ALUSCAN AS

Marine environmental impact from the discharge water

Report from a survey in October 1993

Norwegian Institute for Water Research

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Oslo, Norway 8 Nov. 1993
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Abstract:

Waste water from the aluminium salt slag processing plant ALUSCAN AS in Norway discharges into the open recipient Sunndalsfjorden in western Norway. In October 1993 a diver survey in the vicinity of the discharge was performed. The survey showed visible effects closest to the outlet. A diverse marine flora and fauna was observed at 5-50m from the discharge outlet. Some impact from the discharge was visible at distances up to 50-100 m from the outlet. The effect of the discharge was enhanced by heavy sedimentation due to remaining sedimented material from the former iron mine. The discharge water is expected to rapidly dilute and disperse in the large recipient, causing minor eutrophication effects beyond 150m from the discharge outlet.

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3. Aluminium-slagg	3. Aluminium salt slag
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For the Administration

Torgeir Bakke

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Preface

This report contains supplementary doccumentation on the marine environment surrounding the process plant ALUSCAN AS in Norway. Certain specific questions related to the environment was the background for the report. It was decided that a submarine survey by a skilled diver and biologist from The Norwegian Institute for Water Research, NIVA, was the best way to doccument the environmental situation.

A submarine and shoreline survey was performed on 27 October 1993 by Dr. Are Pedersen from NIVA. We enjoyed smooth cooperation with the management and staff at ALUSCAN, who also arranged with the boat and the security backup diver. Kjell O. Sjøli (director of ALUSCAN) was the main local coordinator.

Are Pedersen also systematized the observational data and compiled the text on the biology. Torulv Tjomsland from NIVA performed the computer modelling. Lars G. Golmen made the physical evaluations, and managed the project, which had to be performed on very short notice.

Contents

1. SUMMARY

The main impression from the survey can be summarised as:

- The toxic effects of the discharged water on the marine life in general are less than expected and restricted to 5-10 m from the outlet. Further away from the outlet some signs of eutrophic conditions were observed. The surface discharge may have caused establishment and extensive growth of the observed green algae. The green algae were found in larger quantities at some distance from the discharge than close to it. This may confirm the findings from the previous laboratory studies, which told that eutrophication effects will not occur at high concentrations of discharge water.

- 5m from the previous outlet several species of animals were recorded. Even closer small demersal (living close to bottom) and pelagic fish were observed. Within a few meters from the old outlet kelp less than one year old had settled, indicating favourable conditions.

- The occurrence of large quantities of mussels, especially older ones near the outlet area, means that the conditions have been acceptable for several years. The community structure at the outlet including the pipeline itself indicated a relative young community with numerous hydroids and small kelp plants.

- The diversity of the littoral zone in particular increased as one moved further away from the outlet, indicating increasingly better conditions at a distance of 50 to 100 m away from the outlet. This increase may be due to some toxic effect near the outlet. The observed sedimentation, however, of small particles from the former mining activities was significant, and may also explain some of the reduction in diversity close to the outlet.

- The effects from the former mining activities are decreasing. Still the sedimentation influences the impact assessment study of the ALUSCAN discharge. It is thus recommended that the discharge region be monitored at regular intervals, in order to assess the long-term impact of ALUSCAN discharge as the impact of the solid mine waste declines.

2. INTRODUCTION

The present report mainly presents results from the inspection and diver survey at ALUSCAN AS performed by NIVA in October 1993. We feel it necessary, however, also to make some general introductry comments in order to make the report more accessible to readers not being familiar with background information.

3. THE PLANT AND THE MARINE DISCHARGE

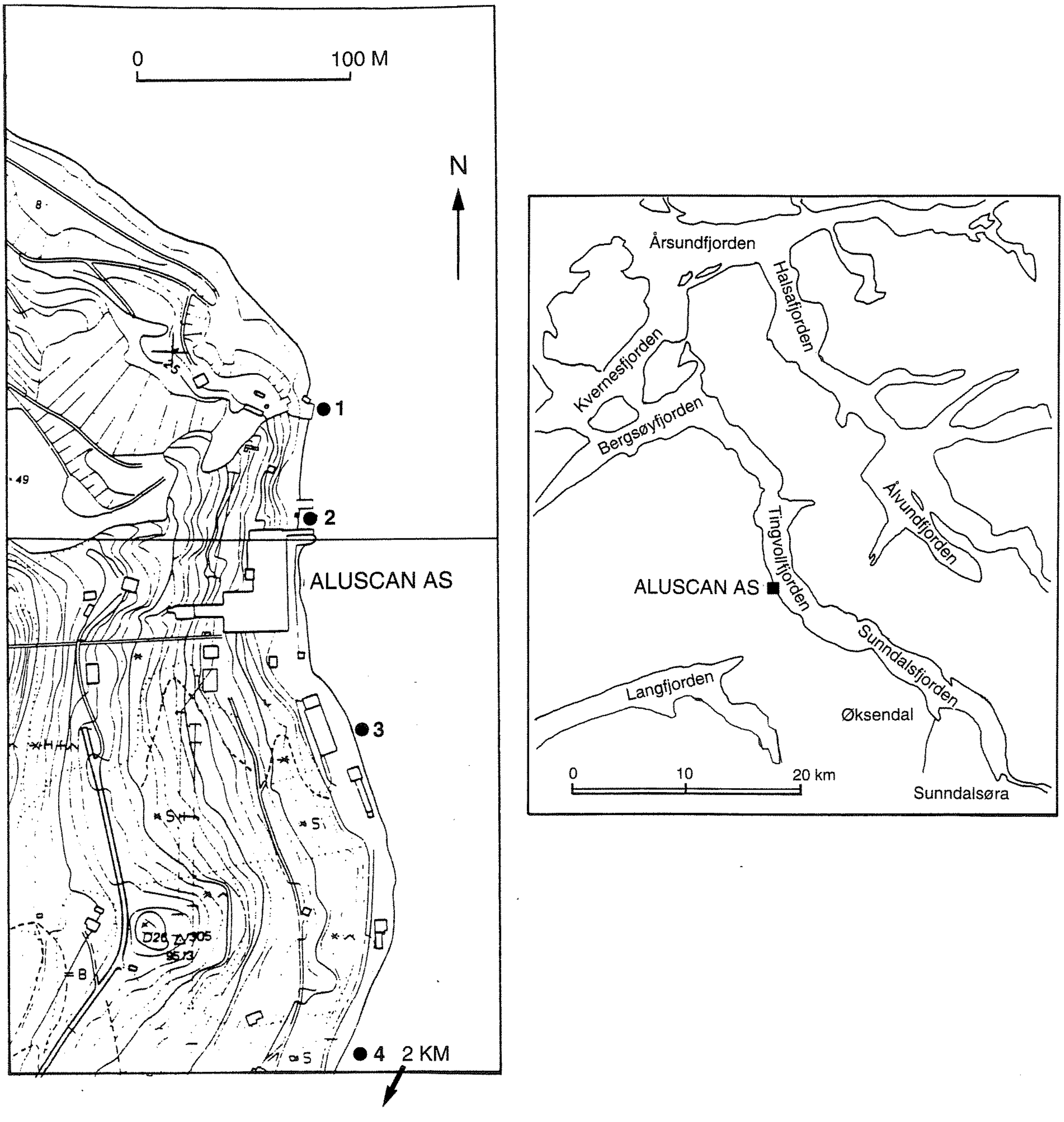


Figure 1. Map of Sunndalsfjorden and stations on which diving were performed down to about 15m depth.

ALUSCAN AS was established in 1989 as a recycling plant for aluminium salt slag. The plant is situated in Sunndalsfjorden (Fig. 1) on the NW coast of Norway, near the town Kristiansund. The fjord is ca 50 km long, typically 2-5km wide and several hundred meters deep. The mouth of the fjord faces the Norwegian Sea, and there are no topographic restrictions such as shallow sills or narrow sounds that significantly limits the water exhange with the open sea (Molvær 1990).

After slag treatment and aluminium extraction, the remaining waste water and material (mainly containing salts and Al-oxide) is deposited in the iron mine shafts of the former Rødsand Gruber. In the deep mine shafts sedimentation of particles and suspended material takes place. Local fresh water drainage seeps into the shafts during rainfall.

Since 1992 the outlet water from the deposit shafts mainly has been discharged into Sunndalsfjorden at about 15m depth near the harbour piers. Soon the discharge pipe will be changed to reach 30m depth or more. Due to varying rainfall, also the discharge flux varies through the year. The monthly average is about 100,000m^3, of which ca 75% derive from the production.

ALUSCAN is located on the ground of the former mine Rødsand Gruber, which closed down in 1983, after nearly 100 years of operation. The purification activities implied huge amounts of waste particulate matter that simply was dumped into the fjord nearby. Thus sediments developed over a large bottom area, extending several kilometers into the deepest part of the fjord. Since 1983, some smaller amounts of dust and gravel has been dumped from a sand factory. Otherwise the pollution situation in the region has improved significantly the last years. Only small amounts of bottom sediments remain in the near-shore region, due to resuspension and mudslides.

4. PREVIOUS ENVIRONMENTAL INVESTIGATIONS

Several investigations have been performed in the Sunndalsfjord, mainly related to the large aluminium plant at Sunndalsøra at the head of the fjord, some 20km from ALUSCAN. Samles of water and sediments were also collected near Raudsand in 1986 and 1988. Some impact from the former iron mine were found in the deep water sediments, with V, Fe and Cu concentrations 3-10 times above background, and reduced number of species in the bottom fauna (Rygg and Næs, 1989). It was concluded that the bottom area was in a transition phase towards a more normal situation that would take some years. It must be stressed that impact was detected in the deep parts of the fjord only (depth range 93m - 335m), i.e. much deeper than the expected impact zone form the present ALUSCAN discharge.

The water quality in the main parts of Sunndalsfjorden (excluding the inner part near the aluminium plant) was found to be satisfactory in the mid-1980's, as reported by Molvær, (1990) and Pedersen, (1990).

Recently NIVA and others presented a report (Iversen et. al. 1993) on various environmental issues directly related to ALUSCAN. It was stated that the discharge water theoretically might have some local impact, depending on the flux of pollutants. This conclusion was based on results from laboratory experiments with marine algae, and did not include tests on other organisms. The algae tests clearly showed effects at high concentration and reduced growth even at 1% concentration. It was not investigated which was the most critical discharge components, but evidence for eutrophication effects was suspected to be due to the high ammonium concentration.

The impact zone was theoretically postulated to reach ca hundred meters downstream from the discharge. Impact would be resticted to a depth interval from about 10m to 25m depth with a discharge at 15m depth. No visual bottom inspection (baseline investigation) was performed before the ALUSCAN discharge was established. Neither had any follow-up investigation on the marine environment been undertaken before the study in 1992 (Iversen et. al. 1993). Since the latter was mainly based on laboratory tests and chemical analysis, it was found necessary to make an impact study by a diver, in order to assess the actual situation. The present report describes the main findings from the diver survey.

5. DISCHARGE COMPONENTS

The main critical discharge substances are ammonia, aluminium, hydrogen sulphide (H_2S), phosphine (PH_3) and some metals. Measured pH is in the range 9.4-10, i.e. slightly more basic than seawater (pH ca 8). Theoretical effects due to these components were evaluated by Iversen et. al. (1993), mainly based on EPA values. Aluminium was not particularely treated in the study. Al concentrations were measured to be in the range 17-27mg/l, which is on the order og 10^4 times the natural concentration in seawater. Upon dilution with seawater, Al is expected to convert to Al-hydoxide.

Dissolved Al has numerously been reported in the literature to cause cronic or lethal effects on fish in freshwater. Effects in freshwater seem to peak at a pH of about 5, releated to the Al^{3+} ion. When pH increases towards the normal of ca 7 for freshwater, dissolved Al precipitates and effects rapidly reduce. Little is known about Al effects on biota in seawater. As pH for seawater is ca 8, and the buffer capacity is far larger than for freshwater, the effects will be different and probably smaller due to the different chemistry. At high pH (8-12), Al appears as aluminates, possibly in polymer form (Cotton and Wilkinson 1972). This may be the case for the discharge water at ALUSCAN, which initially has a pH between 9 and 10.

6. HARDBOTTOM ORGANISMS

Hard bottom organisms i.e. algae and animals attached to a rocky substrate and unable to move from its site, are good indicators of environmental quality. Such organisms can not escape if they are exposed to some toxic effluent. They will die if the time of exposure and the concentration of the effluent are unfavourable. Different species or groups of organisms react differently to different toxins, hence some organisms will be more sensitive to toxins than others. Consequently in a gradient from a toxic outlet one will find an increase in number of species of hard bottom organisms as the distance to the outlet increases.

6.1. The survey

The aim of the survey was to detect any effects of the discharge on marine life in general. One should also focus on marine hard bottom organisms i.e. larger algae (seeweeds) and animals. Any fish especially demersal and fish which are bound to a restricted area were of special interest.

Scuba - diving was performed on 4 locations of which 3 were in the near vicinity of the outlet from the company (Fig. 1).

All vegetation and fauna easy to identify *in-situ* were registered in an abundancy scale from 1-4, 1 being single records, 2 scattered, 3 common and 4 dominating species. All observations done by the marine biologist were recorded by use of an underwater telephone cable system connected to a tape recorder onboard the supporting vessel. Comments on all photographic shots were also registered on the tape. One film was taken at each of the four stations. The registrations were then transferred to a computer. NIVA has different macros and scripts in different computer programs to facilitate computations on the data . In appendix 1 selected pictures from all stations are shown.

6.2. Results

6.2.1. General description of the stations

The table below (table 1) gives a brief summary of what was found at the 4 stations. It is clear that the total number of species (taxa) found during this survey are low i.e. 67 taxa. Usually with more intensive survey one would expect to find more species. The aim of the survey was, however, to give a **brief** description of the marine life in the vicinity of the outlet and to estimate the area of influence from the outlet which might have severe effect on the marine flora and fauna. One should also bear in mind that the survey was performed at a time of year when most annual organisms, especially algae, are not found. Even so the difference in the calculated indexes (table 1) gives an indication of the communities at the stations and their level of stress.

Station R01 do have the least number of species as one should expect being so close to the outlet. The species occurring there also showed an high degree of dominance which is an indication of some sort of stress.

Table 1. Summary of the number of species (taxa), amount, dominance index, diversity, evenness and the 5 most important species (taxa) found at the different stations. The whole transect from 15m an up to the surface are summarised.

Station/Year	01 93	02 93	03 93	04 93
Number of species	25	38	29	26
"Amount"	201	304	173	241
Index of Dominance	27	11	12	22
"Diversity"	2.6	3.2	3.1	2.3
"Evenness"	0.5	0.6	0.8	0.4

5 most Dominating "Taxa" (findings) in decending order at the respective stations

01 93
Mytilus edulis
Laomedea sp.
Asterias rubens
Serpula vermicularis
Chlamys GROUP

02 93
Mytilus edulis
Laomedea sp.
Serpula vermicularis
Polysiphonia elongata
Desmarestia aculeata

03 93
Asterias rubens
Enteromorpha intestinalis
Mytilus edulis
Polysiphonia elongata
Ascophyllum nodosum

04 93
Echinus acutus
Coralliniacea indet.
Pseudolithoderma extensum
Cruoria pellita
Galathea sp.

The stress can be either caused by low salinities, toxic effluents or e.g. excessive grazing. At this station it will most likely be caused by the outlet. The community structure did also show resemblance to communities in the first phase of recolonization with a lot of hydroids and young kelp plants. This is an indication that the conditions have become better the last year. It can be caused by the recent close down of the mine with less particulate material deposited to the fjord and resulting in less turbid waters and less sedimentation. A sugested monitoring program in the vicinity of ALUSCAN`s outlet in the years to follow will document the indicated positive trend.

Station R02 had the highest number of taxa, the highest diversity, the highest biomass (amount) and the lowest index of dominance. All these values indicate that this station is the richest "best" station of them all, but when comparing station indexes one have to take other environmental factors such as available substrate, type of substrate, slope, exposure, direction (north south etc.), difference in currents, salinity, etc., into consideration.

Station R03 had less suitable substrate below 2m depth and Station R04 (reference) was exposed to extensive grazing by sea urchins (Fig. 5 & 6). Looking at the indexes for the upper 2m in the sublittoral gives another picture of the difference between the stations (tab. 2). The number of species in the upper 2m of the transect indicates that station R01 is the only station that are clearly affected and most probably by the outlet from ALUSCAN.

Table 2. Summary of the number of species (taxa), amount, dominance index, diversity, evenness and the 5 most important species (taxa) found at the different stations. Only the upper 2m of the transects are included.

Station/Year	01 93	02 93	03 93	04 93
Number of species	7	17	11	11
"Amount"	33	55	49	43
Index of Dominance	24	16	18	19
"Diversity"	1.8	2.7	2.2	2.3
"Evenness"	0.9	0.8	0.8	0.9

5 most Dominating "Taxa" (findings) in decending order at the respective stations

01 93
Enteromorpha intestinalis
Mytilus edulis
Cyanophyceae indet
Carcinus maenas
Ulvaria/Ulva

02 93
Ascophyllum nodosum
Enteromorpha intestinalis
Fucus sp.
Cyanophyceae indet
Mytilus edulis

03 93
Enteromorpha intestinalis
Fucus vesiculosus
Ascophyllum nodosum
Sphacelaria radicans
Rhodomela confervoides

04 93
Echinus acutus
Diatoms-Schizonemastadium
Ascophyllum nodosum
Coralliniacea indet.
Membranipora membranacea

At a distance of 10m from the outlet, fucoids (important brown seaweeds) were observed. This indicates that the conditions at a distance of some 10m from the outlet show little toxic effect. Signs of eutrofication were registered in the large quantities of green opportunistic seaweed (*Enteromorpha spp.*) found at stations R01, R02 and R03. *Enteromorpha spp.* were the most dominating seaweed at station R01 and station R03, and the second most dominating one at station R02 (Tab. 2).

The reference station R04 was dominated by grazing sea urchins resulting in barren areas below 2m. Hence it is difficult to compare this station directly with the findings at the other stations. The destructive grazing by sea urchins might be suppressed at station 1 and 2 due to toxic effect of the outlet or by heavy sedimentation at these stations.

Station R01

Station R01 near the discharge was located just around the pipeline gate. Some time ago the pipeline had broken and the remaining pipeline was exiting at 1m depth 5m out from the shore at the time of the survey. The old pipeway and discharge location at 15m depth could still be detected. The waste water from the plant can sometimes contain heavy salt water which sinks or interleaves the water column. Sometimes it will be more fresh and break through to the surface. For all incidents bottom organisms will for a certain length of time, be exposed to the waste water.

Within a distance of 2-3m from the old pipeline outlet, no hard bottom organisms were found. In this area large deposits of salt aggregates were observed. Further away at 3-4m distance small kelp plants were observed (Fig. 7.). 5m from the old outlet at suitable substrates, several organisms were observed (Tab.3 in Appendix 1).

Large quantities of mussels (*Mytilus edulis*) (Fig. 8) were found as deep as 18m with the main occurrence at 4-5m depth. Usually these mussels are predated by starfish (mainly *Asterias rubens*) (Fig. 9) and one will find very few older mussels. The population of starfish at the station was scarce considering the amount of available food in the area. Starfish and sea urchins are also sensitive to changes in the water quality especially salinity and heavy sedimentation. The sedimentation at the station was significant and caused an additional stress to the attached hard bottom organisms. Below 10m depth where the sedimentation was heaviest, sensitive organisms as tubeworms (*Pomatoceros triqueter & Serpula vermicularis*) and barnacles (*Balanus balanus*) seem to prefer overhanging substrate (Fig. 10).

Other characteristics for this station were the large amount of hydroid (*Laomedea spp.*) (Fig. 11). These are opportunistic species which will colonize available space whenever the conditions are favourable. They usually reproduce at spring. After some months most of the hydroids will be predated on by seaslugs (cf. *Dendronotus frondosus*) (Fig. 12) and only their stolon (stems) will be found.

The station did not have a normal littoral belt of seaweeds. The rock surface in the upper 2m was also covered with salt deposits 5mm thick (Fig. 13). Some mussels and green seaweed (*Enteromorpha sp*) (Fig. 14) grew in/on this indicating low toxicity of the salt (not tested). The top of the salt was covered with a layer of cyanobacteria.

The station also showed definite sign of eutrophication with a well developed belt of green seaweeds (*Enteromopha spp. & Ulva /Ulvaria.*) (Fig. 14). Pedersen (1990) did, however, not find any signs of eutrophication in the Sunndalsfjord except for in the innermost 1km of the fjord and at one site near Tingvoll due to a local farm.

At the day of the survey there was no wind. The discharge water could therefore be detected at the surface of the sea. It had a brownish colour and at 5m distance from the outlet it was 3cm thick. The surface water had a distinct smell of hydrogen sulfide and another unidentified smell was noticeable.

Station R02

This station was located 50m north west of the outlet and the largest number of species were found at this station even though the sedimentation was significant. Shipment of gravel and sand are done in this area which causes the heavy sedimentation. The sedimentation was of the same magnitude as at station R01 (Fig. 10).

The marine life at the station were affected by heavy sedimentation similar to station R01. The abundance of different organisms was high at this station compared with R01 and a larger number of species was found i.e. 38 against 25. The biomass or amount of organisms increased with 50% from station R01 to R02 (Tab. 1). The most characteristic features at the station were that the littoral zone had a distinct fucoid belt consisting of *Ascophyllum nodosum* and some other fucoids *Fucus serratus* and *Fucus sp.* The sublittoral zone was characterized by a more diverse community. Especially hydroids and red seaweeds were frequent (Tab. 2). The large quantities of mussel were less dominant on the station. Several of the filter feeding organisms observed at both station R01 and R02 prosper at places with relative strong currents. This indicates that the current condition at the two stations are favourable.

The direction of the tidal current during the survey was from station R01 towards R02 (northwards) and the brownish discharge water could be seen as a ca. 10 cm thick surface layer. The colour was not as dark brown as at station R01 due to mixing with underlying seawater. The bad odour could still be detected at this station.

Station R03

The station was located 120m south east of the outlet. Sandy bottom dominated the station below 2-3m. The sediments were very fine and underwater avalanches of fine sediments were observed resulting in some stratified turbid layers at about 15m. On suitable substrate kelp (*Laminaria sacchrina*) (Fig. 7) was frequent. Mussels (*Mytilus edulis*) (Fig.8) were less dominant at this station possibly due to the high number of star fish (*Asterias rubens*) present. Several star fish were feeding on mussels (Fig. 9). Also a number of large flounders (*Pleuronectes platessa*) were seen. A halibut (*Hippoglossus hippoglossus*) about 7-8 kg was also observed. In the upper 2m the seaweed belt was well developed but affected by heavy sedimentation. A small brown algae (*Sphacelaria cf. radicans*) and a very fine red one (*Audoniella cf. floridula*) resist heavy sedimentation and were indeed covered with a 1cm layer of fine sediments. The plant formed a woven net in the sediment (Fig 15). Two fucoids *Ascophyllum nodosum* and *Fucus vesiculosus* seemed to be in good condition, but another important fucoid, *Fucus serratus,* seemed in less good condition maybe due to heavy sedimentation and several epiphytes (Fig. 16). It may be an effect of the discharge water, but if so, most probably an indirect effect due to eutrophication as the station seemed to contain many small epiphytes and an abundant belt of green opportunistic algae - both being indications of eutrophication.

Station R04

Unfortunately this station had very little marine growth below 1m due to excessive grazing by sea urchins (*Echinus acutus*) (Figs. 5 and 6). The dominating organisms except the sea urchins were encrusting algae (*Lithothamnion spp.* and *Pseudolithoderma sp*) which resist grazing. In small crevasses and caves scattered vegetation and fauna were observed. These barren areas have been observed in the Sunndalsfjord previously in 1987 and 1988 (Pedersen 1990). Pedersen found that below 5-6m most of the vegetation in the Sunndalsfjord were grazed by sea urchins. The grazing is not a local phenomena. Most of the coastline from 62°N and almost up to the Russian border is heavily grazed by different sea urchins.

In the littoral zone the *Ascophyllum* -belt was well developed with its normal undervegetation. Below this belt at 1m the massive front of sea urchins occured. Sea urchins as previously mentioned do not like brackish water and therefore in periods with heavy freshwater supply to the fjord they are forced down to several meters depth.

6.2.2. Multivariate analysis

Based on the transect registrations multivariate analyses have been performed on the species composition at each station. Two sets of data have been analysed. One including all depths and all taxa (occurring from scattered to dominating) and the other all taxa within the upper 2m.

The methods have been videly used the last 5 years and are found to be a powerful tool in describing differences between communities at different sites (Pedersen & Rygg 1989, Warwik et al. 1991). Here only the Multi Dimensional Scaling (MDS) will be shown.

The distance between stations in the MDS-plot will refer to the difference in community structure between stations. This means that if two stations have a very similar community composition they will occur close to each other on the MDS-plot. If the stations on the other hand are quite different, they will be plotted far from each other in the MDS-plot.

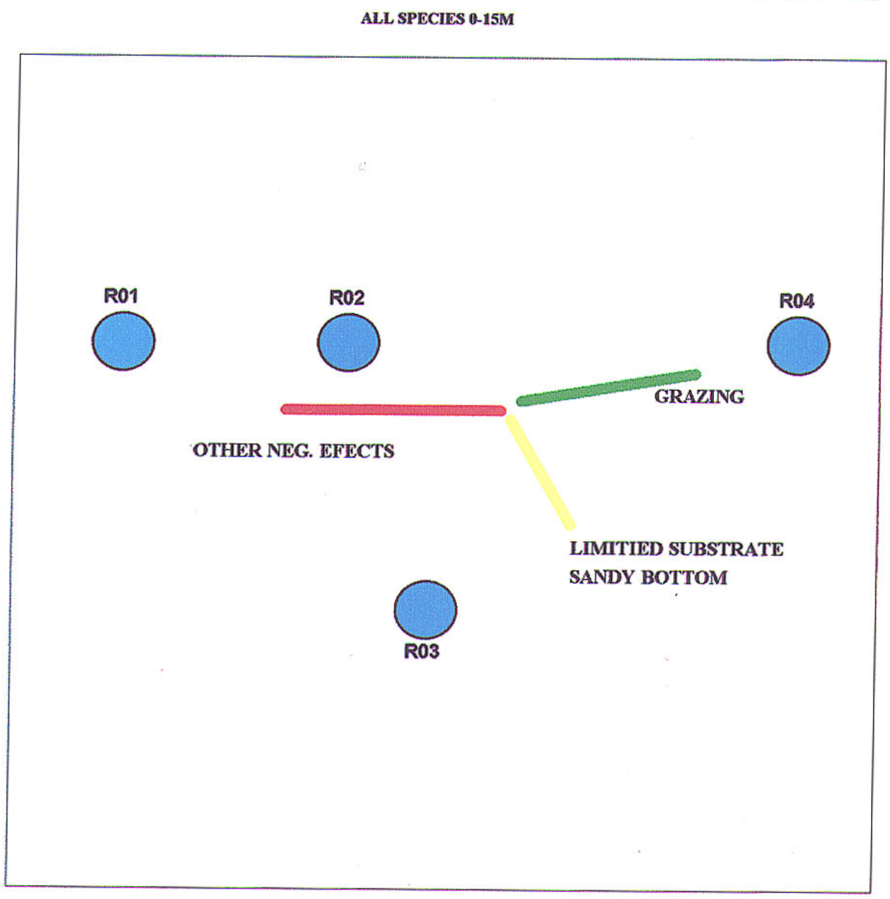
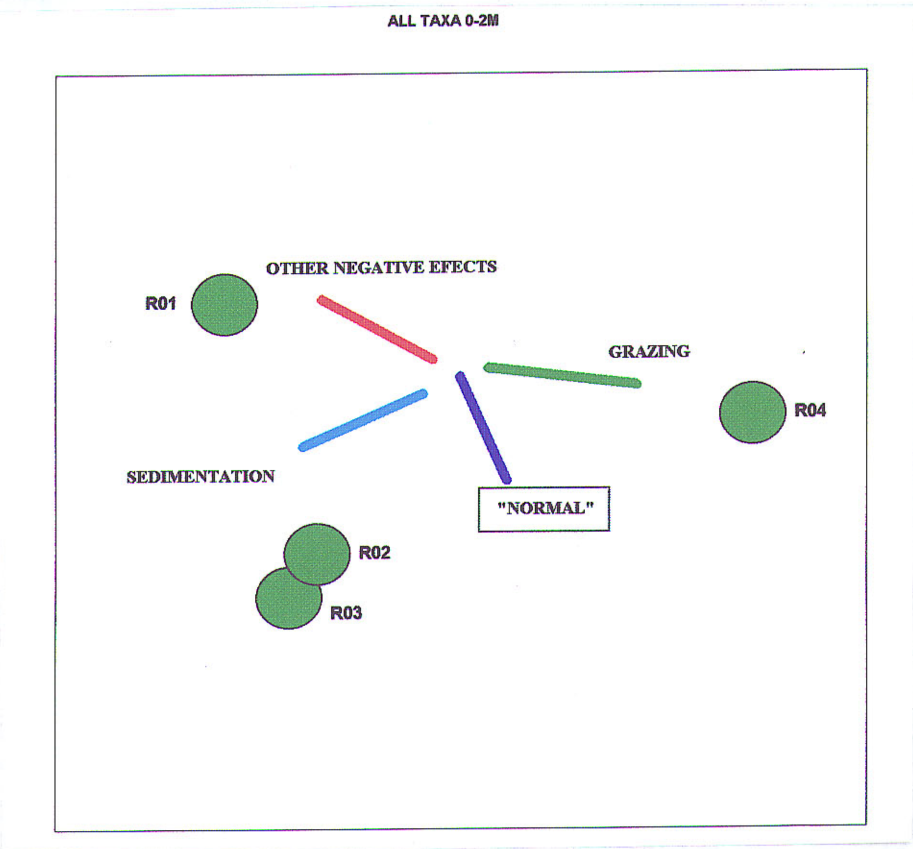


Figure 2. MDS-plot of the community structure based on all observations from the surface down to 15m except single findings.

Figure 2 shows that station R04 and R03 are quite different from the other stations due to grazing and lack of substrate. It must be stressed that the lines and text in the plot, are based on a subjective explanation for the positioning of the stations in the plot.

Figure 3 shows the similarity of the community structure in the upper 2m at the four stations. The lines are also here based on a subjective explanation on the constellation among the stations. In this figure the effect of grazing is reduced and to some extent also the sedimentation. The community structures at station R02 and R03 seem very similar. Station R04 is still affected by the extensive grazing between 1 and 2m, resulting in a reduction of a number of species. From figure 2 and 3 it is obvious that station R01 is the station most affected by the discharge. The impact on stations R02 and R03 are less.



Figur 3. MDS-plot of the community structure based on all observations from the surface down to 2m except single findings.

7. PHYSICAL MODELLING OF THE DISCHARGE

7.1. General

The discharge water from ALUSCAN will be rapidly diluted with ambient sea water in Sunndalsfjorden. The physical mechanisms governing the dilution at any time will depend on the actual currents and hydrographic conditions, which will vary somewhat with time. Untill recently the water was discharged at a depth of 15m outside the quay. Although the discharge line was broken some time ago, causing the water to discharge at only 1-2m depth, the former situation is expected to determine over all conditions for marine flora and fauna in the discharge area as reflected in the results from the diver survey. Thus modelling of the 15m deep discharge seem to be of most relevance in the present context.

The flux of discharge water varies both on the short and long term between near zero and a maximum of about 100l/s, as was doccumented in the previous NIVA report (Iversen et al. 1993). Also the specific density of the discharge water varies according to the fresh water content (or salinity). The variation in flux and density values will also cause some variation in the dispersion pattern in the fjord, as shown by the following numerical modelling.

The discharged water essentially goes through two stages: One called primary dilution (jet phase), and one for the secondary dilution or dispersion. The first accounts for the processes of dilution in the initial stage until the discharged water interleaves in the water column at its neutrally buoyant level (or at the sea surface/bottom). The second takes into consideration the horizontal dispersion due to the water current in the ambient.

7.2. Primary dilution

In order to calculate the primary dilution of the discharge, we have run the computer model "JETMIX" of NIVA, which based on given input simulates the initial jet-phase, and the subsequent buoyancy phase of the discharged water.

7.2.1. The model

The model is based on a set of simple first order differential equations, expressing conservation of momentum and mass during the mixing with stratified ambient water. The mathematical formulation essentially follows the one of Fan and Brooks (1969). The adaption to computers is desribed by Bjerkeng and Lesjo (1973).

Input to the model is one or several (observed) vertical hydrographic profiles of the ambient water, i.e. salinity and temperature versus depth. Then parameters related to the specific discharge are fed into the computer (volume flux, pipe diam. etc).

Output
The model outputs (for each input scenario) the level of neutral buoyancy for the discharged water, and the associated dilution in the center of the plume. Also given is the overshoot depth (minimum depth in the case of a rizing plume) before the neutral situation.

7.3. Secondary dilution

After neutral interleaving of the discharge plume, the discharge water physically will start to spread horizontally. This is the second stage of dilution, which is highly dependent on the current and lateral velocity shear in the ambient recipient. Effect of wind is assumed to stimulate the current and mixing. Surface waves will help to mix the discharge water vertically, and additionally enhance the secondary dilution.

The time for the buoyant plume from the pipe to reach its neutral level will be of order half a minute or less (mostly depending on actual stratification in the ambient fjord). During this time period the plume will be displaced horizontally only a small distance (a few meters) in the direction of the main currents.

During the primary dilution process, the plume will grow wider. In the neutral position the plume width in the cross-current direction will be on order of the difference in depth from the discharge. Actual current conditions will then determine the shape of the influence area, as the discharge water spreads horizontally. With weak or zero current (e.g. during tidal peaks) the discharge plume will spread out in radially to all directions.

According to the current measurements made so far (1992 and 1993), the radially symmetric case will be a non-typical situation at ALUSCAN. The typical situation will be the discharge water spreading parallel to the shoreline. The typical surface current speed will be ca 5-10cm/s.

As the discharge is carried away from the discharge site, it is continuously diluted by lateral and vertical turbulent diffusion. Some discharge parameters, such as pH may be regarded as to behave in a non-conservative manner in the recipient, i.e. they are not dispersed due to turbulence and mixing only. The effects of such secondary processes have not been calculated explisitly, but qualitative results still may be derived.

7.3.1. The secondary dilution model

To model the fate of effluents, we have used a simple point-source advection-diffusion model. The mathematical equations are based on the classical works such as of Reynolds (1894) and Taylor (1922). The model has been run and checked against measured values, with generally satisfactory results after some initial calibration (Tjomsland and Molvær 1986).

The simplified formulation is as follows:

$$\partial C/\partial t = -U\partial C/\partial x + K\partial^2 C/\partial x^2 + K\partial^2 C/\partial y^2 + kC + S,$$

where C(x,y) is the effluent concentration, t is time, U is the downstream current velocity (along-shore), K is the horizontal eddy diffusion coefficient, k is the concentration decay constant, and S is the source supply of effluents.

In the calculations, k (the decay constant) was set to zero. This is probably realistic for most of the effluents, which will behave as conservative substances. Parameters such as pH and Al may, however, not behave conservatively, but undergo (chemical) transitions during the fluid transport downstream. Other substances may undergo precipitation or flocculation. It is beyond the scope of the present study to validate these latter effects.

7.4. Results

The main results are presented and briefly discussed. The topic is rather complex and a full treatment is beyond the present scope.

7.4.1. Primary dilution

In a typical situation during autumn the discharge water will interleave somewhere between 9 and 19m depth, with the actual depth essentially depending on density of the discharge water, and only to a minor extent on the flux rate. Upon interleaving at its neutrally buoyant level, the dilution factor will be about 10, i.e. 1 unit volume of discharge mixed with 10 volumes of ambient (fjord) water.

The summer situation will give somewhat shallower interleaving of about 7-8m depth for the low density water, and deeper (> 25m) for the high density water. The calculated dilution factors for the two cases were 15 and 20 respectively.

According to the calculations the water discharging at 15m depth never mixes into the near-surface or surface water.

7.4.2. Secondary dispersion

We have calculated the horizontal dispersion based on a modest dispersion coefficient of $1m^2/s$. This conservative size will represent conditions with weak current shear (weak turbulence), and as such represents the "worst case" in terms of mixing efficiency in the recipient. Actual dispersion conditions will vary with time. At any rate it is difficult to assess the true dispersion without supporting field measurements such as colour or tracer studies.

Results for two cases of flux, and current speed equal to 10cm/s are presented in Fig. 4. Only the near-field (0-1km distance downstream) is shown, with dilution gradually increasing away from the discharge location. It must be noted that the fields and factors shown represent dilution of the discharge water after interleaving, i.e. after it has undergone the primary dilution phase described previously. According to the primary dilution calculations ("JETMIX" model) the dilution factors already had reached 10-20 before the process of secondary dispersion starts.

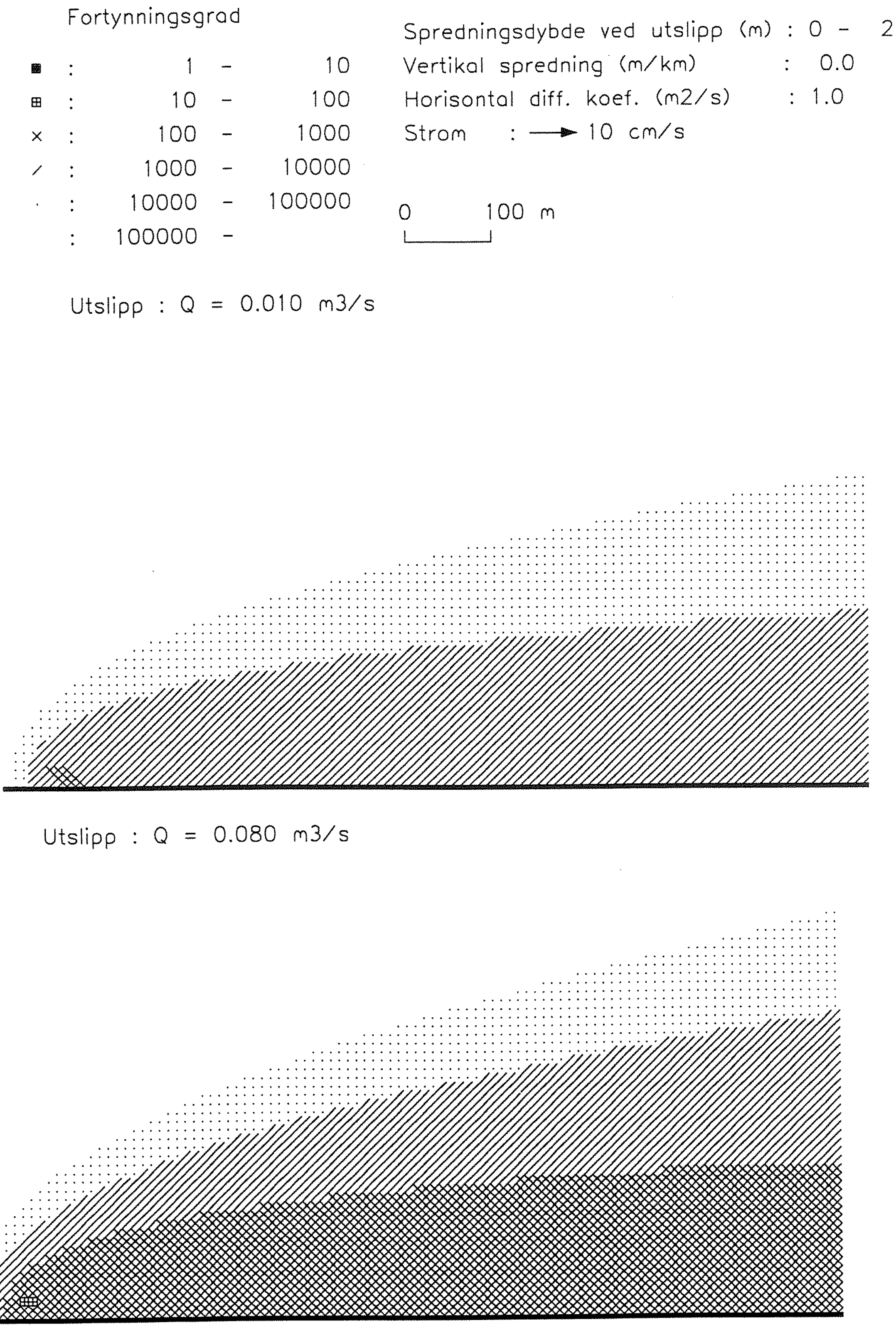


Figure 4. Results from the modelling of the secondary dilution (dispersion). Current = 10 cm/sec. Flux = 0.01 m³/sec. (upper frame), and flux = 0.08 m³/sec. (lower frame).

Cross-stream the total dilution rapidly decreases to values above 100,000 some 100-300m offshore. Along-stream (down-stream) the dispersion field sustains longer due to the advection factor. At distances beyond 5km the dilution is above 10,000 for either high or low discharge flux.

8. DISCUSSION

The previous NIVA study (Iversen et al., 1993) showed that marine algae (phytoplankton) under constant exposure from the discharge water in laboratory containers were subject to effects at concentrations as low as 1% (100-fold dilution with pure sea water). The tests were performed with continuous exposure over a time span of several days. The results as such may not be surprising, taking into account the different toxic components present in the discharge. Microorganisms such as phytoplankton are generally considered being the most sensitive under chemical exposure. This is also the reason why they are commonly used in tests for toxisity.

The present study do show some impact on the hard bottom communities near the discharge (station R01). Even on the pipeline itself different species had settled. Some 50m from the discharge conditions improved.

There is actually no contradiction between the results from the previous laboratory tests and the present studies. The former findings are not excluded by the present ones. It must be borne in mind that the very sensitive phytoplankton was exposed for length periodes of days. Normally one will expect that the exposure time for pelagic organisms towards concentrations above 1% in the vicinity of the ALUSCAN discharge at most will be a couple of hours. This is too short time to pose any significant threat to the phytoplankton passively drifting by.

The physical modelling also shows that the discharge water normally will interleave in the water column deeper than the most productive and light-exposed layers in the fjord. Thus with a submerged discharge effects on phytoplankton will be limited. This also holds true for effects of eutrophication which was found to become growingly important with decreasing discharge concentrations in the laboratory tests. As the diluted discharge water will be contained in layers below the most productive layers, the potential for effects of eutrophication is minor.

Signs of eutrophication (green seaweed monocultures) were found on both stations R01, R02 and R03 in the shallow (littoral) zone. Due to a broken pipeline the discharge water mixed into the surface layer. The discharge water had a characteristic and unattractive smell that could be sensed as far downstream as on station R02. The smell may partly be due to H_2S and hydrogen, possibly amoniac. This smell is espected to dissapear when the deep discharge outlet is established. Water samples collected in the surface layer some 5m from the surfacing discharge plume did not show any sign of oxygen depletion. This indicates that the water itself is rapidly depleted in H_2S when exposed to the air, thus also rapidly removing one or more of the toxic substances.

The surface discharge might have caused establishment and extensive growth of the observed green algae. The green algae were found in larger quantities at some distance from the discharge than close to it. This may confirm the findings from the previous laboratory studies, which told that eutrophication effects will not occur at high concentrations of discharge water (i.e. not close to the discharge) where toxic effects inhibit growth.

The shoreline near and at the premises of the ALUSCAN plant has been exposed to mineral deposition throughout several decades, untill 1991. After the close-down of the mine, drainage from land may have caused both particulate deposition and possibly certain negative chemical impact on marine life, that still pertains to the situation. Presently the recipient area may be regarded as still being under transition into a situation with no mining, thus making an impact assessment for the ALUSCAN discharge itself harder to perform. Other factors such as sedimentation, heavy grazing by sea urchins, as well as natural year-to-year variations add to the complexity of the situation.

Under any circumstance the observed gradients (biological differences between stations) show that ALUSCAN discharge do have some impact on biota. But this impact may not be regarded as severe, and it is very limited in space, both horizontally and vertically.

It is recommended that the discharge region be monitored at regular intervals, in order to assess the long-term situation, and to obtain data related to declining effects of the former mining activitites.

9. LITERATURE

Bjerkeng, B. and A. Lesjo, 1973: *Mixing of a jet into a stratified environment.* Rep. No. O-126/2, NIVA, Oslo.

Carr, M.R., (1991). *User guide to PRIMER (Plymouth Routines In Multivariate Ecological Research).* Version prepared for training workshop on Multivariate Analysis of Benthic Community Data, University of Oslo, October 25-27.

Cotton, F.A. and G. Wilkinson, 1972: *Advanced Inorganic Chemistry. A Comprehensive Text.* Interscience, N.Y., 1145 pp.

Fan, L.N. and H. Brooks 1969: *Numerical solutions of turbulent buoyant jet problems.* Rep. No. KH-R-18, Calif. Inst. of Tecnology, U.S.A.

Iversen, E., H. Kolderup, R. M. Konieczny, L. G. Golmen, E.R. Lømsland and M. Oehme 1993: *Environmental issues related to the processing of salt slag at ALUSCAN AS.* Rep. No. 2883, NIVA, Oslo, 78 pp (in Norwegian).

Molvær, J., 1990: *Environmental monitoring in the Sunndalsfjord, with emphasis on water exhange processes.* Rep. No. 2406, NIVA, Oslo, 45 pp (in Norwegian).

Pedersen, A., 1990: *Shallow water biota in the Sunndalsfjord.* Rep. No. 2372, NIVA, Oslo, 61 pp (in Norwegian).

Pedersen, A. & Rygg, B., (1990). *Program for the long term monitoring of the trophic status of the coastal areas in Southern Norway, Part I. Benthic Organisms,* NIVA report O-89131, 33p. (In Norwegian).

Rygg, B. and K. Næs, 1989: *Sedimented mine deposits in the Sunndalsfjord near Raudsand.* Rep. No. 2266, NIVA, Oslo, 29 pp (in Norwegian).

Reynolds, O., 1894. *On the Dynamical theory of incompressible viscous fluids and the determination of the criterion.* Phil. Trans. Roy. Soc. London **A**, Vol 186.

Taylor, G. I., 1922: *Diffusion by continuous movements.* Proc. Math. Soc. London Ser. 2, Vol 20.

Tjomsland, T. and J. Molvær, 1986: *Testing a simple mathematical dispersion model on the Glomfjord.* Rep. No F505, NIVA, Oslo, 29 pp (in Norwegian).

Warwick, R.M. & Clarke, K.R., (1991). *A comparison of some methods for analysing changes in benthic community structure.* Journal of the Marine Biology Association, U.K., 71, 225-244.

10. APPENDIX 1 - Lists of organisms found at each station

Table 3. Distribution of species with depth at station R01.

Vertical distribution of hard bottom organisms

Observer ARE Tidal corrections Y/N
Clerk ARE

Signs: 1 = Single 2 = Scattered 3 = Common 4 = Dominating

= Have to be regist.
Format: A = Alfanum. S = Num

Locality: S1

Station R01 Date 24.10.93 Barom mm Hg Deepest Depth 18
Exposure 2 Direc. 10 Slope 40 Bottom type SS
Supplementary investigations : Stereofoto m Quadrates -- m Kelp -- m Video min. TS m Photo J
Station AASS Bottom type: Rock; Rock/Pebbels incl. saltaggr. and sand
Format: Loc: AS Slope: moderate sedimentation; Heavy sedimentation/ Grey fine particles
Date: dd.mm.åå Horisontal view: 10m; 10m
Observ: AAA

Kode	cf	sp	NB	TAXA	<1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	>30
SERVE				Serpula vermicularis																	3	3	3	3													
BALBU				Balanus balanus																	3			2													
CHLAQ				Chlamys GROUP															2	2	2	2	2	2													
CORPA				Corella parallelogramma																				1													
MYTED				Mytilus edulis		2	2	4	4	4	4	4	3	3	3	3	3	3	3	2	2	2	2	2													
BUCUN				Buccinum undatum																			1														
ASTRU			PM	Asterias rubens					2	2	2	2						2	2	2	2																
CHAVA				Chaetopterus variopedatus																	2																
POMTR				Pomatoceros triqueter																	3																
LAOMZ				Laomedea sp.								3	3	3	3	3	3	3	3	3	3																
POMMI	1		M	Pomatoschistus minutus								2	2	2	2	2	2	2	2	2	3																
CIOIN				Ciona intestinalis														2	2																		
POLVR			M	Pollachius virens													3	3	3																		
ECHAC			PM	Echinus acutus															2																		
LAMSA		1		Laminaria saccharina juv.											2	2	2	2																			
MODMO				Modiolus modiolus														2																			
ANOMQ				Anomiidae group											2	2	2	2																			
DESAC				Desmarestia aculeata											3	2	2	2																			
DENFR				Dendronotus frondosus														1																			
CARMA			M	Carcinus maenas			2	2				1																									
SPLSU				Spirulina subsalsa								3																									
PLEPL			M	Pleuronectes platessa							1																										
FUCVE				Fucus vesiculosus						1																											
ENTIN	2			Enteromorpha cf.intestinalis		3	3	2																													
PORPZ				Porphyra sp.				2																													
ULVUL				Ulvaria obscura/ Ulva lactuca			3																														
SALT				Salt-Crust		4	4																														
CYANO				Cyanophyceae div.indet i Salt		3	3																														
ASCNO			*	Ascophyllum nodosum		2																															
SEDIM				Sedimentation		2	2	3	3	3	3	3	3	3	3	3	3	3	3	3	4	4	4	4													
			M=	Mobile																																	
			PM=	Partly Motile	← One PYCNOCLINE on 0.5m																																
			*	Found 10m SE of the outlet																																	

Table 4. Distribution of species with depth at station R02.

Vertical distribution of hard bottom organisms

Observer ARE — Tidal corrections Y/N
Clerk ARE

Occurence: 1 = Single 2 = Scattered 3 = Common 4 = Dominating

[shaded] = Have to be regist.
Format: A = Alfanumm, S = Num

Locality: S1

Station R02 Date 24.10.93 Barom ______ mm Hg Max. Depth 18
Exposure 2 Direc. 10 Slope 35 Bottom category SS
Other investigations : Stereophoto ______ m Quadrates : __ – __ m Kelp : __ – __ m Video; __ min. TS __ m Photo ____
Format: Station AASS; Loc: AS; Date: d.m.åå; Observ: AAA
Bottom type: Sand with rocks - more sand than R01, light grey color
Slope: 40 Heavy sedim. 45 Heavy sedimentation
Horisontal view: 8m 12m

Kode	cf	sp	NB	TAXA	<1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	>30
DESAC				Desmarestia aculeata									3	2	2	3	2	2	2	2	2																
MYTED				Mytilus edulis				3	3	3	3	2	2	2	2	2	2	2	2	2	3																
ASTRU			PM	Asterias rubens												2	2	2	2	2	2																
BALBU				Balanus balanus												3	3	3	3	3	2																
POMMI	2		M	Pomatoschitus cf.minutus							3									3	2																
LAMSA			*	Laminaria saccharina							2	2				3					3																
LAOMZ				Laomedea sp.							4	3	3	3	3	3	3	3	3	3																	
POMTR				Pomatoceros triqueter											2	2				3																	
SERVE				Serpula vermicularis							3	3	3	3	3	3	3	3	3	3																	
LAMSA		j		Laminaria saccharina juv.																2																	
MEMME				Membranipora membranacea																2																	
ANOMO				Anomidae group																2																	
SPLSU				Spirulina subsalsa				3	3		3									2																	
PTEPL	1			cf.Pterothamnion plumula							3					3				2																	
PLEPL			M	Pleuronectes platessa																2																	
ECHAC				Echinus acutus											2	1																					
POLEL				Polysiphonia elongata					2	2	3	3	3	3	3	3																					
MODMO				Modiolus modiolus					3	3						2																					
APOPE			PM	Aporrhais pespelecani												2																					
CHLAO			PM	Chlamys GROUP							1					2																					
POLUR	2			Polysiphonia cf.urceolata											2																						
CARMA			PM	Carcinus maenas					1						1																						
CIOIN				Ciona intestinalis							3		2	2	2																						
ENTIN	2			Enteromorpha cf.intestinalis			4	3	3				3																								
DORIX			PM	Dorididae indet.							2																										
SHIZN				Diatomeer - Schizonemastadiet						3	3																										
CLADZ		s		Cladophora spp.				3	3																												
BALBO	1			cf.Balanus balanoides				3																													
ULVOB				Ulvaria obscura			3																														
FUCVE				Fucus vesiculosus			1																														
CLARU				Cladophora rupestris			2																														
CHOCR				Chondrus crispus			3																														
POLRT				Polyides rotundus			1																														
AUDFL	2			Audoniella cf.floridula		4	3																														
FUCUZ				Fucus sp.		2	3																														
ASCNO				Ascophyllum nodosum		3	3																														
ASCNO		j		Ascophyllum nodosum juv.		3																															
AHNPL				Ahnfeltia plicata			1																														
LITLI			PM	Littorina littorea		2																															
CYANO				Cyanophyceae div.indet i SLAM			4																														
FUCSE				Fucus serratus			2																														
DERMA				Derbesia marina			3																														
METSE				Metridium senile						2																											
			*	not older than two years																																	
			M=	Mobile																																	
			PM=	Partly Motile																																	
			Bold =	Picture taken																																	

Table 5. Distribution of species with depth at station R03.

Vertical distribution of hard bottom organisms

Observer: ARE — Clerk: ARE — Tidal corrections Y/N

Occurence: 1 = Single 2 = Scattered 3 = Common 4 = Dominating

(shaded) = Have to be regist. Format: A = Alfanumm. S = Num

Locality: S1

Station: R03 — Date: 24.10.93 — Barom: mm Hg — Max. Depth: 15

Exposure: 2 — Direc.: 10 — Slope: 20-35 — Bottom category: s

Other investigations: Stereophoto: m — Quadrates: -- m — Kelp: -- m — Video: min. — TS: m — Photo: y

Format: Station AASS; Loc: AS; Date: ddmmåå; Observ: AAA

Bottom type: rock — Mostly very fine sand with som bigger rocks and debris

Slope: 25, 20, 25, 35

Horisontal view: 10

Kode	cf	sp	NB	TAXA	<1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	>30
NEPNO			M	Nephrops norvegicus														1																			
HIPHI			M	Hippoglossus hippoglossus																1																	
LAMSA				Laminaria saccharina											2	3			3																		
MYTED				Mytilus edulis				2	3	3		2							3																		
ASTRU			PM	Asterias rubens					3	3	3	3			3	3			3																		
APOPE			PM	Aporrhais pespelecani								2							2																		
SERVE				Serpula vermicularis											3	2			3																		
POMTR				Pomatoceros triqueter												3			2																		
DESAC				Desmarestia aculeata											2				2																		
POLEL				Polysiphonia elongata								3			3	2	2																				
PTEPL				Pterothamnion plumula								3			3	2																					
EUCAZ				Eucardium sp.												2																					
LAOMZ				Laomedea sp.								2				2																					
SPIRZ				Spirorbis sp.												2																					
ANOMQ				Anomidae group												2																					
CRANZ			PM	Crangon sp.																																	
CIOIN				Ciona intestinalis								3																									
ENTIN	2			Enteromorpha cf.intestinalis		3	3	3	3			2																									
FACEZ			PM	Facelina sp.								1																									
SHIZN				Diatomeer - Schizonemastadiet					3	3																											
SPHRA				Sphacelaria radicans			3	3	3																												
SPHPL				Sphacelaria plumosa					3	3																											
RHOCO				Rhodomela confervoides			2	3	3																												
PORPP	2			Porphyra cf.purpurea					2																												
CLADZ		s		Cladophora spp.				3	3																												
ASCNO				Ascophyllum nodosum			4	3	2																												
FUCSE			*	Fucus serratus					2																												
PLEPL			M	Pleuronectes platessa					2																												
CHOCR				Chondrus crispus				3																													
AUDFL	2			Audoniella cf.floridula				4																													
FUCVE				Fucus vesiculosus		3	3	2																													
AHNPL				Ahnfeltia plicata				2																													
STREB				Streblenemoide alger				2																													
AUDOZ		s		Audouniella spp.				2																													
			*	Some ind. in bad conditions																																	
			M=	Mobile																																	
			PM=	Partly Motile																																	
			1	In general higher diversitet in the the upper 3 m than st R01 and R02 on rocks.																																	
			2	Less suitable hardbottom areas.																																	
			3	Very fine sand - Underwater avalanches.																																	
			Bold =	Picture taken																																	

Table 6. Distribution of species with depth at station R04.

Vertical distribution of hard bottom organisms

Observer ARE   Tidal corrections Y/N
Clerk ARE

Occurence: 1 = Single 2 = Scattered 3 = Common 4 = Dominating

(shaded) = Have to be regist.
Format: A = Alfanum. S = Num

Locality: S1

Station R04 Date 24.10.93 Barom mm Hg Max. Depth 15
Exposure 2 Direc. 0 Slope 40 Bottom category R
Other investigations : Stereophoto m Quadrates : -- m Kelp : -- m Video: min. TS m Photo Y
Station AASS Bottom type: ROCK, BIG ROCKS
Format: Loc: AS Slope: 30, 40
Date: ddmmåå Horisontal view: 8, 10
Observ: AAA

Kode	cf	sp	NB	TAXA	<1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	>30
NEDBE				GRAZED BY ECHINOIDEA			4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4											
LABMI			M	Labrus mixta												1																					
ASTRU			PM	Asterias rubens						2				2								2															
MARGL			PM	Marthasterias glacialis																		1															
CENRU			M	Centrolabrus rupestris																		1															
ECHAC			PM	Echinus acutus			4	4	4	4	3	3	3	3	3	3	3	3	3	3	3	3															
POMTR				Pomatoceros triqueter																		3															
GALST			PM	Galathea strigosa																		2															
STIRO	1		PM	cf.Stichastrella rosea																		1															
MODMO				Modiolus modiolus																		2															
GALAZ			M	Galathea sp.												2	2	2	2	2	2																
CORAX				Coralliniacea indet.				4	4	4	4	4	4	3	3	3	3	3	3	3	3	3															
PHYTR	1			cf.Phyllophora truncata														1																			
PTIPL				Ptilota plumosa														1																			
AUDOZ				Audouniella sp.														1																			
TRAIN	1			Bonnemaisonia hamifera: sporp.														1																			
DHLSA	1			Delesseria sanguinea														1																			
PHYRU				Phycodrys rubens														1																			
PSEEX	1			cf.Pseudolithoderma extensum						3	3	3	3	4	4	4	4	4	4	3	3	3															
CRUPE				Cruoria pellita					2	2	2	2	2	2	2	2	2	2	2	2	2																
SHIZN				Diatomeer - Schizonemastadiet			3	3	3																												
ASCNO				Ascophyllum nodosum			4																														
FUCVE				Fucus vesiculosus		3																															
FUCSE			*	Fucus serratus			3																														
FUCSP				Fucus spiralis		3																															
CLARU				Cladophora rupestris			3																														
CHOCR				Chondrus crispus			3																														
MEMME				Membranipora membranacea		2	2																														
PELCA				Pelvetia canaliculata	2																																
			M=	Mobile																																	
			PM=	Partly Motile																																	
			1	Etensivly grazed																																	
			2	No upright algae only encrusting																																	
			3	Well developed fucoid belt except for FUCSE																																	
			4	No profound sedimentation																																	
			Bold =	Picture taken																																	

11. APPENDIX 2 - Photos from the diving survey

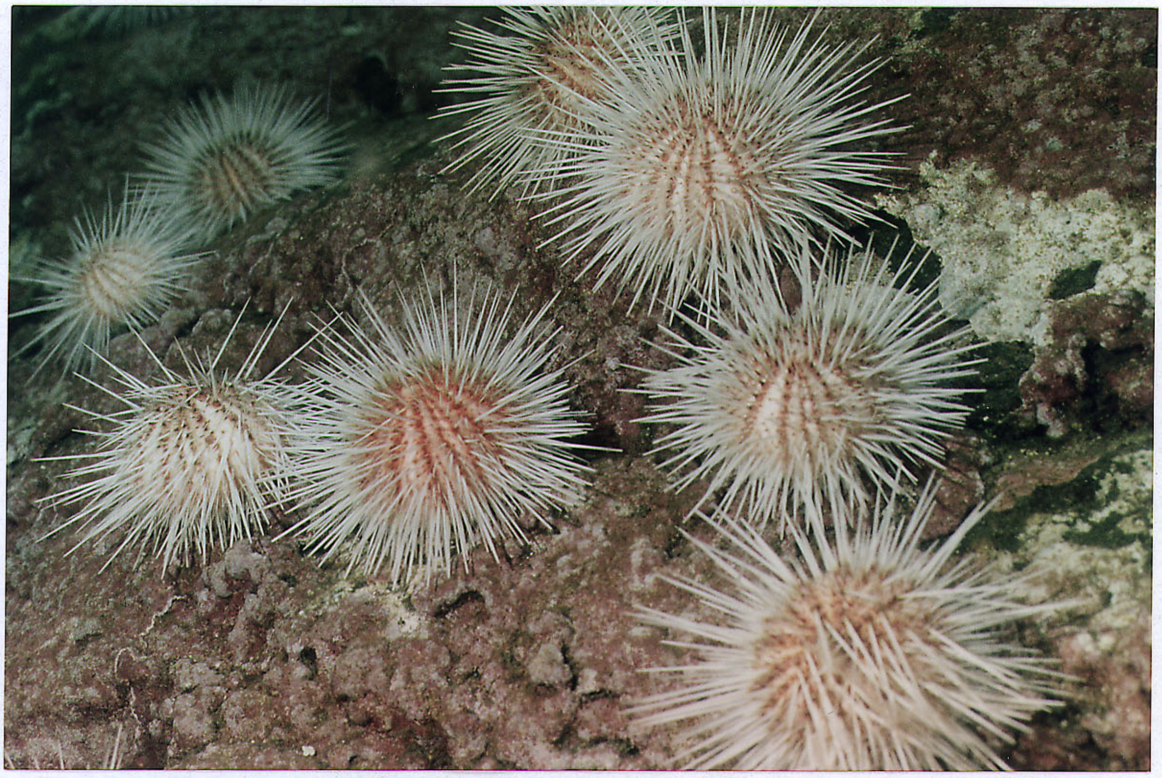


Figure 5. Sea urchins (*Echinus acutus*) dominating from 0m down to 10m at station R04.

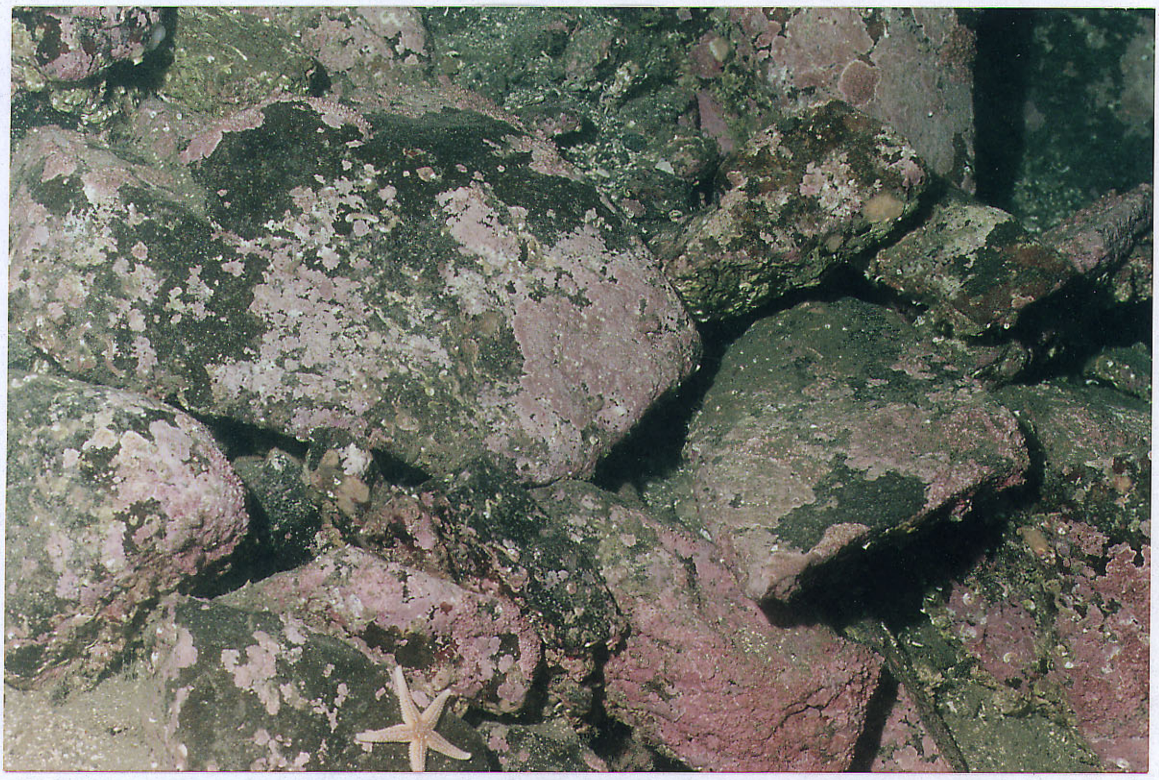


Figure 6. All vegetation and fauna except some encrusting algae (*Lithothamnion spp* & *Pseudolithoderma sp*) were grazed by sea urchins (*Echinus acutus* Fig. 5).

Figure 7. Kelp (*Laminaria saccharina*) found at station R01, R02 and R03. Small tube worms (*Spirorbis sp.*) grow on the blade (*lamina*). Picture taken on station R02.

Figur 8. Mussels (*Mytilus edulis*) found at 5m at station R01 in large quantities.

Figure 9. Starfish (*Asterias rubens*) feeding on mussels at station R03.

Figure 10. Heavy sedimentation caused barnacles (*Balanus balanus*) and different tube worms (*Pomatoceros triqueter & Serpula vermicularis*) to grow at vertical or overhanging rocks at station R01 and R02. Picture from R02.

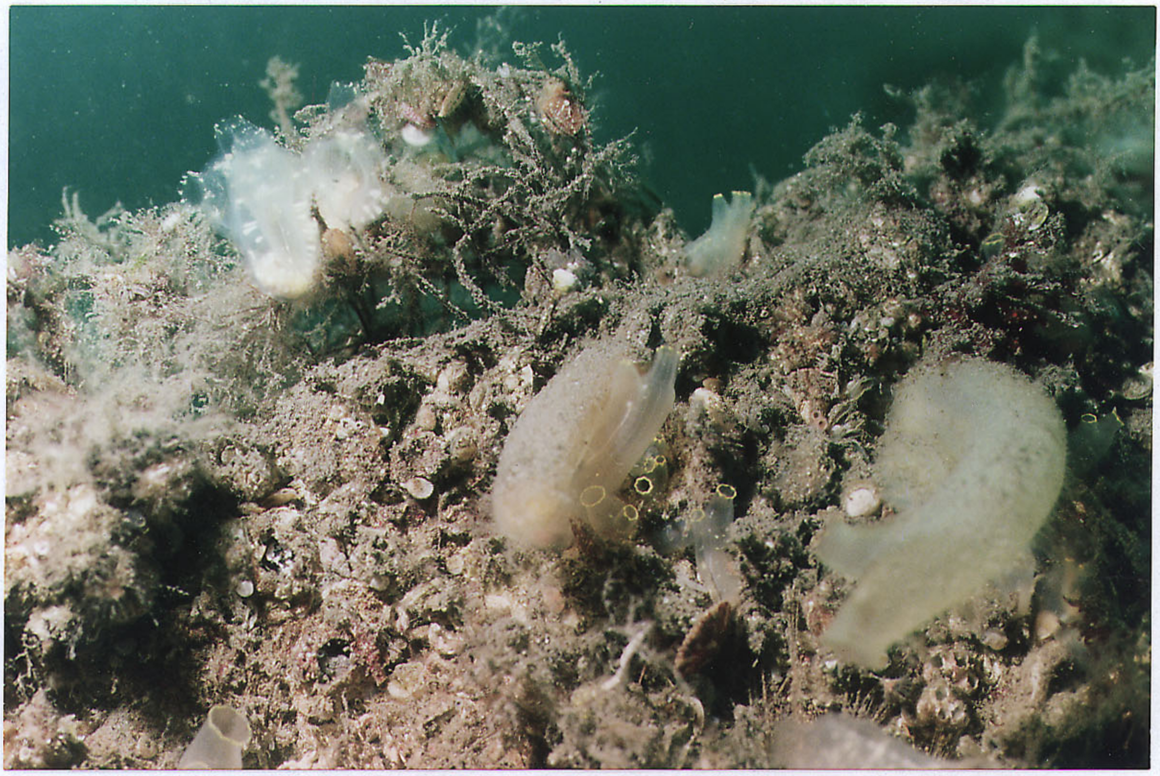


Figure 11. Hydroids (*Laomedea spp*), tunicates (*Ciona intestinalis*), clams (*Chlamys sp*), barnacles (*Balanus balanus*) in a mixture of other organisms at station R02.

Figure 12. Sea slug (cf. *Dendronotus frondosus*) feeding on hydroids at station R01. Different tube worms (*Pomatoceros triqueter, Serpula vermicularis, Chaetopterus variopedatus*) and barnacles (*Balanus balanus*) can also be seen.

Figure 13. Salt aggregating on the surface of rock in the upper 2 meters at station R01. The surface was covered with cyanobacteria and probably diatoms.

Figure 14. Green seaweed's (mainly different *Enteromorpha spp*) among young and older bladdered wrack (brown important seaweed *Ascophyllum nodosum*) at station R02 and R03. Picture from station R02.

Figur 15. A small brown algae (*Sphacelaria cf. radicans*) growing in sediment mats together with a very fine red algae (*Audoniella cf. floridula*). Picture taken at station R03 at 2m depth.

Figur 16. An ecological important brown algae - *Fucus serratus*, being overgrown by small epiphytes and partly covered with fine sediments. Picture taken at station R03.

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