The Norwegian State Pollution Control Authority

Report 339|88

Participating institutions

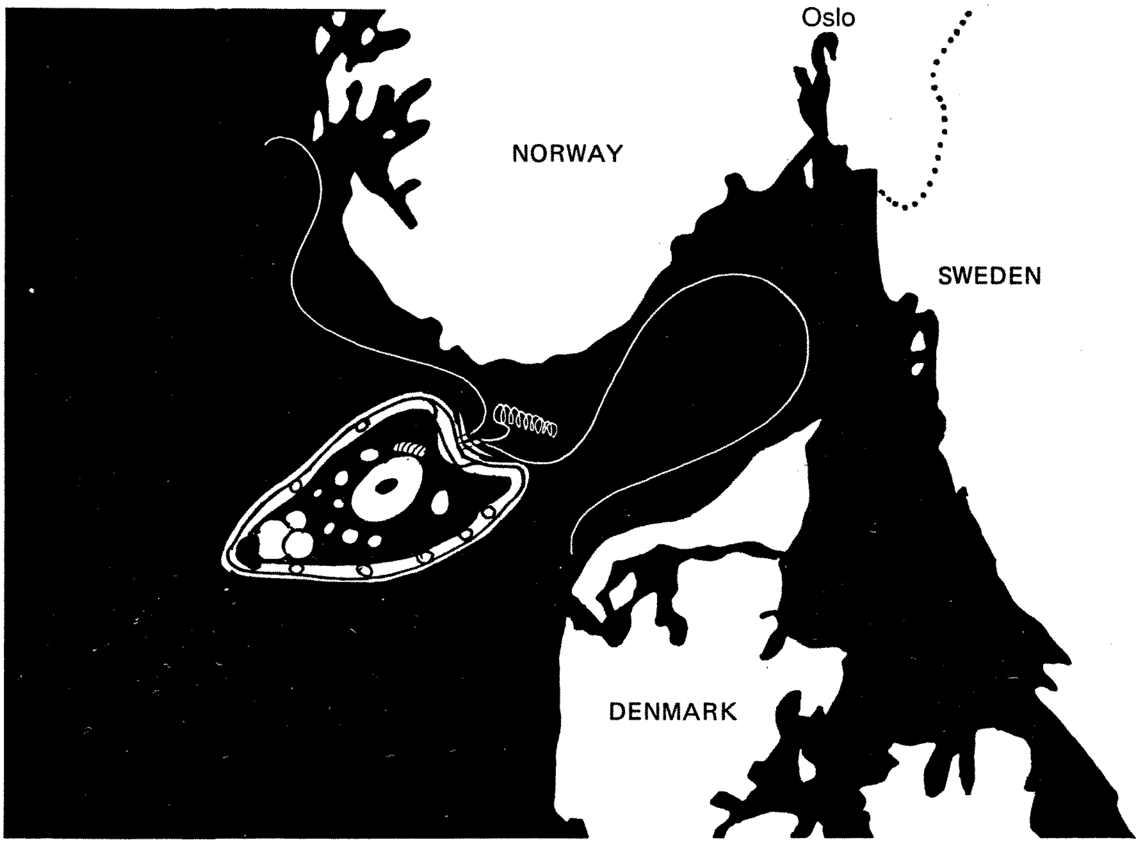
The food inspection services in Dalane
Chief administrative Officer of Vest-Agder County, Environmental Division
Flødevigen Biological Station
Kristiansand Museum
Norwegian Institute for Water Research
Institute for Marine Research, Bergen
University of Oslo, Department of Biology

The invasion of the planktonic algae

Chrysochromulina polylepis

along the coast of southern Norway in May-June, 1988.
Acute effects on coastal biota.

Summary report



NIVA - REPORT

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The invasion of the planktonic algae

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Acute effects on coastal biota.
Summary report.

This report describes the extent of damage to rocky bottom and soft bottom communities as well as to littoral fish. Damage has been registered along the whole of the coastline from the west coast of Sweden to the Haugesund area inclusive. Hardest hit were stretches from Grimstad to Kristiansand and from Farsund to Flekkefjord. Depths between 3 and 16 m were affected along most of the coastal region.In some localities depths of between 0 and 30 m were affected. The acute effects on rocky bottom organisms have been severe. Soft bottom organisms were less affected than rocky bottom organisms. The common dog whelk *Nucella lapillus* was almost completely exterminated. Wrasse showed the greatest mortality among wild fish. The year's cod fry were more or less wiped out. In addition, mortality among farmed salmon was high. New surveys should be conducted to observe any later effects as well as the process of recolonization.

Participating institutions

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Chief administrative Officer of Vest-Agder County, Environmental Division
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FOREWORD

This report presents a summary of damage to biota along the coast of southern Norway as a consequence of the outbreak of the planktonic algae Chrysochromulina polylepis in May-June, 1988.

The report has been printed in two parts. Part A contains a summary and conclusions covering the background, the main results, conclusions, as well as recommendations for follow-up work. Part B contains the reports of the institutions involved.

The summary report has been prepared for the State Pollution Control Authority (SFT) and is part of the National Pollution Monitoring Programme. The Norwegian Institute for Water Research (NIVA) is responsible for editing the report.

Oslo, September 1988.

Nils Petter Wedege (SFT)

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CONTRIBUTORS

The present report is a summary based on reports from field surveys along the coast of southern Norway in May-August, 1988, conducted by various institutions. These reports have been collected in one volume: "The invasion of the planktonic algae *Chrysochromulina polylepis* along the coast of southern Norway in May-June, 1988. Acute effects on coastal biota. Part B. Reports from participating institutions. National Pollution Monitoring Programme. Report 328b/88." The reports are:

1. The food inspection services in Dalane: Masseoppblomstring av *Chrysochromulina polylepis*, mai 1988. Forekomster og skadevirkninger langs kysten av Dalane, Sør-Rogaland. (Author: G.Espeland)

2. Chief administrative Officer of Vest-Agder County, Environmental Division: Kronologisk registrering av observasjoner på Skagerrakkysten 15.5.-22.8.1988. (Author: R.O.Stene)

3. Institute for Marine Research, Bergen: Rapport om oppblomstringen av *Chrysochromulina polylepis* i mai-juni 1988. Overvåking, varsling, oppfølgende tiltak. (Authors: G.Berge og L.Føyn)

4. Kristiansand Museum: Registrering av marin fastsittende algevegetasjon og skadevirkninger forårsaket av *Chrysochromulina polylepis* på utvalgte lokaliteter i Agder. Fylkesmannen i Aust-Agder, miljøvernavdelingen. Rapport 9-1988. (Author: P.A.Åsen)

5. The Norwegian Institute for Water Research: Invasjon av planktonalgen *Chrysochromulina polylepis* langs Sør-Norge i mai-juni 1988. Akutte virkninger på organismesamfunn langs kysten. Datarapport fra NIVAs undersøkelser. Statlig program for forurensningsovervåking. Rapport 329/88. (Authors: J.A.Berge and others)

6. Flødevigen Biological Station: Algeoppblomstringen i Skagerrak mai 1988. Effekter på bunnfauna på Sørlandskysten. Meldinger Nr. 3-1988. (Authors: J.Gjøsæter og T.Johannessen)

7. University of Oslo, Department of Biology: Rapport fra undersøkelse om effekter på bunnlevende organismer og strandlevende fisk på kyststrekningen Langesund-Tvedestrand etter oppblomstringen av *Chrysochromulina polylepis*. (Authors: B.Edvardsen and others)

Chapter 7 ("Mulige årsak/virkning-sammenhenger") based on briefing by Olav Skulberg, NIVA.

C O N T E N T S

1. AIMS - CONCLUSIONS - RECOMMENDATIONS

1.1 Background and aims

Mortality among commercially reared salmon on the west coast of Sweden on May 9, 1988, was linked with the bloom of a planktonic algae. The algae was identifed as the golden-brown algae Chrysochromulina polylepis, and it was determined that it was toxic. The carpet of algae made its way along the Norwegian coastline, spreading with coastal currents westwards and northwards to Hordaland where the bloom culminated around June 2. On June 9 phyto plankton in the areas affected in Vestlandet appeared to be normal for the time of year. The greatest density of algae cells in various areas of Skagerrak is shown in Figure 1. The algae "invasion" caused death and damage to organisms in shallow water along the coast of Skagerrak. On the basis of sporadic observations it was decided to conduct a systematic survey in order to determine the extent and type of ecological damage.

There are two main types of damage: damage to populations and damage to individuals. Damage to populations consists of a decrease in the number of organisms (biomass), or changes in the composition of age classes. These changes may be due to mortality or to reduced reproductive ability. Damage to individuals consists of various symptoms of disease such as discolouration, changes in behaviour patterns, the loosening of organs, etc, in addition to death. Criteria for determining the extent of the damage were: (1) the geographical extent of the area affected, (2) the depth at which effects were recorded, (3) the numbers within the populations of individual species that were dead or damaged, (4) the degree of damage (dead - seriously affected - slightly affected). The need for further investigations and other measures was also to be evaluated.

1.2 Material and Methods

Survey areas and selection of stations

Shortly after the outbreak of Chrysochromulina field work involving several institutions was organized with the aim of examining effects on rocky bottom organisms, soft bottom fauna, zooplankton and fish. A map indicating the location of sampling stations is shown in Figure 2-3.

The University of Oslo surveyed four main areas: Langesund, Jomfruland, Risør and Tvedestrand. The total number of stations was 17. Three of these stations (two in the Langesund area and one in the vicinity of Jomfruland) had been surveyed by divers previously.

Flødevigen Biological Station carried out diving surveys in the Risør area (9 stations), the Arendal area (7), the Farsund area (2), and Flekkefjorden (3). At a number of these diving stations samples were also collected with a shore seine or a trammel net for purposes of comparison with previous years.

The Kristiansand Museum (Per Arvid Åsen) resurveyed 8 stations between Mandal and Hidra which had been surveyed twelve years previously.

NIVA´s 37 rocky bottom stations and 63 soft bottom stations were selected so as to provide comprehensive coverage of the entire southern coast and to determine the geographical limits of the effects. It was anticipated that the most farreaching effects would be registered in shallow waters. Consequently most of the soft bottom stations (Fig. 3) were located at depths of less than 30 m. However, some stations were located at greater depths so that any effects that could be attributed to sedimented cells of Chrysochromulina could be investigated. Some of the stations had been surveyed prior to the algae invasion, so that the situation could be compared before and after the outbreak.

Collection and Registration Methods

Registration on rocky bottoms was carried out by marine biologists diving along the bottom from the shoreline down to a maximum depth of 30 m. The occurrence of attached algae above a certain size, invertebrate animals and fish was registered and photographed where applicable, and their condition recorded.It is difficult to record small organisms using this method.

The registering of fish was accomplished using a shore seine, a net, and the registration of dead fish within a given area (quantitative dives). Fish in open water masses in Skagerrak were recorded by the Institute for Marine Research, Bergen.

Samples of soft bottom fauna were collected using a grab, a scraper, and a benthiic sledge. The soft bottom in the tidal zone was sampled using a manually operated cylindrical tool. The material was examined to determine the species and the number of individuals in each species.

Zooplankton were collected with a scoop net.

1.3 Conclusions

THE WIDESPREAD BLOOM OF CHRYSOCHROMULINA POLYLEPIS RESULTED IN MASSIVE DAMAGE TO FARMED FISH, LITTORAL WILD FISH, INVERTEBRATE ANIMALS, AND ATTACHED ALGAE ON ROCKY BOTTOMS. DAMAGE TO ANIMAL COMMUNITIES ON SOFT BOTTOMS AND TO ZOOPLANKTON IN OPEN WATER MASSES WAS SIGNIFICANTLY LESS.

IF IT IS THE CASE THAT THIS BLOOM MARKS THE COMMENCEMENT OF A PERIOD WITH MORE FREQUENT BLOOMS OF TOXIC ALGAE SUCH AS CHRYSOCHROMULINA THE RESULT IN THE LONG TERM MAY BE THE DEPLETION OF BOTH ALGAL AND ANIMAL COASTAL COMMUNITIES.

Areas affected

The effects were felt from the west coast of Sweden to a point south of Bømlo in Hordaland (Fig. 4). Most seriously affected were stretches of the coast from Grimstad to Kristiansand, and from Farsund to Flekkefjord. The outer coastal regions were generally more vulnerable than the innermost areas of the fjords. Along most of the coast there was good correlation with regard to the area affected between animals and attached algae. Between Haugesund and Bømlo, however, damage to animals extended a little further north.

Mortality and damage was registered from the surface down to a maximum depth of approximately 30 m. In most localities the lowest level affected was between 14 and 25 m depth. The upper 2- 3 metres were, as a rule, less visibly affected.

Photographs showing the effects are shown in Figure 5.

Fish

Farmed fish in many fish farms were severely affected by the algae outbreak. Hardest hit of wild fish in littoral areas were wrasse (Labridae) such as Labrus bimaculatus, rock cook (Ctenolabrus rupestris) and to some extent goby (Gobiidae) as well as younger yearclasses of cod (Gadus morhua) and whiting (Merlangius merlangius). The year´s cod fry (0-group) was almost entirely wiped out. The most vulnerable species were those with a behaviour pattern which did not allow them to avoid water affected by algae.

In open sea areas a normal distribution of fish has been observed at the various water layers subsequent to the algal bloom. The probable explanation for this is that pelagic species have avoided water affected by algae and returned at a later stage. Bottom fish in open waters have their habitat at deeper water layers than those directly affected by Chrysochromulina.

There is some uncertainty as to what extent fish larvae and fry were affected. These have little or no power of movement and those located in the upper 20 - 30 m may have been affected. However, observations made after the bloom indicated that fish larvae were to be found in the sea over the whole of Skagerrak.

The areas and depth affected by the algal bloom were small compared to the total distribution area of commercial fish species.

Zooplankton

Observations of the pelagic larvae of invertebrate bottom animals indicated apparently normal numbers at two stations in the Langesund-Jomfruland area. There was little investigation of zoo- plankton along the rest of the coast.

Rocky bottom animals

The most severly affected rocky bottom animals were Echinodermata and snails (Gastropoda). Dog whelks (Nucella lapillus) were almost wiped out. In addition sea urchins (Echinus esculentus), starfish (Asterias rubens), periwinkles (Littorina littorea), common whelks (Buccinum undatum), netted dog whelks (Nassarius reticulatus) and pelican´s foot shell (Aporrhais pes-pelecani). In contrast mussels (Bivalvia) and oysters (Ostrea edulis) appeared to be little affected.

The effects on crabs seemed to be limited. However dead edible crabs (Cancer pagurus) were observed. In at least one area in the vicinity of Flekkefjord mortality among edible crabs was total. The lack of observation material made it difficult to determine whether there was any damage to lobster (Homaris vulgaris). Along the coastal zone from Langesund to Tvedestrand there appeared to be normal populations of the small crustaceans sandhoppers (Amphipoda) and marine isopods (Isopoda). Nor did barnacles seem to be affected.

Most frequently affected of the larger Anthozoa was dead men´s fingers (Alcyonium digitatum).

Attached algae

Red algae appeared to be the most severely affected of attached algae. Typical red algae such as sea beech (Delesseria sanguinea), Dilsea carnosa and Ptilota plumosa evidenced the greatest damage.

The brown algae Desmarestia aculeata and Halidrys siliquosa were affected at a small number of stations. Observations made at the end of the survey period may indicate that kelp species have also suffered damage.

Two species of green algae were found to be affected.

Fewer species of attached algae were found in parts of Sørlandet in 1988 than in earlier surveys in the 70's and 80's. Part of the explanation for this may be a general increase in pollution loads in Skagerrak in recent years. However registration in 1988 was less comprehensive.

Soft bottom animals

Surveys of soft bottom fauna up to June 1988 indicate that this part of the ecosystem suffered significantly less damage than rocky bottom communities. One exception was the burrowing sea urchin In a number of locations damage to these consisted of a partial loss of spines. Though the effects on soft bottom fauna may be underestimated because they will be less visible that in the case of rocky bottom organisms and fish, soft bottom fauna are probably better protected because of their burrowing mode of existence.

Delayed effects and recolonization

Any delayed influences on benthic communities will presumably occur via two mechanisms: (1) by sedimentation (settlement) of Chrysochromulina, and (2) by a failure in recruitment due to the extermination of the benthic fauna's pelagic (free-floating) larvae. Very many benthic species (also at great depths) pass through larvae stages where larvae live pelagically in the upper water layers where Chrysochromulina flourished. Information about the potential toxicity of sedimented algae is inadequate, nor has it been ascertained whether there has been a significant reduction in the numbers of pelagic larvae.

In several locations where there had been mass mortality among benthic organisms, living individuals of the same species were later observed (starfish, fish). Moreover observations confirmed that the red algae, sea beech had recommenced growth as early as July, indicating that the algal toxin is either shortlived or that there is a rapid dilution to non-toxic levels. The toxin is unlikely to impede recolonization processes directly. Reared fish which showed symptoms of illness recovered when the fish were moved to better water. It may be the case that lower organisms have a comparable ability to recover after moderate exposure to the algal toxin.

In the long term the biology of the species will determine the course of recolonization in the various biota. This will be dependent on: (1) methods of reproduction (number of progeny. methods of dispersal), (2) migratory ability (along the coast and from deeper to shallower waters), (3) distance to reproductive populations.

It will take longest to recolonize populations of species which have few eggs, a direct development without any pelagic larvae stage, and little migration. The common dog whelk (Nucella lapillus), a species that was almost wiped out, belongs to this category. Most of the other animals affected have a pelagic larvae stage which ensures that they are dispersed relatively easily and can repopulate affected areas.

Recolonization will occur partly by the settlement of pelagic larvae and partly by immigration of adult individuals.

The recolonization of populations of attached species can occur via pelagic larvae stages. Most species spawn annually, so that recolonization can take place within 1-2 years if the dispersal of larvae is favourable.

It is anticipated that the long-term consequences for most species will be limited and that after 1-2 years they will probably have regained their normal densities. However, it is anticipated that recolonization in the case of the dog whelk, which has a restricted dispersal ability, will take a very long time, possibly more than 10 years. For this species, therefore, the effects have been catastrophic, underlining the need for separate follow-up surveys.

1.4 Recommendations

A. New surveys should be conducted at selected stations to check any delayed effects as well as the commencement of repopulation. In the period from July-September sedimented toxic algae may have affected benthic organisms, especially on soft bottoms. Surveys in autumn 1988 will confirm or rebut this. Surveys in June 1989 will establish the stage of recolonization reached.

B. A survey should be made to determine the presence of unharmed populations of dog whelk in the inner reaches of fjords which may not have been affected by the algae invasion. The long term consequences for this species could then be predicted more accurately.

C. Experimental ecotoxicological studies should be conducted in order to acquire an understanding of the operative mechanisms of the toxins produced by Chrysochromulina.

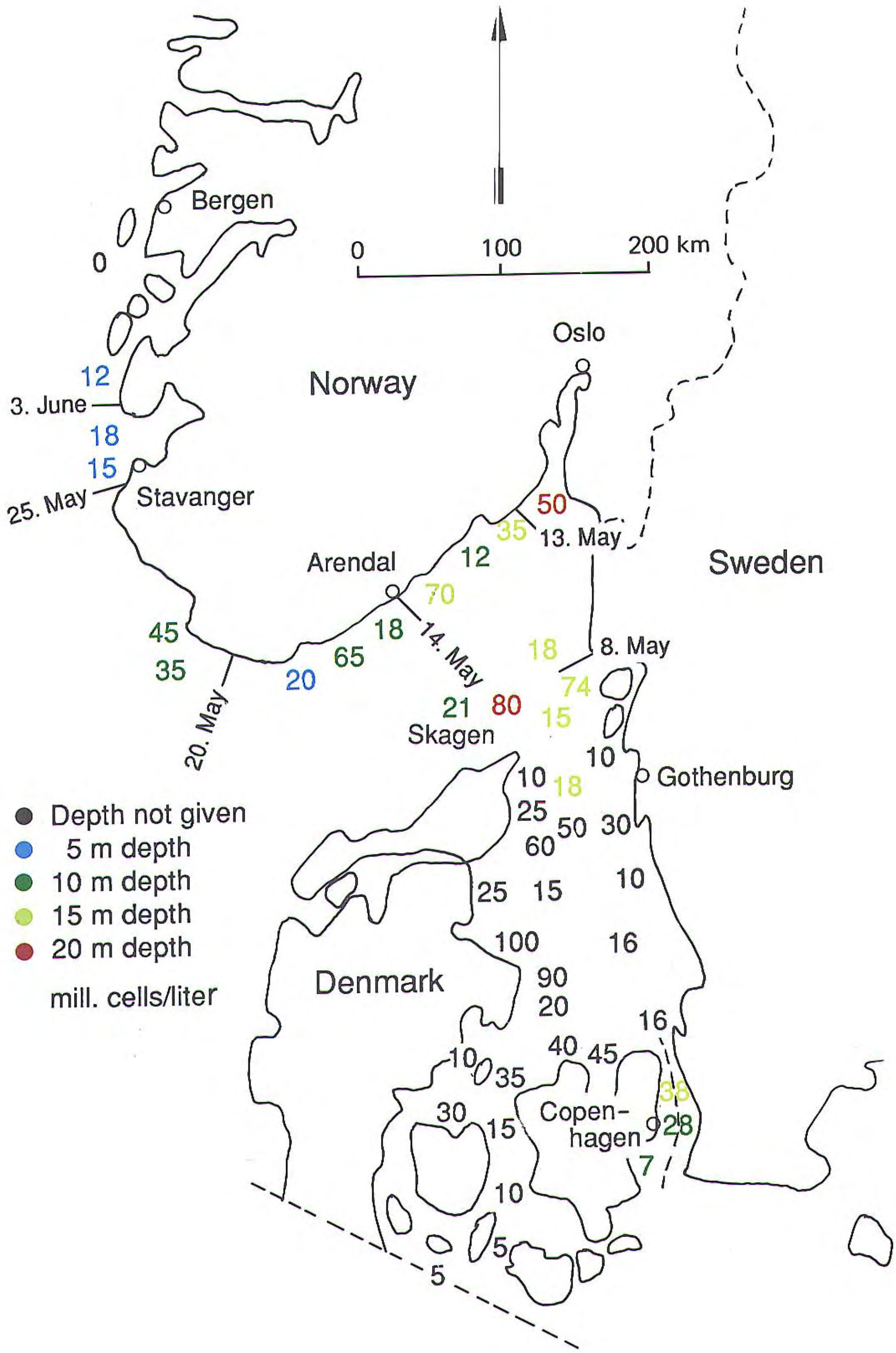


Figure 1. Greatest density of *Chrysochromulina polylepis* millions of cells per litre in different areas of Skagerrak and Kattegat. The dates show the advance of the algae front.

Figure 2. Map showing survey stations for rocky bottom organisms and littoral fish along the south coast of Norway in May-June, 1988.

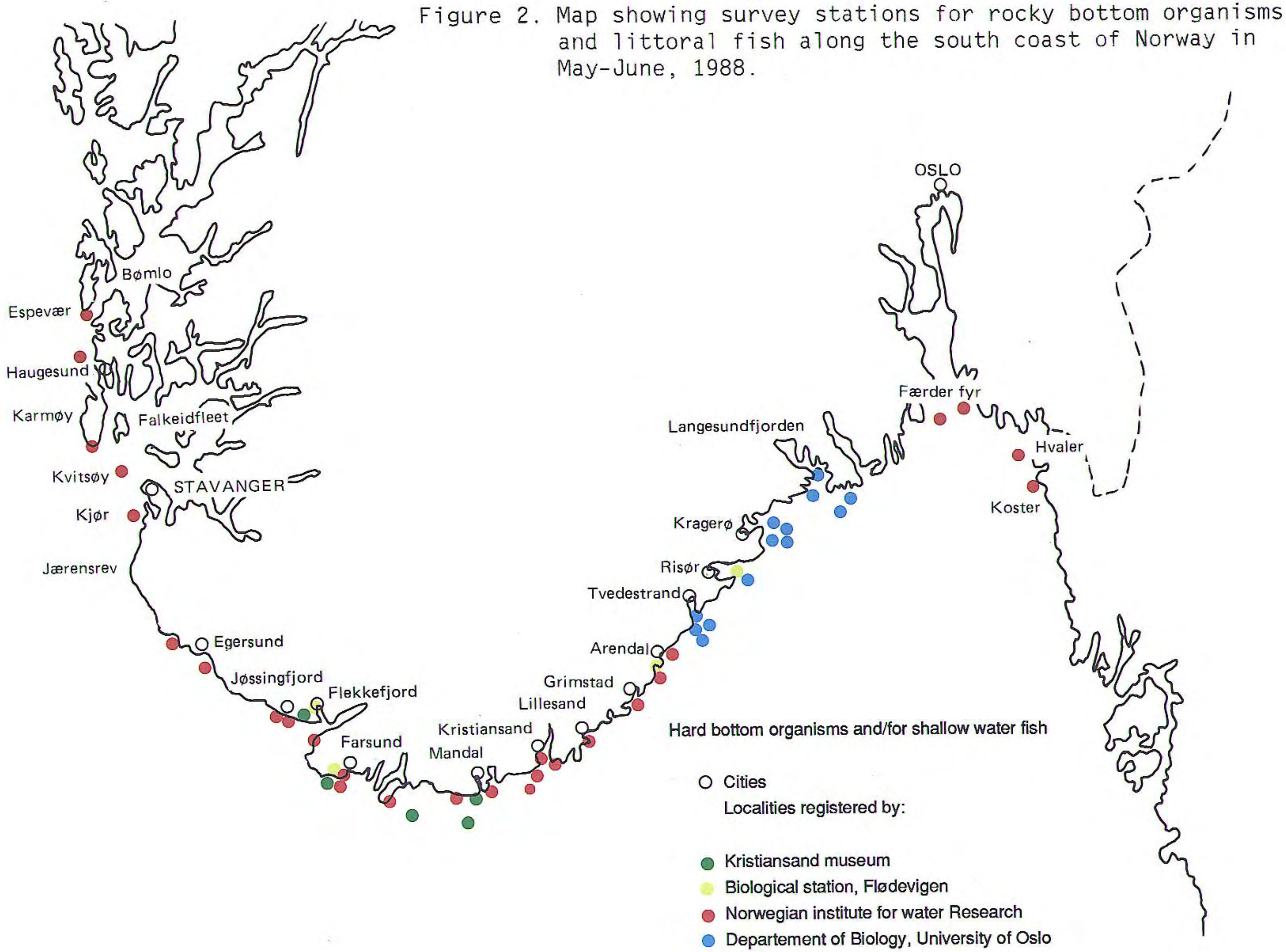
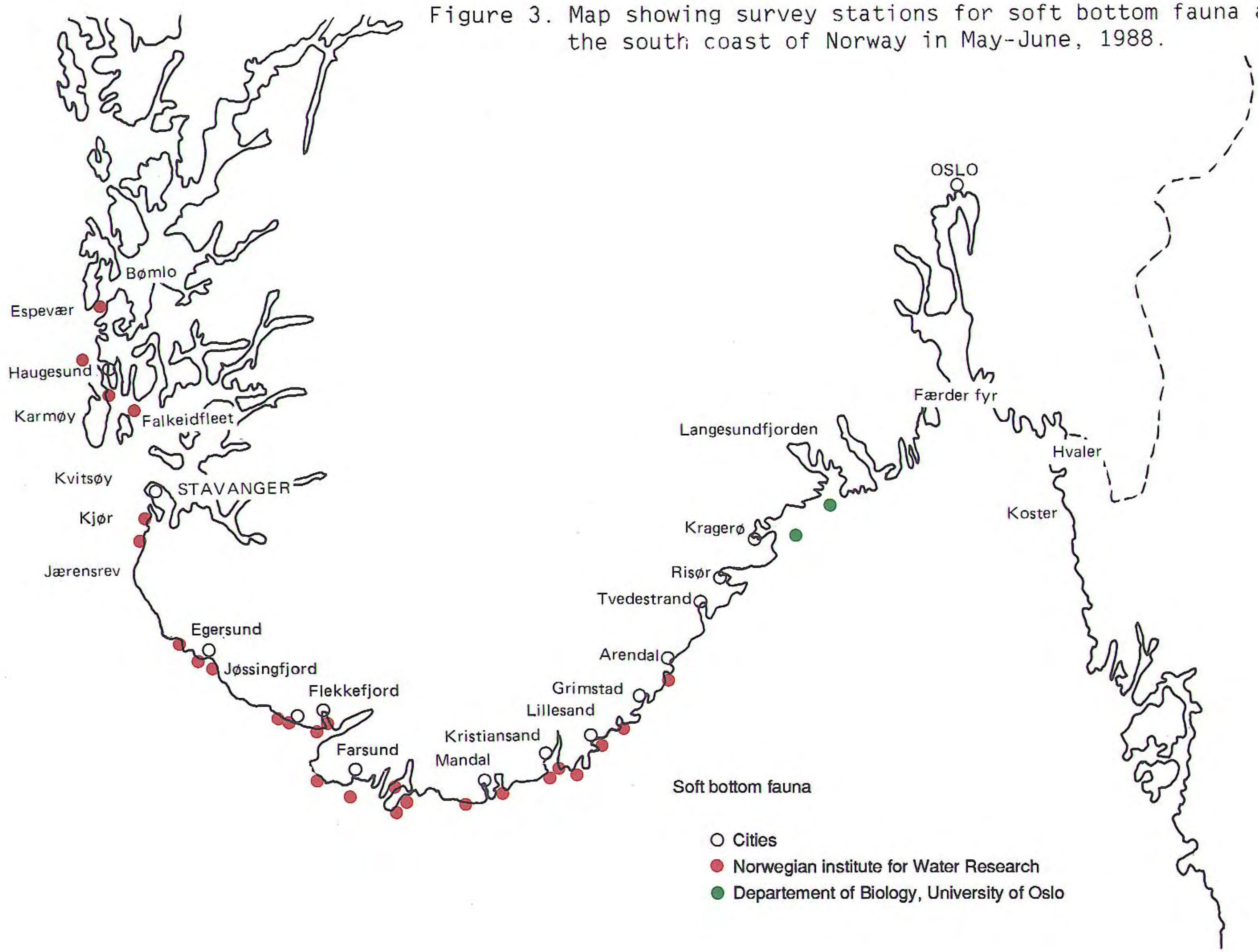


Figure 3. Map showing survey stations for soft bottom fauna along the south coast of Norway in May-June, 1988.



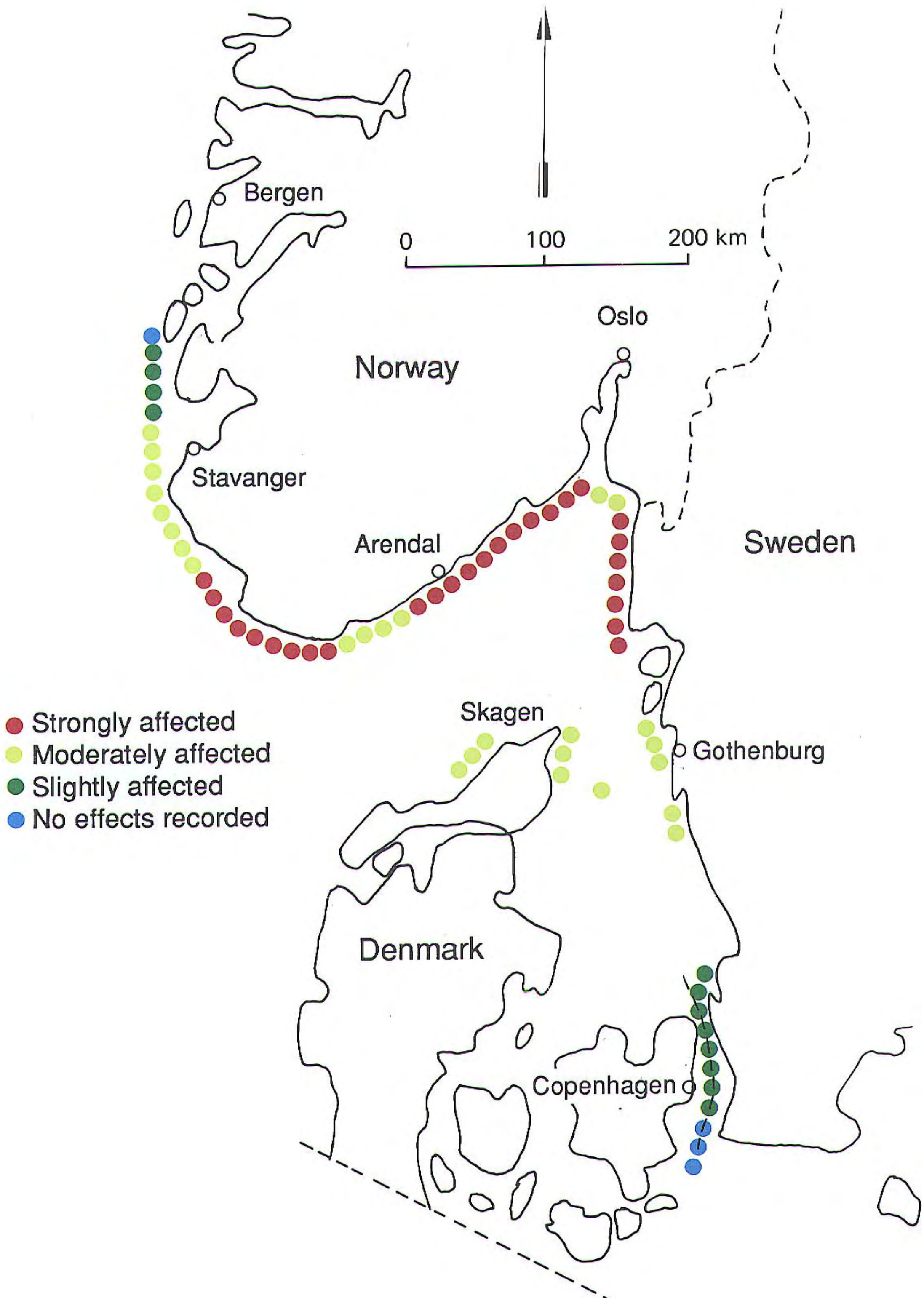


Figure 4. Geographical extent of the area affected and the degree of damage to the biota along the south coast of Norway in May-June, 1988.

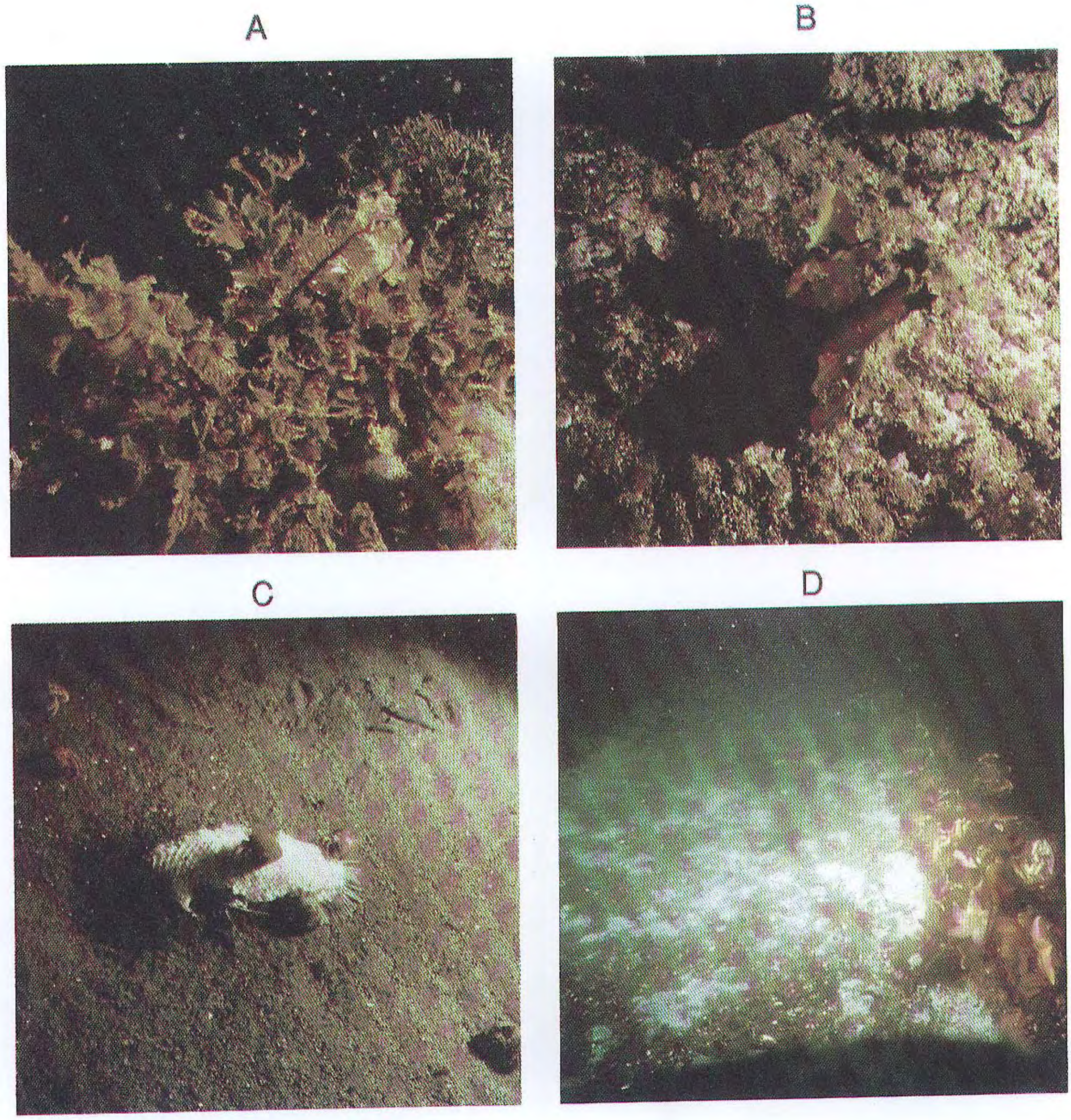


Figure 5. Organisms affected by the planktonic algae <u>Chrysochromulina polylepis</u>

A. Frayed sea beech (<u>Delesseria sanguinea</u>)
B. Discoloured <u>Dilsea carnosa</u>
C. Carcass of an unidentified wrasse, with a hermit crab (<u>Pagurus bernhardus</u>) grazing on the fish.
D. Severely affected sea bed with disintegrating organisms. The common starfish (<u>Asterias rubens</u>) on the right

2. Introduction

The mass outbreak of the algae Chrysochromulina polylepis was first discovered because of mortality among commercially reared salmon on the west coast (Lysekil) of Sweden on May 9, 1988. The bloom of algae spread with the Norwegian coastal current up to Hordaland where the bloom culminated around June 2. On June 9 plant plankton in the areas affected in Vestlandet appeared to be normal for the time of year.The maximum concentration of algae was measured at 90 mill. cells per litre at Skagen, while maximum concentrations of 36 mill. cells per litre were measured in Vestlandet (Egersund) (Fig. 1).

2.1 Rocky bottom organisms / Littoral fish

The main type of habitat from a depth of 0 to 30 m along the affected stretch of the Norwegian coast (from the Swedish border to Vestlandet) is the rocky bottom. This depth interval is within the range where the greatest concentrations of algae were found. In consequence it was natural to survey the biota of this type of bottom to determine the extent of any damage.

Rocky bottoms from a depth of 0 to 30 m have a large biomass per unit area consisting largely of attached organisms. Many of these species are perennial. The various communities in shallow areas on rocky bottoms normally keep to restricted depth intervals. This fixed depth distribution means that one will obtain a fairly good overview of conspicuous deviations which are typical of the area generally by carrying out a survey of abnormal conditions along a vertical belt (transect) in one location.

Many of the organisms in a rocky bottom community are attached or have little power of movement. Unlike fish, therefore, they have no way of avoiding water masses with unsuitable water quality other than, for example, by closing their shells. However, this cannot be done continuously for a prolonged period, and as a result such organisms must either tolerate the water masses they are exposed to or perish. Rocky bottom organisms are comparatively large. In consequence, it will take some time for the remains of dead animals to decompose. This means that dead or damaged organisms may be observed for a relatively long period of time (weeks-months) after the occurrence of the incident.

In the case of fish, only dead individuals can show that there has been exposure to toxic effects. The presence of fish in an area after the occurrence of an environmental disturbance does not necessarily mean that there has not been any mortality. Fish may have returned after conditions were again satisfactory. The technique which was most frequently employed (diving transects) is only suitable for registering dead fish. Due to the relatively restricted area that is investigated in each transect information about acute mortality is provided only where there is a high density of fish which do not avoid toxic water masses.

Catches of fish with a shore seine and net may indicate abnormally low numbers if the anticipated size of the catch is known, e.g. on the basis of previous collection at the same location.

An overview of the various investigations that were conducted is presented in the chapter giving results for rocky bottom organisms/littoral fish.

2.2 Soft bottom organisms

Animals which live in and on bottom sediments (soft bottom fauna) comprise a significant part of the organism spectrum along the coast.

Soft bottom fauna may be vulnerable to the effects of Chrysochromulina in two main ways: via water containing algal cells or toxin from the algae, or via the sedimentation of algae building up a layer on the bottom. The latter mechanism could have a potential effect on areas deeper than those affected by the "living" belt of algae.

The proof of effects on soft bottom fauna rests principally on negative indications, i.e. the lack of species or an exceptionally low number of individuals. The methods employed in the collection of samples considerably limit the extent to which observations of the animals´ status, e.g. whether they are alive or have died recently, can be made. All material is preserved during field work and is studied in detail later.

2.3 Zooplankton

Zooplankton in littoral areas were surveyed within the area covered by the University of Oslo (Langesund-Tvedestrand). Samples were collected with a WP-2 net with a 200µm mesh, drawn vertically from a depth of 100-0 m, and a Mini-Neuston net (with a mesh of 150um) which collects surface plankton down to a depth of 30 cm. More open sea areas were covered in investigations varried out by the Institute for Marine Research, Bergen, with a scoop net (275 µm) drawn from 200-0 m and from 30-0 m.

3. Survey areas and selection of stations

Shortly after the bloom of Chrysochromulina field work was planned by several institutions to examine any effects on rocky bottom organisms, soft bottom fauna and littoral fish (Table 1, Figs. 2 and 3). The University of Oslo selected 17 stations in the area from the Langesund Fjord region south to Tvedestrand. In addition 7 inspections were carried out in the tidal zone and at two shore seine stations in the same area. Flødevigen Biological Station surveyed the Risøy area (9 diving stations), the Arendal area (7), the Farsund area (2), and Flekkefjord (3). At a few diving stations catches were also made with a shore seine and a trammel net. Per Arvid Åsen of the Kristiansand Museum revisited 8 stations between Mandal and Hidra which he had surveyed 12 years earlier in connection with his thesis.

NIVA´s 37 rocky bottom stations were selected taking these locations into account so as to provide comprehensive coverage of the entire south coast and thereby determine the geographical extent of the effects. As regards the selection of stations, locations that were presumed to be little affected by pollution from land were preferred. All the stations, with the exception of two (St.1B, 1C, and 2), were located in exposed situations.

Table 1. Survey areas, selection of stations and purpose, in connection with the bloom of the algae <u>Chrysochromulina polylepis</u>, May-June, 1988. KRMU = Kristiansand Museum, SBSF = Flødevigen Biological Station, UOBI = University of Oslo, Department of Biology, NIVA = The Norwegian Institute for Water Research.

Area investigated: / Number of stations (aims)	survey of the tidal zone	diving station	shore seine station	net station	trammel net station	grab sampling (soft bottom)	triangular scraper	plankton survey	station code	institution responsible
Syd-Koster		1							OA	NIVA
Hvaler		3							OB OC OD	NIVA
Færder fyr		1							OE	NIVA
Langesundfjorden		2							B C	UOBI
			2						A D	UOBI
				2					A D	UOBI
					1				E	UOBI
						1			E	UOBI
Kragerø		3							H I K	NIVA
			1						L	UOBI
				2					I L	UOBI
					1				J	UOBI
						1			F	UOBI
							3		F G J	UOBI
Risør		9							1-9	SBSF
		1							M	UOSF
			18						12-15 18-22 24-26 30 32-35	SBSF
					25				1 5 6a 6b 7 9 10-13 15-16 18 20-31	SBSF
Tvedestrand	2								N O	UOBI
		3							N O Q	UOBI
						5			13-14 16-18	NIVA
							4		15-17	NIVA
Arendal		6							11-16	SBSF
		3							4 4B 5	NIVA
			9						1-9	SBSF
				8					2-6 9-11	SBSF
						9			6-10 12 19-21	NIVA
							5		7-8 11-12 21	NIVA
Grimstad		7							1 1B 1C 2 3 6 7	NIVA
						13			I-VI 1-5 22-23	NIVA
							10		I-IV VI 1-5 21	NIVA
Lillesand		2							8 9	NIVA
						7			24-30	NIVA
							2		25 28	NIVA
Kristiansand		1							6.4	KRMU
		4							9-12 12B	NIVA
						7			31-34 34B 35-36	NIVA
							2		32 37	NIVA

Table 1 (cont.)

Number of stations – aims

Area investigated	survey of the tidal zone	diving station	shore seine station	net station	trammel net station	grab sampling (soft bottom)	triangular scraper	plankton survey	station code	institution responsible
Songvaar		1							5.11	KRMU
						3			38 41-42	NIVA
							2		39 40	NIVA
		1							13	NIVA
Mandal		2							4.5 4.21B	KRMU
		3							14-16	NIVA
						1			43	NIVA
							4		44-47	NIVA
Lindesnes		2							3.17B 3.8	KRMU
		1							17	NIVA
						2			48 51	NIVA
							3		49-50 52	NIVA
Lista/Farsund		1							2.2	KRMU
		2							17-18	SBSF
						1			54	NIVA
							2		53 56	NIVA
		1							18	NIVA
Hidra/Varnes		3							19-21	SBSF
		1							1.2	KRMU
		2							19-20	NIVA
						1			58	NIVA
							2		57 59	NIVA
Jøssingfjord		1							21	NIVA
						2			60-61	NIVA
Egersund		2							22-23	NIVA
						6			62-68	NIVA
							1		68	NIVA
Jærens rev						1			69	NIVA
							1		69	NIVA
Rott		1							24	NIVA
						2			70-71	NIVA
							2		70-71	NIVA
Kvitsøy		1							25	NIVA
Karmøy		1							26	NIVA
						1			73	NIVA
Falkeidflæet						1			72	NIVA
Haugesund/Espevær		1							27	NIVA
						1			74	NIVA
Bømlo		1							28	NIVA
						1			75	NIVA

Similarly it was anticipated in the case of soft bottom fauna that the most severe impacts would be discovered in shallow bottoms. Consequently, the majority of stations were located at depths of less than 30 m (Fig. 3). However, only two stations were located at depths of less than 10 m. on account of the difficulty of finding suitable soft bottoms at such shallow depths. From 16 to 40 m there is relatively good coverage (Table 2). The stations in the deeper sector had two purposes: (1) to correlate results against a depth gradient in order to bring out the contrast between affected stations in shallow waters and unaffected stations at greater depths, and (2) to determine whether deep stations were affected as a result of the sedimentation of Chrysochromulina.

Table 2. The distribution of soft bottom fauna stations according to depth.

DEPTH (M)	STATIONS
5-10	II, 48
11-15	51, 64
16-18	I, V, 42, 65
19-20	10, 38, 53, 69, 70
21-25	58, 61, 67, 75
26-30	5, 26, 74
31-40	28, 63, 66
41-60	III, 71, 72
140	7

Altogether 63 soft bottom fauna stations were sampled with a grab. Some of these had been sampled previously in connection with other projects. Unfortunately very few of the latter were located in shallow waters. Samples of the material collected from 28 stations were studied, i.e. species and numbers were determined. A number of samples were also collected with a benthic sledge and scraper. Material collected in this way was evaluated in part on board. The location of soft bottom fauna stations is shown in Figure 3.

4. Material and methods

4.1 Rocky bottom communities

4.1.1 Diving surveys

At each of the stations selected, registration of prominent macroscopic bottom algae and animals was undertaken. In principle, this covered the area from the upper to the lower limits for the growth of attached "leafy" or filamentous algae, which was in practice down to a depth of 10-30 m. Surveys were mainly carried out in sectors with a breadth of 5-20 m. from the shore. The registration was carried out by a diving marine biologist. Observations comprised chiefly depth, type of substratum, inclination, algae and animal species and their condition at various depths: unaffected (healthy) or various degrees of severity such as dying, feeble, dead (all covered by the term "sick". Topographical conditions (unfavourable or highly varied bottom) frequently resulted in deviations from the intended path, especially in water deeper than 5 m. A rough evaluation of the catch was made categorized as follows: individual finds, sparse, normal, and dominant. Observations were first and foremost aimed at the larger forms of life.

The presence of living and dead littoral fish was also recorded by the divers. The presence of living and dead fish in the same locality indicates that toxic effects have been present, but that there has been a later migration of fish from unaffected depths, or a return of fish which had sought refuge elsewhere.

Observations carried out by divers form the main body of data in the survey. Moreover, these observations were supplemented with video films and photographs. A few reports from amateur divers were also included.

Diving clubs along the south coast were contacted at the instigation of the Flødevigen Biological Station. At the annual reunion of these clubs held on the island of Tjøme on June 5 attention was directed towards the recording of damage and a representative for NIVA held a course. Later a registration form was sent to the clubs and a follow-up course was held at Flødevigen.

4.1.2. Collection of fish

In order to evaluate the effects on fish, surveys were also carried out under the auspices of the Flødevigen Biological Station (SBSF), and the University of Oslo, using shore seines and nets (SBSF only) in the Arendal, Tvedestrand, Risør, Kragerø, and Langesund areas. In the case of surveys in the Arendal and Risør regions (Gjøsæter and Johannessen, 1988) catches were compared with corresponding catches in

1986 and 1987, in addition to a quantative collection of dead fish undertaken by divers. Considerable importance has been attached to the observations of the Institute for Marine Research, Bergen, in the evaluation of potential damage to fish resources (Berge and Føyn, 1988).

4.2 Soft bottom fauna

At most stations four parallel samples were collected using a $0.1m^2$ Petersen grab. These parallel samples were incorporated in one. The samples were drained through a 1.0mm mesh prior to conservation.

5. Results and discussion

5.1 Effects on rocky bottom organisms

There is relatively good correlation between the results of the various surveys in the case of the species that are severely affected with only a few exceptions.

5.1.1 Attached algae

It is first and foremost red algae that have been found to be affected (Table 3). Altogether 19 red algae taxa, 3 brown algae taxa, and 2 green algae taxa were recorded as damaged, i.e. frayed or discoloured leaves.

Most severely affected are typical red algae such as sea beech (*Delesseria sanguinea*), *Dilsea carnosa*, and *Ptilota plumosa*. In addition *Membranoptera alata* was registered as damaged at all stations in West-Agder (Åsen, 1988).

In comparison with surveys in West-Agder 1975-76 (Åsen, 1978) and 1982-83 (Green et al., 1985) the survey conducted in 1988 (Åsen, 1988) recorded fewer species of red algae (approx. 53 in 1975-76 and 1982-83 versus 39 in 1988), brown algae (38 versus 28), and green algae (approx. 18 versus 9). Active attempts were made to trace the missing algae. According to Åsen (1988) this cannot be ascribed solely to the outbreak of *Chrysochromulina* but may also be due to a general increase in pollution loads in Skagerrak in recent years.

The large species of kelp (*Laminaria* spp.) have not been conclusively registered as affected; damage, stipes without "leaves", etc., have been ascribed to natural wear and tear. However, observations from several sources (fishermen, amateur divers, Kristiansand Museum, the National Biological Station, NIVA) may nevertheless indicate that the *Chrysochromulina* bloom has had some influence.

Chaetomorpha sp. (=*melagonium*?) and *Codium fragile* are registered as affected of the green algae (single observation).

On the basis of this overview it seems clear that algae with a sparse/"loose" thallus/thallus parts are most severely affected, especially red algae such as *Delesseria sanguinea*, *Membranoptera alata*, *Dilsea carnosa* and *Ptilota plumosa*. More robust red algae such as *Phycodrys rubens* and *Odonthalia dentata* are less affected.

The overall evaluation of attached algae reveal that the coast of counties of Agder appears to be most severely affected (NIVA stations 9, 10, 19, 20).

Table 3. Overview of attached algae visibly affected by *Chrysochromulina polylepis* May-June, 1988.

Organism Latin name	English name
RØDALGER	
Callophyllis laciniata	
Ceramium sp.	
Ceramium rubrum	pottery seaweed
Ceramium strictum	
Corallina officinalis	coral moss
Delesseria sanguinea	sea beech
Dilsea carnosa	
Eutora cristata	
Membranoptera alata	
Odonthalia dentata	
Phycodrys rubens	sea oak
Phyllophora pseudoceranoides	
P. truncata	
Polysiphonia urceolata	
Ptilota plumosa	
Rhodomela spp.	
Rhodomela confervoides	
encrusting red algae	
Trailliella intricata	rødlo
BRUNALGER	
Desmarestia aculeata	vanlig kjerringhår
" *viridis*	mykt kjerringhår
Halidrys siliquosa	skolmetang
GRØNNALGER	
Chaetomorpha sp.	
" *melagonium*	laksesnøre
Codium fragile	pollpryd

5.1.2 Benthic animals

Especially affected of the soft bottom animals was the common dog whelk (Nucella lapillus) which showed a high rate of mortality. In addition, populations of periwinkle (Littorina littorea), common whelk (Buccinum undatum), netted dog whelk (Nassarius reticulatus), mussels (Hiatella arctica) and others were in part significantly affected (Table 4). Echinoderms were very severely affected at a large number of stations, especially starfish, (Asterias rubens) and sea urchins (Echinus esculentus). A complete list of affected species, together with an indication of basic facts about their life history, is presented in Table 4.

The various surveys along the coast indicate that the species which were seriously affected are the same in widespread areas.

A problem as regards the presentation of lists of affected species is that the criterion for determining whether a species is affected is frequently that there have been observations of dead animals. However in normal circumstances there is also a certain amount of mortality which is due to various other causes. Thus there is a danger in the case of species where single deaths have been recorded at one or only a few stations that these may be attributed to the effects of Chrysochromulina when they may also be due to other factors. One such species is Porania pulvillus of which one individual was found affected at one station. A further problem is that a species must be present and recorded from the outset so as to make it possible to observe any changes.

Table 4. Overview of characteristics of invertebrate bottom animals in shallow waters visibly affected by Chrysochromulina polylepis in May-June, 1988.

Hab. - main habitat: h=rocky bottom, b=soft bottom
Feed. - method of feeding: (principal method) s=suspension feeder, f=filter feeder, h=herbivore, k=carnivore, d=detritus feeder, å=scavenger
Rep. - p=life cycle with a pelagic stage
- B=life cycle with a benthic stage only
Degree - estimated degree of damage

0 = unaffected
I = slightly affected, some "sick" individuals
II = moderately affected, parts of the population dead or "sick".
III = severely affected, dead animals found *in situ*, majority of population exterminated or "sick".

Organism Latin name	Norwegian name	Hab.	Feed.	Rep.	Degree
SPONGES					
Halichondria panicea	Bread Crumb Sponge	h	s	p	?
Alcyonium digitatum	Dead Men´s Fingers	h	s	p	II
SEA ANEMONES					
Cerianthus lloydi		b	s	p	?
Metridium senile	Plumose Anemone	h	s	p	I
Urticina felina		h	s	p	I
MARINE BRISTLE WORMS					
Polychaeta indet.		b/h			
Arenicola marina	Lug worms	b	d	p	I
Nereis sp.		b/h	k	p	III
Sabella penicillus		h	s	p	III
CHITONS					
Polyplacophora indet.		h	h	p	III
SNAILS					
Acmea sp.		h	h	p	I
Aporrhais pes-pelicani	Pelican´s foot	b	å	p	III
Buccinum undatum	Common whelk	b/h	å	B	III
Gibbula cinerea	Grey top shell	h	h	p	III
Littorina littorea	Common periwinkle	h	h	p	III
Littorina obtusata	Flat periwinkle	h	h	B	I
Nassarius reticulatus	Netted dog whelk	b/h	å	p	III
Nucella lapillus	Common dog whelk	h	k	B	III
Patella cf. *vulgata*	Common limpet	h	g	p	III
MUSSELS					
Anomoniidae indet.		h	f	p	III
Cyprina islandica	Ocean quahaug	b	f	p	II
Hiatella arctica		h	f	p	II
Mytilus edulis	Blue mussel	h	f	p	I
BARNACLES					
Balanus improvisus		h	s	p	I

Table 4. (cont.)

Organism Latin name	Norwegian name	Hab.	Feed.	Rep.	Degree
CRABS					
Cancer pagurus	Edible crab	h/b	k/å	p	I
Carcinus maenas	Common shore crab	h/b	k/å	p	I
Pagurus cf. bernhardus	Hermit crab	h/b	å/d	p	I
MOSS ANIMALS					
Electra pilosa		h	s	p	II
STARFISH					
Asterias rubens		h/b	k	p	III
Porania pulvillus		h/b	k	p	?
BRITTLE STARS					
Ophiura albida		h/b	k/d	p	II
SEA URCHINS					
Echinoidea indet.				p	
Echinus esculentus		h	h/k	p	II
Psammechinus miliaris		h	h/k	p	II
SEA SQUIRTS					
Ascidiacea indetn.			f	p	
Ascidiella spp.		h	f	p	III
Ciona intestinalis		h	f	p	III
Corella parallelograma		h	f	p	III
Styela rustica		h	f	p	III

The significance of the ecological effects recorded must be evaluated against the percentage of the total population affected. In the case of a few species, observations of damage have been made at several stations but these have constituted only an insignificant number of individuals in relation to the total population. This applies especially to mussels (Mytilus edulis), hermit crabs (Pagurus cf. bernhardus), barnacles (Balanus) and perhaps large kelp (Laminaria hyperborea). This means that observed mortality /damage in the case of these species is insignificant in the context of the entire population. However, in the case of other species (Nucella, Echinus, Asterias), mortality was practically total in the areas/depths that were affected. For these species the life history´s strategy and behaviour will determine future consequences for the population in that area.

Invertebrates of commercial interest among the natural biota on rocky bottoms are probably limited to lobster (Homarus gammarus) and edible crabs (Cancer pagurus). At most stations where dead crabs were found, living individuals were also recorded. One exception was an area directly east of Lista Lighthouse (NIVA- station 19 - Vårnes) where a massive total mortality of crabs was observed. There were also reports of the total extermination of Lithodes maja (Gjøsæther and Johannessen, 1988) from an area in the vicinity of this station (Hidra). No mortality among lobster has been reported as a result of the algal bloom. However, there is insufficient observation data for this species to determine whether there has been any significant mortality. This year´s lobster catch may perhaps provide the answer.

Mortality was minimal, however, for other crustaceans such as barnacles (Balanus) and hermit crabs (Pagurus cf. bernhardus). In the case of small crustaceans such as isopods and sand hoppers (Amphipoda) there is some mortality. It is difficult to determine the extent of the damage to these groups, however, because the technique employed in observation and collection is not suited to animals of their size.

As far as mussels are concerned it appears that saddle oysters (Fam. Anomiidae) and Hiatella arctica have suffered marked damage in widespread areas. In one location (Nordfjorden in the vicinity of Risør) approximately half the population of o-shells (Modiolus modiolus) was dead. In contrast mussels (Mytilus edulis) and oysters (Ostrea edulis) did not appear to be significantly affected. Both living and dead mussels of other species were also found. Dead individuals were mostly found singly so that there was no basis for determining whether they had been exposed to algal toxins.

Snails (Gastropoda) appear to be relatively hard hit. This applies especially to the common dog whelk (Nucella lapillus) (Table 4). Moreover, populations of periwinkles (Littorina littorea), common whelks (Buccinum undatum), netted dog whelks (Nassarius reticulatus), pelican's foot shell (Aporrhais pes-pelecani), and Gibbula were also found to have suffered considerable damage in part (Gjøsæter and Johannessen, 1988). The common periwinkle (Littorina littorea) is a species which is abundant in the tidal zone and in somewhat deeper water. This species was significantly affected in part in some areas of Sørlandet and Vestlandet (Tisler, areas around Grimstad, Risør, and Arendal) whereas registrations west of Mandal where the species was apparently healthy were sporadic. In all probability stations west of Mandal were too exposed for there to be large numbers of the common periwinkle. In areas where the periwinkle was affected this could take the form either of death or that individuals lay on their "backs" with their bodies partly out of the shell but still alive. Many of these individuals survived.

The most frequently affected of Anthozoa was dead men's fingers (Alcyonium digitatum). Furthermore species such as bread crumb sponge (Halichondria panicea) and Urticina felina were also affected to some extent.

Echinoderms appear to be the other main group in addition to snails that is hardest hit. This applies particularly to sea urchins such as Echinus esculentus which grazes on kelp and starfish such as Asterias rubens which preys on mussels. In areas where the effects on Echinus were sublethal, the spines on top were either missing or else they had assumed an unnatural position.

Sea squirts (Ascidiacea) are a group of organisms which have held their own in most areas with the exception of the Ascidiella species. Nevertheless, there was some mortality among other species in this group. In a few areas (e.g. Skårekrakk on the coast of Østfold) there were large populations of sea squirts. The clear demarcation between living and dead individuals enabled a fairly accurate determination of the lower limit for effects to be made.

5.1.3. Geographic distribution

Surveys of shallow water organisms revealed that the whole of the coast from South-Koster to the Haugesund area was to some extent affected by Chrysochromulina polylepis. From the Haugesund area northwards no damage to algal vegetation was recorded while one had to travel further north to Bømlo to find the registered benthic animals more or less unaffected. At Bømlo sea urchins (Echinus esculentus), which had proved to be one of the most vulnerable species, were all alive. However, here too the surface spines of a few individuals were not erct. These observations indicate that Bømlo lay north of the northern limit for damage to attached algae and very close to the northern limit for damage to animals in June 1988.

The variation in the degree of damage was dependent on the locality. Broadly speaking, damage was greatest in the archipelago and least innermost in the fjords. The surveys of both the University of Oslo, Department of Biology (UOBI) and SBSF imply this. In some areas, however, considerable damage was observed on occasion far inside fjords (Nordfjorden in the Risør area). In addition, there were entirely local variations where the outside of an islet could be more affected than the inside (UOBI). SBSF reports from the Risør region that two areas close to each other showed a relatively large divergence in the extent to which they were affected. A characteristic difference between the two localities was that in the case of the locality (Søndeled) where damage was slight there was a considerable inflow of fresh water. This implies that it is not only the degree of exposure that determines the extent of damage but also the flow of fresh water. Observations that fish have better chances of survival in brackish water than in salt water with the same concentrations of algae confirm this.

The present body of material does not permit any detailed description of any geographic variations in the effects on each single species, firstly because the methods employed are somewhat different, and secondly because the composition of the species at various stations is not exactly the same (a species must be present to be affected). The main impression, nevertheless, is that there is little qualitative variation in the effects of the algal bloom on benthic populations along the outer coastal areas. Local factors such as the input of fresh water and location in relation to the coastal stream appear to be of greater significance than the location on the coast.

5.1.4 Affected depth intervals

The mean lower limit for effects was 16 m basing the calculation on NIVA´s rocky bottom stations. SBSF´s surveys suggest that damage in the Risør, Arendal, and Farsund areas extended to a depth of 10-13 m whereas the surveys conducted by UOBI indicate a lower limit of 10-15 m depth. However, in some places (Flekkefjord and Tromøya) damage was recorded as far down as 30 m. The mean upper limit for effects was a depth of 3 m (based on NIVA´s rocky bottom stations), although damage was reported right up to the surface and the littoral basin (dog whelk).

The lowest limit was often marked by discoloured Dilsea carnosa or sea beech (Delesseria sanguinea). The upper depth affected by Chrysochromulina varied from 0 to 10 m. but lay normally at a depth of 2-3 m. The upper metres were often little affected. The reason for this may have been that at this depth interval turbulent water removed damaged organisms relatively quickly.

Flødevigen has received approximately 50 reports from amateur divers, recording damage from the Swedish border to Haugesund in the period from the end of June to the middle of August. The geographical extent of the damage correlates with NIVA´s findings.

The contribution of amateur divers will also be useful in follow- up surveys.

5.1.5 Observed short-term changes

Short-term changes were evaluated at 4 stations in the Grimstad area: St.1, 2, 3, and 6, which were sampled on 30-31/5 and 15- 16/6. St.2 (Maløy) and 3 (Moistrand) had similar bottom conditions. They were located in sheltered shallow waters with a sandy bottom. St.1 (Graaholmen) and 6 (Prestholmen) were exposed, with a rocky bottom reaching down to the lower limit for diving observations (25-30 m.) St.1 and 6 were comparable, but for technical reasons the initial registrations at St.1 were incomplete. With a proviso on variations caused by the registration methodology, some changes could be traced in the course of the fortnight.

A striking change was the decrease in the numbers of dead or "sick" animals. This was most marked at the two most sheltered stations (St.2 and 3). There was a considerable decline in the bloom of Chrysochromulina from May 30-31 to June 15-16. This, together with decomposition, scavenging, and water transport, may have brought about a decrease in the evidence of effects in June.

At St.3 (Moistrand) hollows in bottom sediment caused by the lug worm (Arenicola marina) were abnormally shaped. Normally these hollows have an even conical shape, but on the first inspection (31/5) most of them were uneven as if the middle section had suddenly dropped 3-5 centimetres. The sides of the middle section had not collapsed inwards, indicating that the change had occurred recently. The base of these hollows was frequently covered by a white film which is often a sign of the decomposition of plants and animals. In this case the film may be due to an accumulation of organisms in the hollows. Two weeks later the hollows made by the lug worm were nomally shaped. This may indicate that the lug worm was only temporarily affected by Chrysochromulina or partiallly damaged. At St.2 (Maløy) where bottom conditions were quite similar there were no registrations of abnormalities in the case of the lug worm.

Asterias rubens and the common whelk (Buccinum undatum) were severely damaged. At both St.2 and 3 these species were registered as "sick" or dead on the first inspection (30-31.5) but there were no registrations two weeks later. This indicates that recolonization in the case of these two species took place from elsewhere.

The periwinkle (Littorina littorea) and the hermit crab (Pagurus cf.bernhardus) were partly damagaed at St. 2 and 3. The percentage of dead or dying common periwinkle declined from an estimated 90% to 20% at St.3. There was no significant change in the percentage (20%) of affected hermit crabs (Pagurus cf. bernhardus) at the same station. These registrations imply that the periwinkle was more severely damaged than the hermit crab.

During this period there were indications that Dilsea carnosa at St.6 was further affected. The lower limit for affected Dilsea carnosa was approximately 10 m on 31 May and 15 m on June 16.

5.2 Effect on wild fish

The extent of damage to fish is determined by (1) the registration of dead fish (NIVA, Flødevigen) and (2) by comparing catches of live fish with what might be expected on the basis of previous experience (UOBI, Flødevigen, Institute for Marine Research, Bergen).

Table 5 provides a summary of the species of fish which were observed or assumed to be affected in littoral areas.

Finds of dead fish by divers a short time after the bloom of Chrysochromulina can, with reasonable certainty, be attributed to the toxic effects of this algae, but they provide only limited data on the total of dead individuals in relation to the population. In cases where only a few individuals were found dead there is a fairly strong likelihood that this may be due to other causes, and, regardless of cause, this is irrelevant in the context of the whole population.

Among the species which were found dead there was a predominance of benthic fish associated with littoral areas. Nevertheless, a few individual pelagic fish such as herring and garfish were also found dead. In contrast, there were no observations of dead sprat, a pelagic fish which is to be found in sizeable numbers in shallow littoral areas. Consequently, the total effects on pelagic species are probably negligible.

An overall assessment based on the finds of dead fish is that species/groups such as wrasse (particularly rock cook and cuckoo wrasse in particular), and to some extent goby, appear to be most affected, but that single individuals of a number of other species of littoral fish have also been affected. A contributory factor to the extreme vulnerability of rock cook, cuckoo wrasse and goby is probably that at that particular time of year they are to be found at the depth level affected by the algal bloom together with various other species (Table 5). Moreover, the behaviour pattern of wrasse and goby in response to stress leads them to seek refuge in their immediate environment below rocks or in rock crevices, or they burrow down into the sand (e.g. Pomatoschistus minutus and Pomatoschistus microps) when they are exposed to stress. The result is that they remain in the toxic water masses and are thereby exposed to toxic effects over an extended period of time. The species most frequently reported dead on the bottom are mainly species of no direct commercial importance.

The problem that arises in connection with catches of live fish is the assessment of the size of a normal catch and the degree of deviation that can be accepted before assuming that an abnormal acute incident has taken place. The Flødevigen Biological Station, (SBSF) has compared shore seine hauls in the Arendal and Risør areas with two previous years. In the Arendal district they found that cod (yearclass 1 and 2), rock cook, and whiting (yearclass 0) were the species that were most sharply reduced in comparison with previous years. In the Risør area cod was reduced in number while there was a slight increase in the numbers of rock cook. There was no registration of whiting at all. Catches carried out with a net showed moderate variations. Surveys in the Langesund-Tvedestrand area make a rough comparison of shore seine catches with what might be expected in the region. The catches were judged to be abnormally small with a low number of species and individuals. In particular, there were remarkably low numbers of goby, wrasse, and flatfish, together with the complete absence of the 0-group of codfish (saithe, cod, whiting, and pollack). In addition it was pointed out that several other groups were poorly represented (pipefish, sticklebacks, viviparous blenny, and to some extent bullhead). The older yearclasses of cod were relatively unaffected by the algal bloom (on the evidence of diving surveys), but they were severely affected at earlier stages (shore seine hauls). The year´s cod fry (0-group) cod was almost utterly wiped out.

Institute for Marine Research, Bergen, has undertaken registrations of fish with a trawl in open sea areas affected by Chrysochromulina (Appendix to Berge and Føyn, 1988). Dead fish were observed in only one area (east of Fredrikshavn). A preliminary overall assessment suggests that the effects on fish in the open sea have been slight.

Table 5. Overview of fish species that are probably affected by the mass bloom of <u>Chrysochromulina polylepis</u>. A rough estimate of the degree of damage is indicated. The institution which has verified damage or death is given, (SBSF = Flødevigen Biological Station, UOBI = University of Oslo, Department of Biology, NIVA = The Norwegian Institute for Water Research) and in cases where only a few individuals were found, this is indicated.

A. Species observed dead or injured (diving observations).
B. The five species of fish which (1) showed the greatest decrease in shore seine catches in the Arendal and Risør areas and (2) the species which UOBI assessed as most affected in catches in the Langesund-Tvedestrand area.

Latin name	English name	Intensity of damage
A.		
<u>Belone belone</u>	Garfish (few)	slight (NIVA SBSF)
<u>Clupea harengus</u>	Herring (few)	slight (SBSF)
<u>Cyclopterus lumpus</u>	Lumpfish (few)	slight (SBSF)
<u>Entelurus aequoreus</u>		slight (SBSF)
<u>Gadus morhua</u>	Cod (adult) (few)	slight (NIVA SBSF)
<u>Merlangius merlangus</u>	Whiting (adult) (few)	slight (SBSF)
<u>Molva molva</u>	Ling (few)	slight (SBSF)
<u>Myxocephalus scorpius</u>	Bullhead (few)	slight (NIVA)
<u>Phrynorumbys norvegicus</u>	Norwegian topknot (few)	slight (SBSF)
<u>Platichthys flesusa</u>	Flounder (few)	slight (SBSF)
Pleuronectidae	Flounder indet. (few)	slight (NIVA)
<u>Psetta maxima</u>	Turbot (few)	slight ? (NIVA)
<u>Salmo trutta</u>	Sea trout	slight ? (SBSF)
<u>Trisopterus minutus</u>	Poor cod (few)	slight ? (SBSF)
Callionymus sp.	(few)	medium (SBSF)
<u>Cilita mustela</u>	Fivebeard Rockling (few)	medium ? (SBSF)
<u>Labrus berggylta</u>	Ballan wrasse	medium (NIVA SBSF)
<u>Pholis gunnellus</u>		medium (SBSF NIVA)
<u>Pollachius pollachius</u>	Pollack	medium (SBSF)
<u>Raniceps raninus</u>	Lesser Forkbeard	medium ? (SBSF)
Syngnathidae	Pipe-fish	medium (SBSF)
<u>Ctenolabrus rupestris</u>	Rock Cook	severe (SBSF)
Gobiidae	Goby	severe (UOBI SBSF)
Labridae	Wrasse, indeterminate	severe (NIVA)
<u>Labrus bimaculatus</u>	Cuckoo wrasse	severe (SBSF NIVA UOBI
	Fish, indeterminate	severe (NIVA)
B.		
<u>Centrolabrus exoletus</u>		severe (SBSF)
<u>Ctenolabrus rupestris</u>	Rock Cook	severe (UOBI SBSF)
<u>Eutrigla gunardus</u>	Grey Gurnard	severe (SBSF)
<u>Gadus morhua</u>	Cod (0 and 1 group)	severe (UOBI SBSF)
Gobiidae	Goby	severe (UOBI SBSF)
<u>Labrus bimaculatus</u>	Cuckoo wrasse	severe (UOBI SBSF)
<u>Merlangius merlangius</u>	Whiting (0-group)	severe (UOBI SBSF)
<u>Platichthys flesus</u>	Flounder	severe (SBSF)
<u>Pollachius pollacius</u>	Pollack (0-group)	severe (UOBI)
<u>Pollachius virens</u>	Saithe (0-group)	severe (UOBI SBSF)

1) Fish could not be identified due to decomposition

Observations of farmed fish have revealed that there are differences between species as far as vulnerability to Chrysochromulina is concerned. Cod proved to be less vulnerable than salmonidae. Moreover the effect of Chrysochromulina on fish appears to depend on salinity because salmonidae tolerated concentrations of algae (10 x 106 cells/litre) at a salinity of 10 o/oo while they died at the same concentrations in water with a salinity of approximately 30 o/oo (Berge and Føyn, 1988). This implies that the toxin affects mechanisms connected with osmoregulation (the regulation of the salt balance).

The surveys referred to were mainly carried out in littoral areas or in fjords. In more open sea areas a normal distribution of fish has been observed in the water column (Berge and Føyn, 1988). This is probably due to the fact that pelagic species have avoided water affected by algae and that benthic fish in open waters have their habitat in deeper water layers than those directly affected by Chrysochromulina. However it is debatable to what extent fish larvae and fry are affected. Taking into consideration the fact that these have little or no power of movement, one would assume that these stages were relatively severely affected in the case of species which have eggs in the upper 20-30 m. in the period in question (May). Observations carried out after the bloom indicate however that there were fish larvae in the whole of Skagerrak. The area and depths that were affected by the algal bloom were small in relation to the geographical distribution of commercial fish species. It is therefore unlikely that damage to resources as a consequence of a reduction in the youngest stages will be registered other than in the case of local coastal populations of cod (Berge and Føyn, 1988).

Geographical distribution of the effects on littoral fish

An overview of the geographical extent of the area where there has been damage to fish is probably best illustrated by the mortality observed in fish farms. Mortality of farmed salmonidae caused by Chrysochromulina is reported from Sweden (Lysekil) to Hordaland. In the case of wild fish a reasonably comprehensive background material is available only for the area from Langesund to Arendal where the effects on fish were quite severe in part. (Report from UOBI and Flødevigen). This applies particularly to some types of wrasse of no commercial interest, but also to the younger stages of commercial fish such as cod and whiting (Gjøsæther and Johannessen, 1988). There are too few diving observations from the north-west region of the area surveyed (Rogaland and Hordaland) (Table 1) to permit the determination of an accurate northern limit for effects on wild fish. Experiences in Dalane (Espeland, 1988) indicate that cod is less vulnerable than salmon. On the strength of an observation based partly on a hypothesis that salmon is relatively vulnerable to the algal bloom in comparison with wild fish, and partly on the fact that the bloom culminated in the southern regions of Hordaland, it must be assumed that severe effects on wild fish are limited to the area from the Swedish coast to Hordaland. No dead wild fish were found north of Rogaland in the course of diving surveys. This confirms that damage to populations of wild fish does not extend north of Rogaland, nor are depths of more than 30 m affected.

5.3 Soft bottom organisms

The University of Oslo surveyed soft bottom fauna at two littoral stations and two deeper stations in the Langesund-Kragerø area. NIVA collected samples from 63 stations on the stretch of coast between Tvedestrand and Bømlo. The material from 28 of NIVA´s stations has been analyzed.

The following traits in results may indicate the influence of Chrysochromulina.

- low number of individuals
- limited variety of species
- absence of specific species or groups that one would expect to find
- changes in relation to earlier observations at the same station
- incidence of damaged or dead animals

Moreover, if such observations correlate with shallow water (related to the occurrence of Chrysochromulina), they will point to Chrysochromulina as the cause.

Results from the University of Oslo indicated that soft bottom fauna from Langesund to Kragerø were unaffected. The composition of species and individual numbers corresponded to what could be expected in normal circumstances both in shallow and deeper waters.

At NIVA´s stations the number of individuals varied from less than 100 pr.m^2 to approximately 1000 pr.m^2. The lowest density of individuals was found at the shallowest station (6 m.). Otherwise there was no correspondence between density of individuals and depth (Fig. 6). The low total of individuals at the station located at 6 m was probably due to the sampling. The volume of sediment in the grab samples was, in fact, only 1/4 of the total volume of the full grab. The conclusion is that Chrysochromulina had not reduced the total number of individuals of soft bottom fauna at any of the sampled stations.

The diversity of species, expressed by a widely used index (H) varied between 2.2. and 5.2. Usually the diversity of species is greater than 3.1 but this may be less as, for example, in the case of pollution episodes (Rygg 1986). With the exception of one station at 40 m where it was difficult to get up sufficient sampling material, the diversity of species proved to have normal values at all stations deeper than 22 m, whereas there was considerable variation at shallower stations (Fig.7). Of the seven shallow stations where the diversity of species was less than 3.1, one was significantly polluted and the sediment contained hydrogen sulphide, three provided little material because of difficult sediment (sand), and one had a reduced diversity of species because of a substantial increase in the number of individuals of one species, not because of a decline in the number of species. The two remaining stations with a species count that was lower than normal, station 38 at a depth of 20 m in Kusevikfjorden and station 48 at a depth of 6 m in Kirkevågen, may be affected by Chrysochromulina. At station 38 crustaceans and echinoderms were lacking of the groups of animals that one would have expected to find.

Two species of the burrowing sea urchins, Echinocardium cordatum and Brissopsis lyrifera, showed evidence of damage at some stations. Individuals had lost their spines, especially on the hind part of the back (Tab. 6). Damaged animals were found from 13 to 56 m depth, and normal animals from 18 to 55 m depth. There was no apparent east-west gradient along the coast.

In the case of nine of the stations there were results from previous surveys. A number of older stations exist, but these are generally located further inside the fjords, at greater depths, or in pollution loaded localities. Clear changes in a negative direction were recorded at one of the stations surveyed earlier (station 10 at a depth of 20 m north of Merdøy). In February, 1988, both crustaceans and echinoderms were found here, but they had disappeared in June. The station, however, is already subject to organic stress and the sediment contains some hydrogen sulphide. Consequently, modest changes in the degree of pollution, and not necessarily Chrysochromulina, may have caused the absence of crustaceans and echinoderms in June.

In addition to a grab, a triangular scraper or benthic sledge were also used at some stations. These tools cover a larger area than the grab, thereby providing more material (more species and individuals). A few hauls using a scraper or bottom sampler were also carried out independently of the grab stations. The material conserved has not yet been worked up. However, an evaluation of the material was carried out on board. Field observations may be summed up as follows: It was not possible to determine any abnormalities in the material collected. Species that are characteristic of the various biotopes where sampling took place appeared to be present in normal numbers. There were no observations of recently dead bivalves or snails.

The conclusion from surveys of soft bottom fauna up to June,1988, is that Chrysochromulina has caused considerably less damage to this part of the ecosystem than to rocky bottom communities. One exception was the burrowing sea urchins. In some localities damage amounted to a partial loss of spines. However, limitations in the network of stations, and problems with the collection of grab samples in shallow waters may have resulted in the oversight of effects. The burrowing behaviour pattern of soft bottom animals may have provided greater protection.

Table 6. Findings of normal (-) and damaged (+) individuals of the sea urchins Echinocardium cordatum (Ec) and Brissopsis lyrifera (Bl).

STATION	LOCATION	DATE	DEPTH	SPECIES	CONDITION
I	Vikkilen	880530	18	Ec	+
I	"	880615	18	Ec	-
III	Gråholmen	880530	55	Ec	-
III	"	880615	55	Ec	-
5	Fevikkilen	880615	28	Ec	-
26	Skallefjorden	880617	30	Ec	-
42	Tånevikkilen	880619	18	Bl	+
53	Einarsneset	880620	20	Ec	-
58	Grunnevik	880621	24	Ec	+
61	Rekefjord	880621	24	Bl	-
63	Vibberodden	880622	38	Ec	+
64	Grunnsundhlm.	880622	13	Ec	+
71	Rott	880623	47	Ec	-
72	Kårstø	880624	56	Ec	+
74	Røvær	880624	30	Ec	-

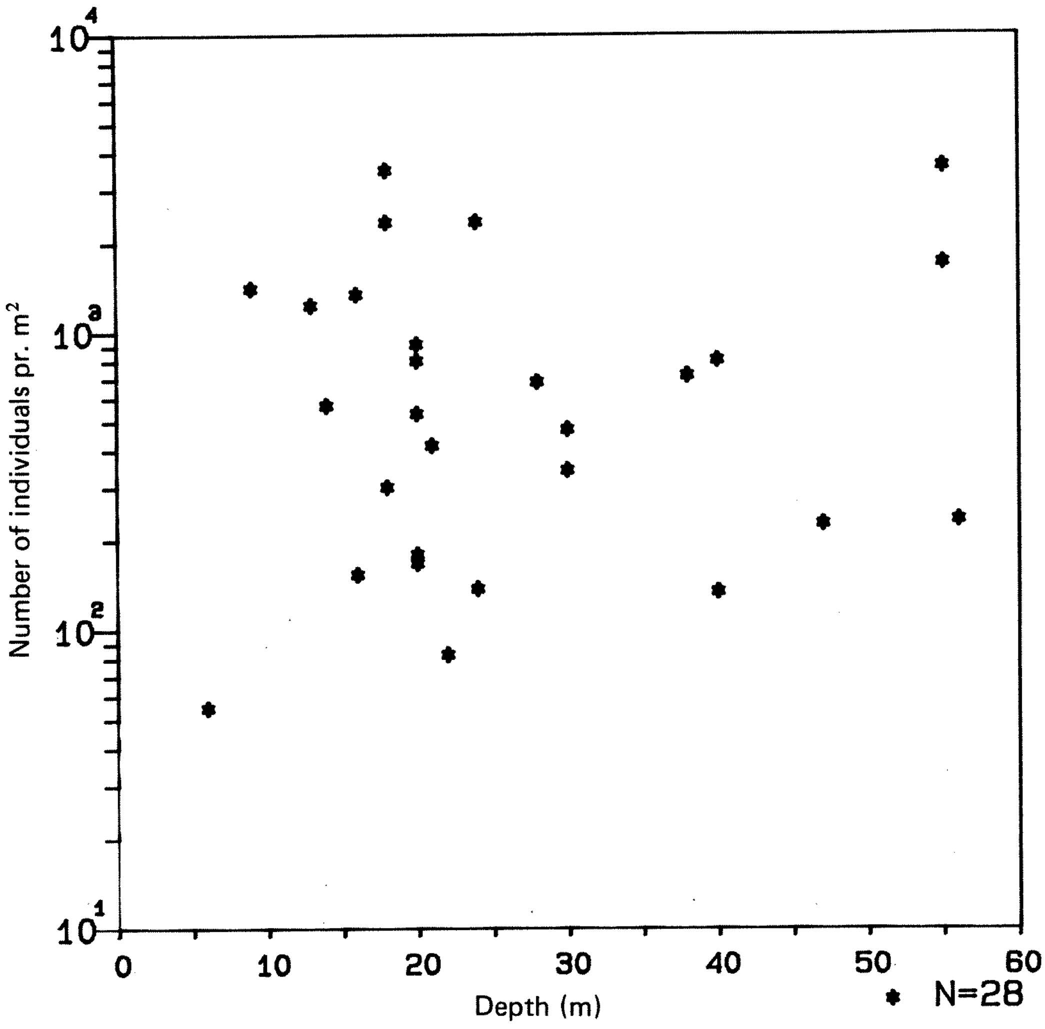


Figure 6. Total of individuals of soft bottom fauna pr.m² for stations at various depths (m) in May-June 1988.

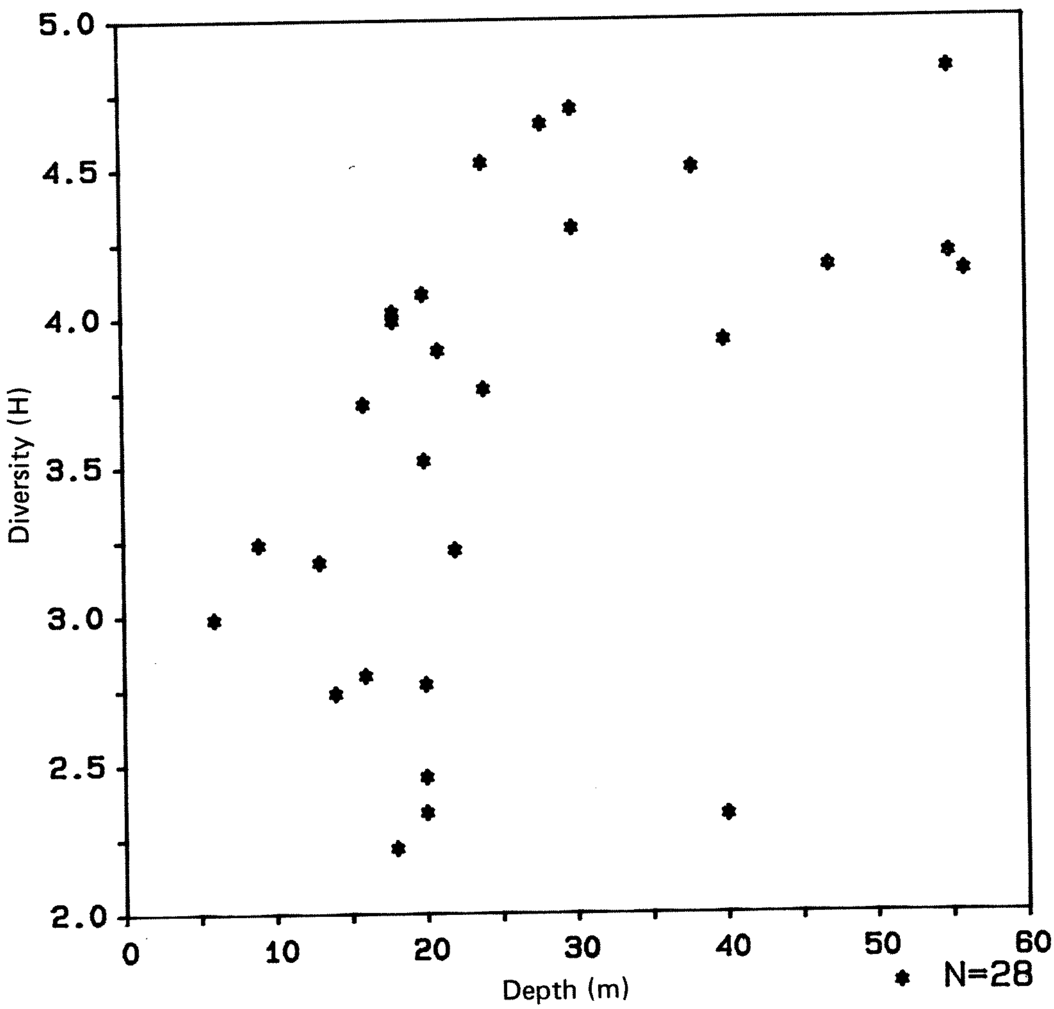


Figure 7. Diversity of species (H) at stations at different depths (m) in May-June, 1988.

5.4 Zooplankton

Surveys in the Langesund-Tvedestrand area (6-9 June) revealed a plankton composition that was normal for the time of year. There were no obvious irregularities or deficiencies in their composition. Moreover, no visible effects were established for bottom animals at the pelagic larvae stage.

The Institute for Marine Research´s surveys (4-12 June) suggest that the condition of crustacean plankton in Skagerrak was generally poor, while in outer Skagerrak plankton was found to be in normal condition.

6. Later effects and the process of recolonization

6.1 Rocky bottom organisms/littoral fish

Later effects on the biota will depend partly on how long-lived the toxin is in the environment and partly on the biology of affected species.

At several localities where there was a mass mortality of benthic organisms immediately subsequent to the algae outbreak later observations have confirmed the return of some of the species, e.g. common starfish Asterias rubens and fish.

Swift recolonization is seen in the case of species which can seek refuge from the algal toxin (e.g. fish), and in species which are located in areas (depths) which are unaffected and which can in the course of time (weeks) recolonize areas previously affected (snails, echinoderms).

It has also been observed that in one area which was registered in June as severely affected, individuals of the Delesseria sanguinea species had recommenced growth from the remaining midrib as early as July (I. Haugen, pers.med).

Such observations indicate that the active toxic component(s) causing damage to benthic organisms are either shortlived in its/their toxic form in the environment, or is/are diluted relatively rapidly to a non-toxic level.

Consequently it is assumed that the toxin produced during the algal bloom does not subsequently hinder the process of recolonization by making the substrate less attractive. Indirectly, however, localities where large quantities of organic material have accumulated may be less attractive because of a local shortage of oxygen and the formation of hydrogen sulphide. This is unlikely to be a major problem because the areas affected are relatively shallow, and are usually situated in exposed areas where the supply of oxygen ought to be abundant. This means that there is a fairly rapid decomposition of dead organic material. Moreover, various scavengers (Pagurus, Cancer, Homarus, some fish etc.) will probably eat the dead animals in the course of the following weeks-months.

Consequences which may be attributable to sub-lethal effects which were not registered in May and June are uncertain. Farmed fish which showed signs of being affected recovered when they were moved to water masses with less toxic algae or lower salinity (Berge and Føyn, 1988). On the basis of these experiences one would assume that sub-lethal effects in May and June will not result in later effects in the shape of further mortality for fish.

Recently extensive mortality has been observed among seals in areas affected by Chrysochromulina. This mortality has not been considered as being related to the algal bloom to any extent. Seal is principally pisciverous and is likely to have consumed fish which have been affected by Chrysochromulina. It is not known to what extent such consumption has had any negative effects on seal. Seal mortality, however, extends both spatially and temporally beyond the scope of the algal bloom. If the bloom has had any significance for seal mortality along the Norwegian coast in the areas affected, it would most probably have been in conjunction with other factors, e.g. by a reduction in the animals´ resistance to infection.

In the long-term the decisive factor in the process of recovery for the various biota will be the biology of the species. In general the recolonization process will depend on:

1. The method of reproduction (number of progeny, method of dispersion).

2. Ability to migrate along the coast and from deeper to shallower areas.

3. The proportion of the species´ distribution at depths where mortality has occurred.

4. Distance from reproductive species.

Recolonization will take longest in the case of populations of species with few eggs, a direct development without a pelagic larvae stage, with little power of movement, and remote from areas (vertically and horizontally) with surviving individuals of the same species. The sole representative of this category is the common dog whelk (Nucella lapillus) which has experienced considerable mortality. The common whelk (Buccinum undatum) has not a pelagic larvae stage either, but lives at deeper levels than the dog whelk. The total population was therefore less affected. Nucella often occurs in large numbers and is one of the main predators. Consequently its absence will have a marked effect on the biota of the tidal zone.

The common dog whelk lays eggs in capsules which are attached to the substrate. Each capsule contains several hundred eggs of which only 10-12 develop fully after four months. (Young and Thompson, 1976). This species has very limited powers of migration on account of its creeping mode of life. Only by means of sporadic transport on floating objects can the species be dispersed over greater distances (km). Furthermore the species is affected at all the stations where it has been observed, up to a point just south of Bømlo. Its main depth dispersal (the tidal zone and down to 2-3 m) does not extend beyond the depth interval affected by the mass bloom of Chrysochromulina. The areas (north of Bømlo) where this snail is to be found in large numbers subsequent to the algae outbreak lie downstream of the main coastal current. The chances that the snail may be dispersed via drifting substrate from these areas are therefore limited. In theory snails could also drift with the Baltic stream to areas along the Norwegian coast. However populations of Nucella in the areas passed by the coastal stream before it reaches Norway are probably also affected. The eastern dispersal limit for this snail is Kattegat.

All in all, this means that there is only a remote possibility that the population of Nucella can be restored in the areas affected in the reasonably near future (10 years) without hastening the process of recolonization by extensive transplantation. The sole possibility for a revival of the populations is that there are source populations within the fjords which can provide a basis for more local dispersal.

All the remaining invertebrates have a pelagic larvae stage which means that severely affected areas can be recolonized relatively easily from unaffected areas. The recolonization will take place by migration of adult individuals or by the settling of pelagic larvae. In the case of animals with a migratory ability recolonization will first occur mainly from depths that are not affected. As far as attached species are concerned, recolonization will occur via pelagic stages at the biologically decreed time. Most species spawn annually so that recolonization can take place within a year. However, several species are perennial. In theory, a natural age distribution in newly recruited areas will not be achieved until after a period corresponding to the longest life cycle. For some species (ocean quahaug) this can amount to 10 years. However, the distribution of different species and age classes of rocky bottom animals is also extremely patchy even in unaffected communities when the tidal zone is excluded. Moreover, not all individuals of the same species are affected in areas which have been influenced. This means that after a period of 1-2 years, communities will more or less have returned to normal in areas which were severely affected in the summer of 1988, with the exception of the common dog whelk.

In other regions where algal blooms have resulted in mass mortality in the natural biota, worms have been observed to have regained their position in the community as early as one year later.

6.2 Soft bottom fauna

The conclusion from surveys of soft bottom fauna in June was that only minor effects of Chrysochromulina could be identified. If the algae in the water masses caused direct effects, these ought to have been visible in June, as happened in the case of parts of the rocky bottom communities and fish. Any later effects on soft bottom fauna may operate via two mechanisms: (1) by sedimentation (settling) of algae, and (2) by a failure of recruitment due to the elimination of the pelagic larvae of benthic fauna. Very many benthic species (also at great depths) have larvae stages which live pelagically in the upper water levels where Chrysochromulina occurred. There is insufficient evidence as to the extent that sedimented algae can have had toxic effects, or whether pelagic larvae have been reduced in any significant numbers. Any benthic effects will emerge later. A check of later effects on soft bottom fauna should be carried out by a resurvey in the autumn of 1988 and in June, 1989, of a selection of stations sampled in June 1988.

7. Possible cause/effect correlations

Work to determine whether Chrysochromulina polylepis was toxic and the mode of action of the toxin was commenced immediately after the first observations of toxicity in the wake of the bloom. It was not known previously that this flagellate could cause toxicities. A combination of bio-tests and chemical methods proved that Chrysochromulina polylepis was toxic (Underdal et al. 1988).

Chrysochromulina polylepis is a member of the algae class Prymnesiophyceae. There are several toxic species in this class, and of these Prymnesium parvum is the most studied. There is a comprehensive documentation related to the toxin of Prymnesium parvum (Skibo 1981, Kozakai et al. 1982).

A natural assumption was that a similar toxin was present in the systematically related species Chrysochromulina polylepis. This proved to be the case. Using chemical extraction methods, tests of liver cells and mouse bio-assays, the presence in Chrysochromulina polylepis of a toxin with properties similar to those described for the prymnesian complex (Underdal et al. 1988) was confirmed. The toxic effects of the prymnesian complex comprise several categories demonstrated both in real situations and in laboratory experiments. The broad spectrum of biological effects is associated with e.g. toxic effects on cells, blood cells, the nervous system, fish, and bacteria (Skibo 1981). The toxin from Prymnesium is described as being chemically related to glykolipids (Kozakai et al. 1982).

Surveys of sampling material collected during the bloom of Chrysochromulina polylepis in Norwegian coastal waters in May- June are in preparation (August 1988). The toxin has been determined in e.g.:

- extracts of cells of Chrysochromulina polylepis in the natural population.
- extracts of water from the bloom of Chrysochromulina polylepis.
- extracts of mussels collected in areas which had had contact with the bloom of Chrysochromulina polylepis.

- extracts from the intestines of fish collected in areas affected by the bloom of Chrysochromulina polylepis.

As far as the biological effect of the toxin is concerned, the following may be mentioned:

- The algal toxin functions by destroying the cell membrane.
- This results in paralysis.
- Analysis has shown that there is an increased concentration of the algal toxin in the blue mussel.
- The toxin is not found in fish meat.

The present results show a clear relationship between the bloom of Chrysochromulina polylepis, the production and excretion of a toxin, and toxicity in the biota of the coastal areas affected.

Following the bloom of Chrysochromulina polylepis effects have been recorded on very different groups of organisms such as fish and attached algae. This appears to indicate that the toxin either acts on fundamental biological processes which are common to a number of groups of organisms, or that the toxin acts on a number of very different biological processes. The first explanation is most probably correct. A mechanism which may explain the effects on many different groups of organisms is the influence on transport via the cell membranes.

It is uncertain to what extent the toxin has any utilitarian value for the algae which produces it. However, in connection with mass blooms of other algae (Gymnodinium breve) resulting in toxic effects on the natural biota (Simon and Dauer, 1972, Steidinger and Ingle, 1972) it has been suggested that the release of nutritional salts from dead organisms can stimulate further algal growth (reported in Steidinger and Ingle, 1972).

Chrysochromulina polylepis is an algae which can obtain organic nutrition by taking in particles in addition to photosynthetic activity. Therefore, it is conceivable that the toxic effects on other organisms may increase the amount of accessible dead organic particles in the water masses in the short-term. A third hypothesis is that toxic effects on other organisms reduce competition and grazing on the part of other organisms, thereby favouring Chrysochromulina polylepis.

8. Literature

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