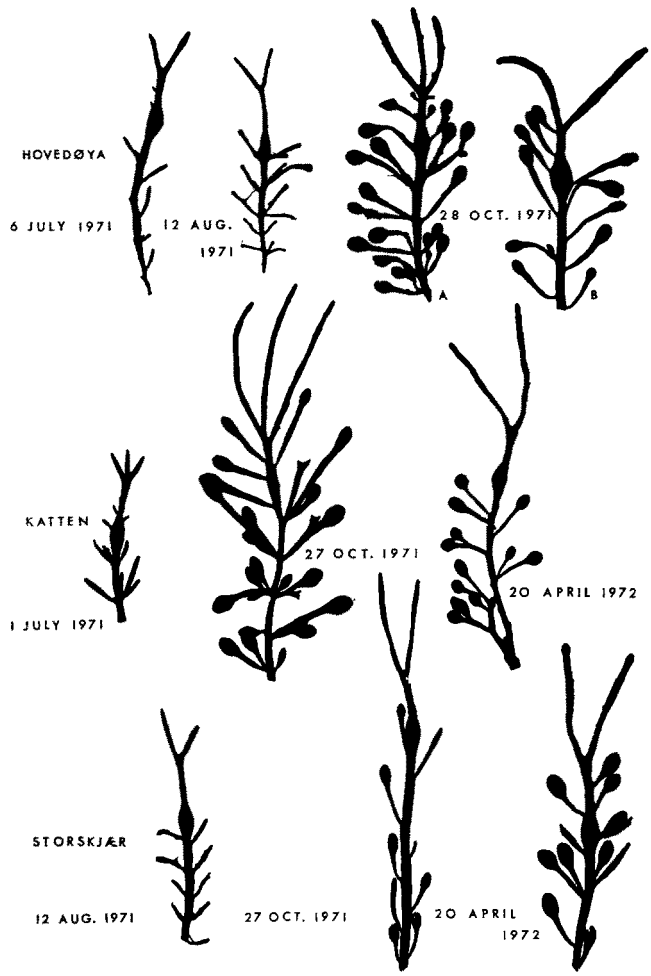

Fig. 2: *Ascophyllum nodosum*. Distal regions of plants from the three localities to show growth and development at various times of the year

No essential differences between the transplanted and native plants were observed in vegetative growth and maturation of generative structures. In Figure 2 some representative shoots taken from the three localities at different times of the year are depicted. The mean annual increase in length was approximately 7 cm, but an exact

documentation requires a greater number of measurements of a greater number of plants.

The plants in the Hovedøya locality were more infested with epiphytes than those in the other localities. The plants which were measured were "weeded", others were overgrown by *Enteromorpha* spp., *Ulva lactuca*, *Ceramium strictum*, small *Mytilus*, etc; these overgrown plants probably get their photosynthesis reduced due to a reduction in light supply, but this was not investigated further. Increasing epiphytism on fucoids in polluted water was also mentioned by GRENAGER (1957).

The results mentioned above indicate that there is in the inner Oslofjord no essentially inhibitory effect of the polluted water on the growth of *Ascophyllum nodosum*. The critical phase appears to be the establishment and growth of germlings on the substrate.

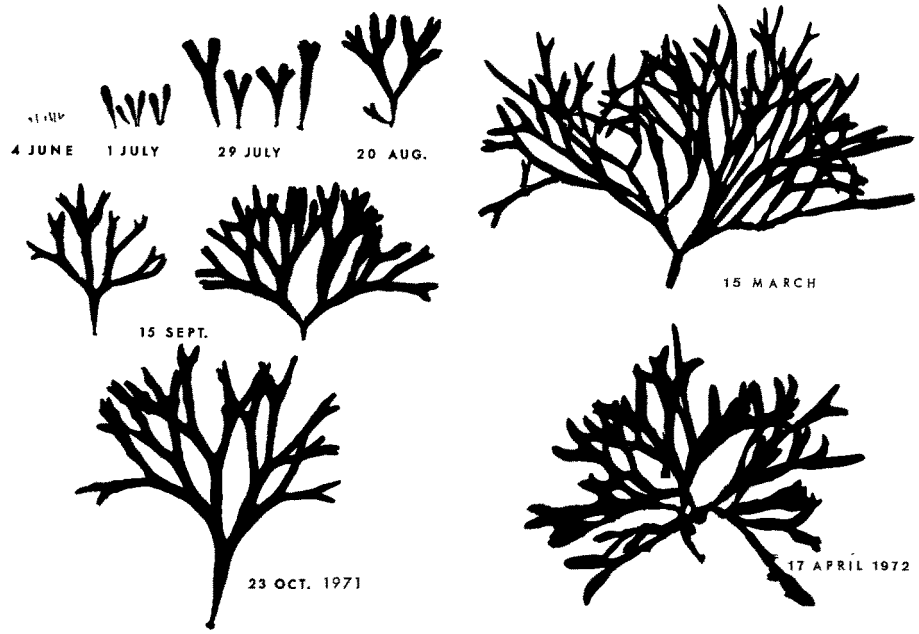

Fig. 3: *Fucus distichus* ssp. *edentatus*. Germlings of various age from a stand at the locality Katten. In the specimen from 17 April 1972 all apices were fertile

It is well known that reproduction in *Ascophyllum nodosum* is not very effective, even in habitats favourable for the species. This may be seen after harvesting the *A. nodosum* by scraping, or on new breakwaters, where several years may be required for *A. nodosum* to populate the rocks (KNIGHT & PARKE 1950, PRINTZ 1959, BAARDSETH 1968). On the other hand, in settled communities *A. nodosum* is very stable due to the longevity of individual plants. SUNDENE (1953) has mentioned the importance of ice-scouring during winter as a reason for the absence of *A. nodosum* in many localities in the Oslofjord.

Recent experimental work carried out by SUNDENE (personal communication)

shows that germlings of *Ascophyllum nodosum* grow very slowly in culture as well as in nature the first two years, attaining a size of 0.1–0.2 cm after one year and 0.5 to 1.5 cm after a second year. In addition, the fertile period of *A. nodosum* is restricted to a short period of the year (March to June in the Oslofjord). These details in its autecology may, at least partly, explain why *A. nodosum* has difficulty in establishing itself successfully in many localities. In the polluted part of the inner Oslofjord increased competition for the substrate is experienced, especially in summer when the growth of *Enteromorpha* spp. is optimal and the *Enteromorpha* carpet has a shading effect on prospective germlings.

In conclusion, the observations on *Ascophyllum nodosum* presented are in favour of the second of the two hypotheses mentioned above with regard to the inability of the species to populate the shore in the polluted inner part of the Oslofjord.

Growth and development of *Fucus distichus* ssp. *edentatus*

At the locality Katten, the development of a stand of *Fucus distichus* ssp. *edentatus* was followed from the germling state (0.5 cm) to fertile plants (Fig. 3). In some of the plants investigated all shoots terminated in receptacles after 10 months. These plants degenerated after one year when fertile branches were shed. Some plants also bore sterile shoots with an intact apical cell to continue vegetative growth of the plant. Mature receptacles were found from March to June.

SUMMARY

1. Littoral algal vegetation was studied at three localities in the inner Oslofjord; one in the Drøbak area, and two in the more polluted inner basin.
2. Regrowth and succession on cleared strips were followed for 16 months.
3. The phaeophycean *Ascophyllum nodosum* was a common species in the inner part of the fjord at the turn of the century, but has disappeared with increase in pollution.
4. Well-grown specimens of *Ascophyllum nodosum* were transplanted from the Drøbak area to the inner basin. No essential differences in vegetative growth and maturation of generative structures were observed.
5. Growth and development of *Fucus distichus* ssp. *edentatus* were followed from the state of germlings to fertile plants.
6. Regrowth proceeded more slowly in the Drøbak locality than in the localities in the inner basin, where a dense carpet of *Enteromorpha* spp. etc. was formed.
7. It is assumed that the increased competition for substrate and the shading effect of the *Enteromorpha* carpet reduces the chances of *Ascophyllum nodosum* germlings of becoming established in the inner basin.

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