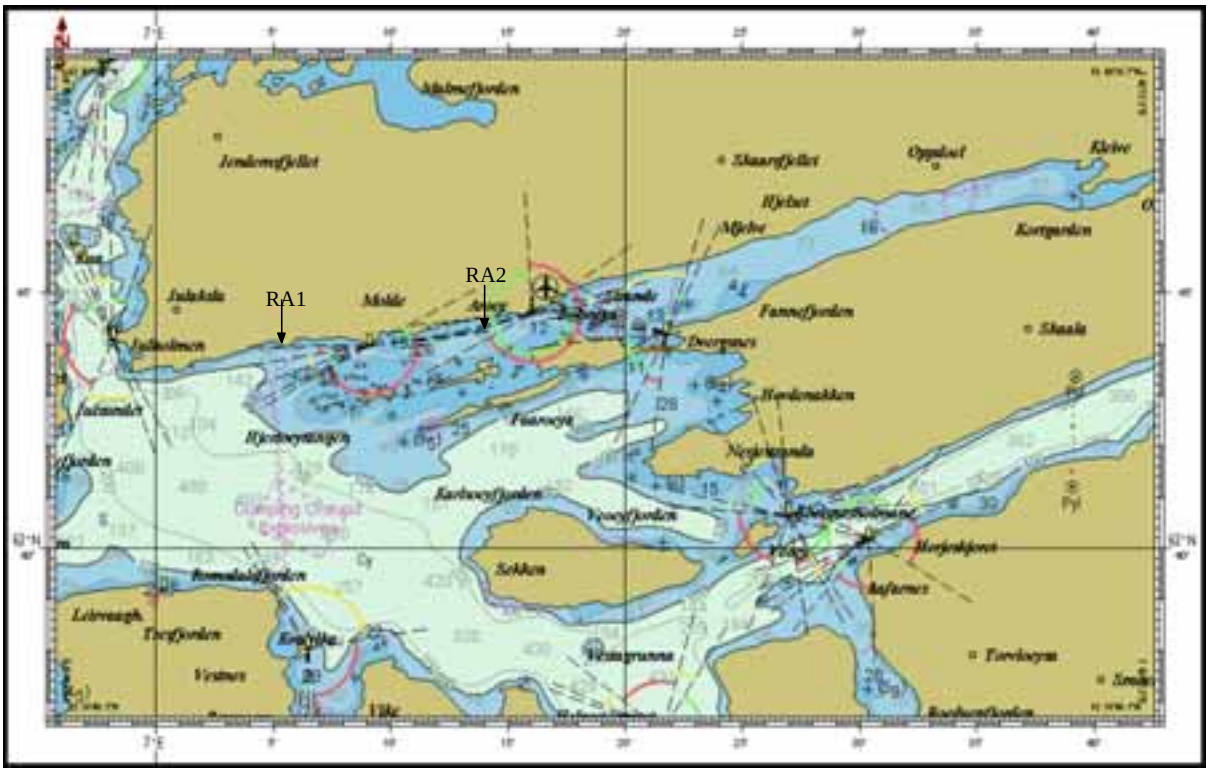
REPORT SNO 5056-2005

Molde- and Fannefjord, Møre and Romsdal

Assessment of discharges of municipal waste water with regard to the requirement of secondary treatment in the EU Urban Waste Water Directive



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Abstract

In general the environmental conditions in the Molde- and Fannefjord were classified as Very Good. This classification corresponds to the fact that the nutrient load from municipal sewage contributes a small part of the total load for the fjord system. At RA2 the hard bottom flora and fauna showed local indications of increased nutrient load and the bottom around the outfall was covered by sludge. Except from these local effects this study did not show any negative effects on the marine environment from the outfalls from RA1 and RA2. From the above description follows that the Moldefjord and the Fannefjord are not adversely effected by the present discharges of municipal sewage.
Near the fish farm at Grønnes some indications of eutrophication on hard bottom flora in the littoral zone were observed, but not on soft bottom fauna or water quality parameters.

4 keywords, Norwegian	4 keywords, English
1. Moldefjorden	1. Moldefjord
2. Fannefjorden	2. Fannefjord
3. Avløpsdirektivet	3. Urban Waste Water Directive
4. Kommunalt avløpsvann	4. Municipal waste water

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Molde- and Fannefjord, Møre and Romsdal

Assessment of discharges of municipal waste water with regard to the requirement of secondary treatment in the EU Urban Waste Water Directive

Preface

In 2003-2004 the Norwegian Institute for Water Research (NIVA) carried out a study of the environmental conditions in the fjord areas around Molde city. The main objective was to provide the city authorities with information about the environmental status of the fjord areas, and especially information that is relevant for a decision whether the city shall apply for a permit for treatment less stringent than secondary treatment for plants RA1 and RA2.

The present report is an abbreviated version of the project report, which was written in Norwegian.

Oslo, August 18 2005

Jarle Molvær

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Summary

Background and objectives
The European Urban Waste Water Directive (1991/271/EØF and 1998/15/EØF) focuses on secondary treatment for discharges of waste water to marine waters from agglomerations of more than 10000 PE. The two largest treatment plants – RA1 and RA2 - in the city of Molde are both primary treatment plants.

The city of Molde has described the objectives of this study as follow:
1. *Provide the competent communal authority with up-to-date information about the environmental status of the arae, for further decision making on whether the city will apply for a permit for treatment less stringent than secondary treatment for the RA1 and RA2 plants.*
2. *Supply a baseline for future environmental monitoring of the fjord area.*
3. *Document the environmental impacts from a fish-farming settlement which started operating in January 2003 near Grønnes in the Fannefjord (se* **Figure 1***).*

The recipient
The length of the fjord system is ca. 33 km and the surface area is ca. 50 km^2. To the west the Moldefjord has a sill at 30-32 m depth and in the east the Fannefjord has a maximum depth of 75 m. The water mass below 30-35 m is therefore cut off from the coastal water.

Nutrient load
Annually the fjord receives 23 tons of phosphorus and 225 tons of nitrogen, whereof approx. 90% of phosphorus and 70% of nitrogen comes from municipal sewage. Most of the municipal sewage is discharged through outfalls at 37 m depth from the primary treatment plants RA1 (34%) and RA2 (54%). Numerical simulations show that the effluent plume usually is trapped between 15 m and 30 m depth. During situations with very weak vertical stratification and weak currents the plume from RA1 (no diffuser) may reach the surface, in a highly diluted state (400-500x).

For algal growth the nutrient discharge in summer is relevant. A simple nutrient budget shows that the main source of phosphorus and nitrogen is natural water exchange with water masses outside the fjord system, and that the municipal sewage contributes with less than 10% of the total.

Environmental status
Water quality (nutrients, chlorophyll_a, faecal bacteria, secchi depth) assessed from the surface to 15 m depth, is characterised by environmental conditions corresponding to class I (Very Good) according to the Norwegian system for classification of environmental status. According to this classification system the oxygen conditions in both fjord basins were Very Good (>4.5 mlO_2/l). Compared with data from 1983-85 there is no sign of increased oxygen consumption or decreased oxygen concentration.

Biological communities in the littoral zone are representative of general good conditions, and there were few indications of any nutrient impact except from stations close to RA2, where also the bottom was covered by sludge around the end of pipe. The inner parts of Fannefjord showed some symptoms from eutrophication, but probably enhanced by the influence of fresh water. Registration of macroscopic benthic algae and invertebrates showed only few indications of eutrophication. However, compared to the reference station the biological communities at Moldeholmen showed some indications of increased nutrient and organic load.

With one exception all soft bottom stations in the Molde-Fannefjord area were classified as Very Good. This also included stations 250-750 m from the outfalls from RA1 and RA2. For one station in the western part of Fannefjord the classification was Good, according to the index H_{63}.

From the above description follows that the Moldefjord and the Fannefjord are not adversely affected by the present discharges of municipal sewage.

Environmental conditions near the fish farm at Grønnes
The overall environmental conditions were classified as Very Good. No specific effect from the fish farm was identified, although the present discharge of nutrients and organic matter from the fish farm is not known.

The biological community in the littoral zone included relatively few species, but this may be caused by natural conditions and not an effect from the farm. However, some rapid-growing algal species may indicate a certain effect from nutrients from the farm. The soft bottom fauna was classified as Very Good, and did not show any effects from the fish farm.

1. Background and objectives

The European Urban Waste Water Directive (1991/271/EØF and 1998/15/EØF) focuses on secondary treatment for discharges of waste water to marine waters from agglomerations of more than 10000 PE. The two largest treatment plants in the city of Molde, respectively RA1 (12,000 PE) and RA2 (18,000 PE), are both primary treatment plants.

The city of Molde described the objectives of this investigation as follow:

1. *Provide the competent communal authority with up-to-date information about the environmental status of the arae, for further decision making on whether the city will apply for a permit for treatment less stringent than secondary treatment for the RA1 and RA2 plants.*
2. *Supply a baseline for future environmental monitoring of the fjord area.*
3. *Document the environmental impacts from a fish-farming settlement which started operating in January 2003 near Grønnes in the Fannefjord (se* **Figure 1***).*

2. The recipient

2.1 Hydromorphology

The length of the fjord system is ca. 33 km and the surface area is ca. 50 km. To the west the Moldefjord has a sill at 30-32 m depth (east from station M2, see **Figure 1**) and in the east the Fannefjord has a maximum depth of 75 m (**Figure 2**). The water mass below 30-35 m is therefore cut off from the coastal water.

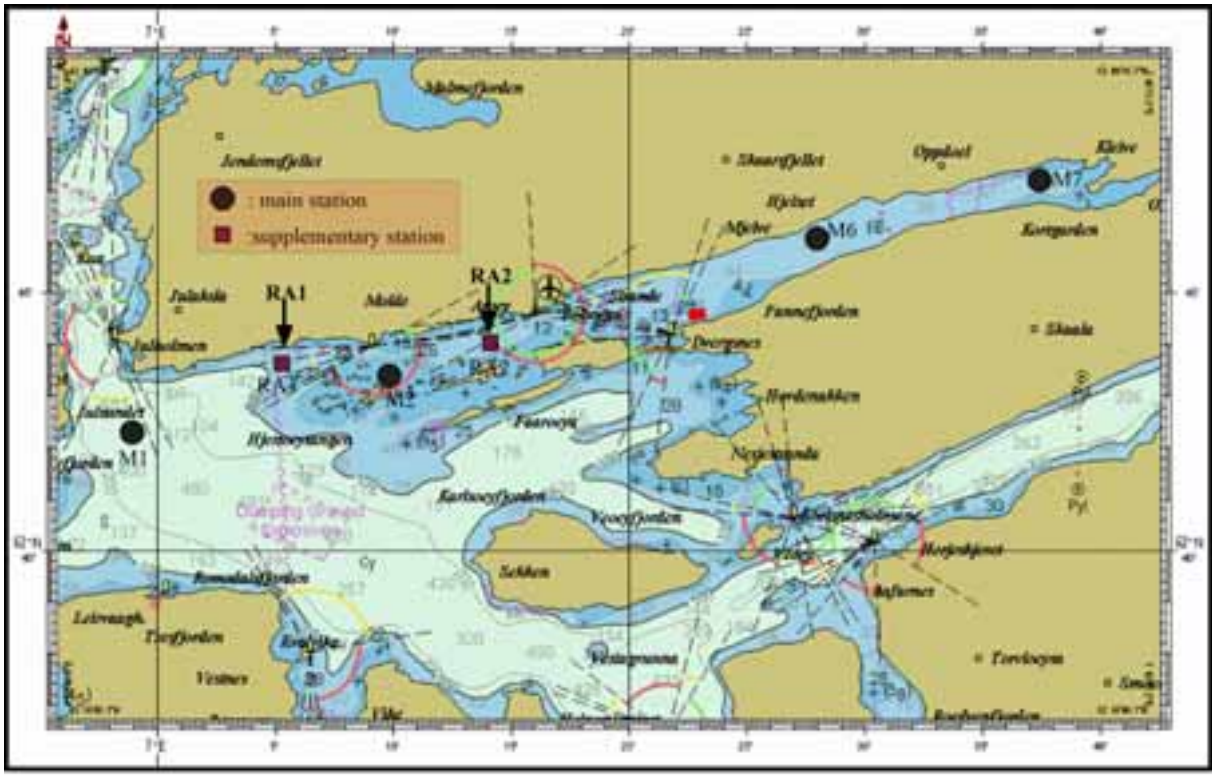


Figure 1. Overview of the area of investigation with locations of the two treatment plants (RA1, RA2) and of the fish-farm ( ).

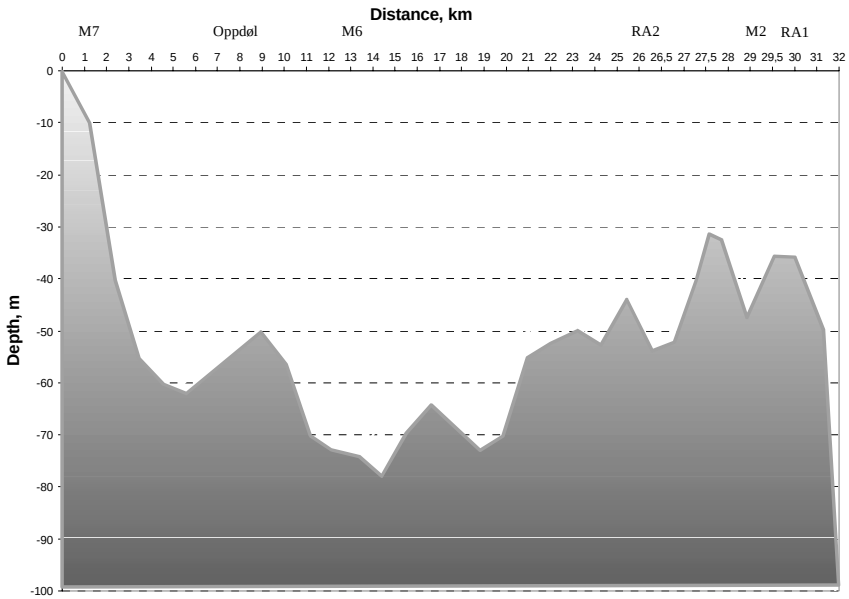


Figure 2. Transect profile from Fannefjord to Moldefjord, as from sea chart no. 33 and 34.

The area is characterised by a classical two-layer hydrological fjord structure made of a low-salinity top-layer, originating from freshwater supply to the fjord (ca. 17 m^3/s) and a salty marine deep layer, separated by a typical 3-8 m brackish layer.

2.2 Pollution sources

Most of the municipal sewage is discharged through outfalls at 37 m depth from the primary treatment plants RA1 (34%) and RA2 (54%). Model runs show that the effluent plume is usually trapped between 15 m and 30 m depth. Under very weak vertical stratification condition and weak current regime the plume from RA1 (no diffuser) may reach the surface, although highly diluted (400-500x). Annually the fjord receives 23 tons of phosphorus and 225 tons of nitrogen, whereof approx. 90% of phosphorus and 70% of nitrogen originates from municipal sewage. The nutrient discharge in summer has significant impact on algal growth. A simple nutrient budget shows that the main source of phosphorus and nitrogen is natural water exchange with water masses outside the fjord system, and that the municipal sewage supplies less than 10% of the total.

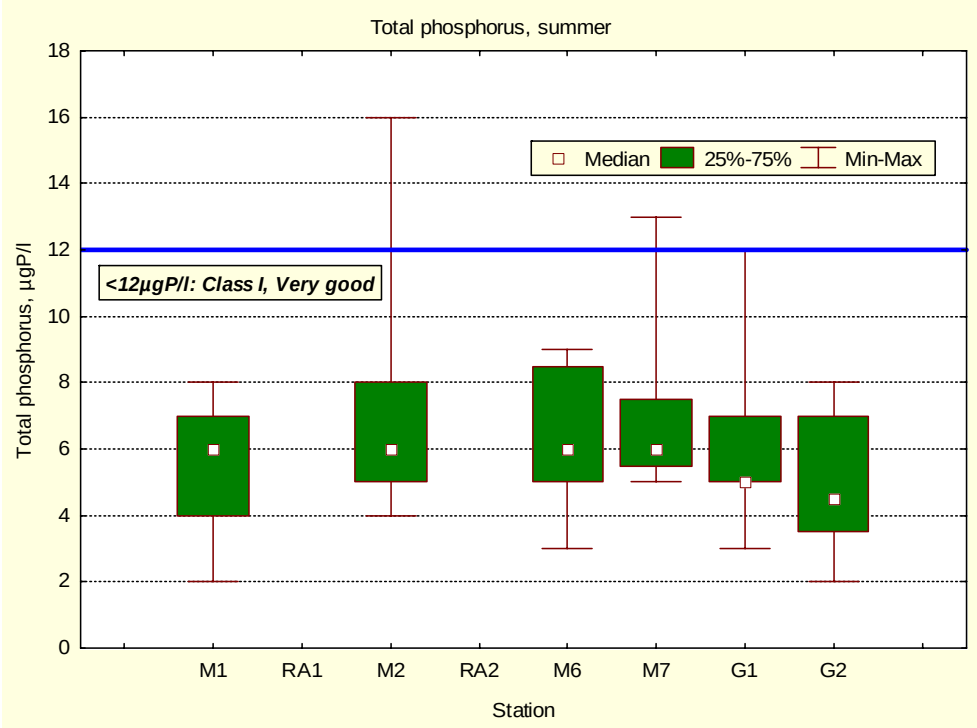
3. Environmental status

3.1 Water quality

Water quality (nutrients, chlorophyll a, faecal bacteria, secchi depth and oxygen) has been assessed according to the Norwegian system for classification of environmental status (Appendix A. . Water samples were taken at the stations M1, M2, RA1, RA2, M6 and M7 (**Figure 1**). Two additional stations located on both side of the fish-farm (hereafter referred to as G1 and G2) were also sampled. Samplings were conducted one to three per month between June 2003 and June 2004.

3.1.1 Nutrients and phytoplankton

Studies of water quality (nutrients and chlorophyll a,) from the surface to 15 m depth show environmental conditions corresponding to class I (Very Good) according to the classification system. Both phosphorus and nitrogen lies with a good margin under the limit to class II (**Figure 3**).



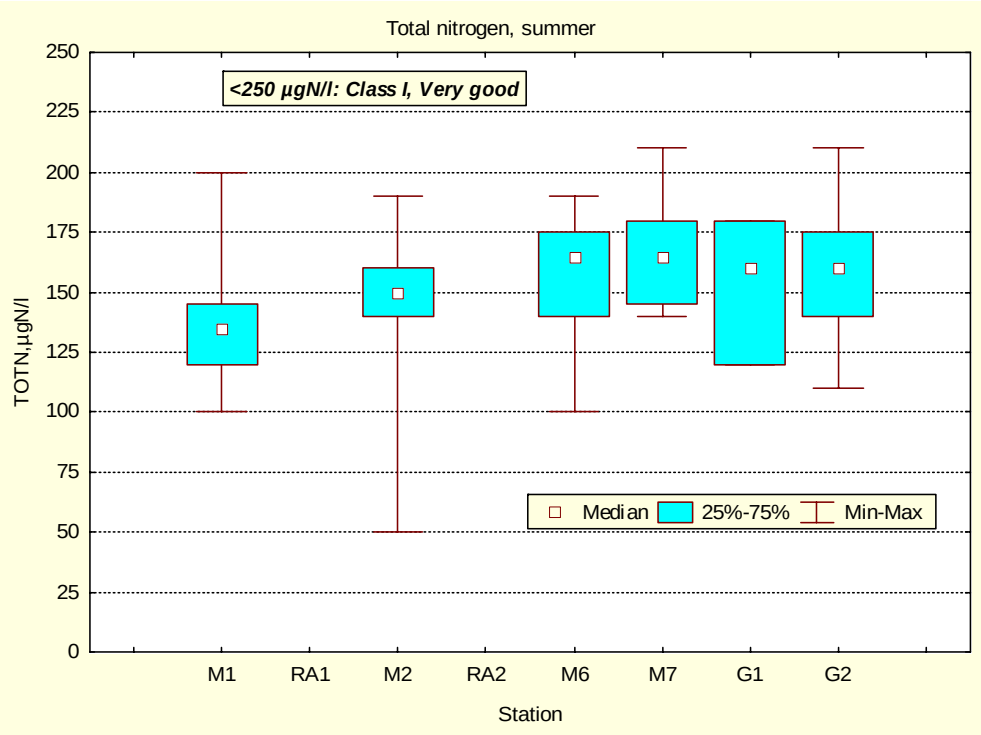


Figure 3. Measurements of total phosphorus and total nitrogen within the top 15 m at M2, and within the top 2 m at the other stations, during the summer period (June- September). Note that the limits between status classes I and II is 250 µgN/l.

This is little different between station M1, located in the strait and other stations deeper in the fjord area, whereas stations located by the fish-farm (G1 and G2) show concentrations significantly lower that the two other stations located in Fannefjord (M6 and M7).

Chlorophyll_a was used as a proxy for phytoplankton biomass. It is not surprising to observe higher concentration inside the fjord area although the difference is quite limited (**Figure 4**).

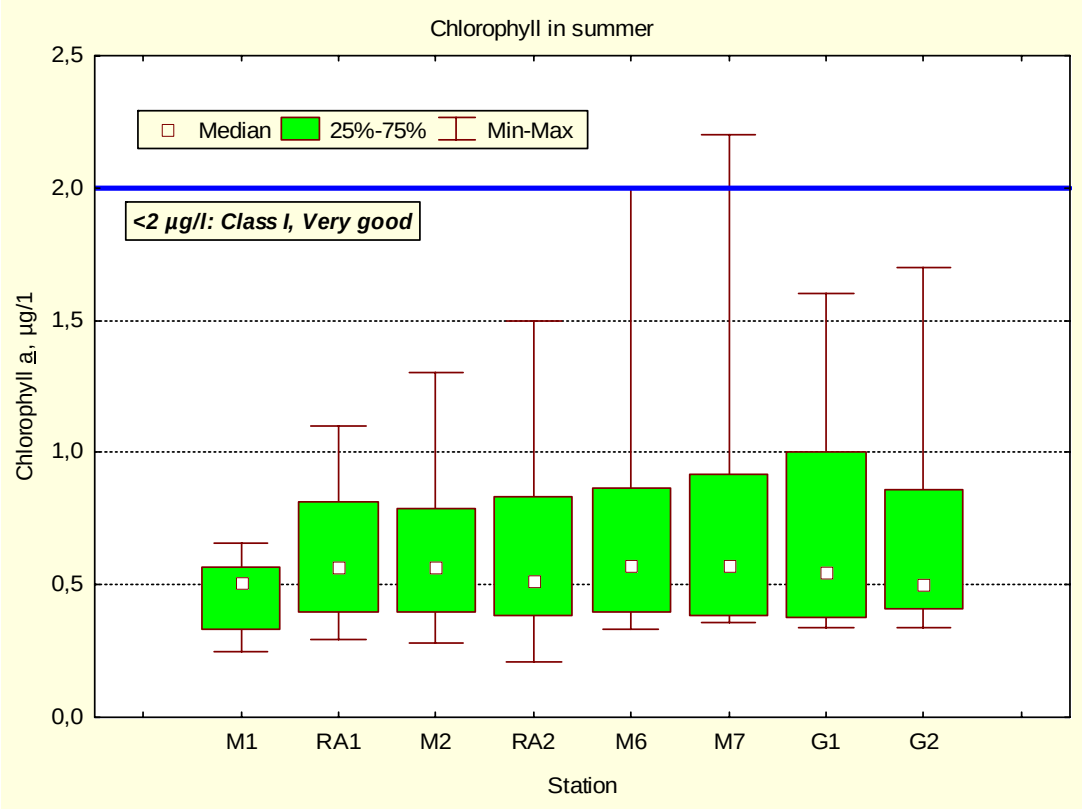


Figure 4. Measurements of chlorophyll_a within the top 15 m at RA1, M2 and RA2, and within the top 2 m at other stations, during the summer period (June – September).

Results for the winter period were similar to those for the summer period.

3.1.2 Bathing waters

Quality of bathing water has been assessed by measuring the concentration of thermo-tolorante coliform bacteria (TBK) at RA1 and RA2, and the water clarity (Secchi depth) at all stations.
All measured concentration of TBK were found as lower than 50 TBK/ 100 ml, giving therefore clearance for bathing (limit set to 100 TBK/100 ml)

Seacchi depths of 8 m in average were observed. The minimum Secchi depth found was 4 m, which is two time higher than the limit of 2 m set as criterium for good bathing waters.

3.1.3 Oxygen condition aroung the fish-farm

According to this classification system the oxygen conditions in both fjord basins were Very Good (<4.5 mlO_2/l) (**Figure 5**). Compared with data from 1983-85 (Nilsen et al., 1987) there is no sign of increased oxygen consumption or decreased oxygen concentration.

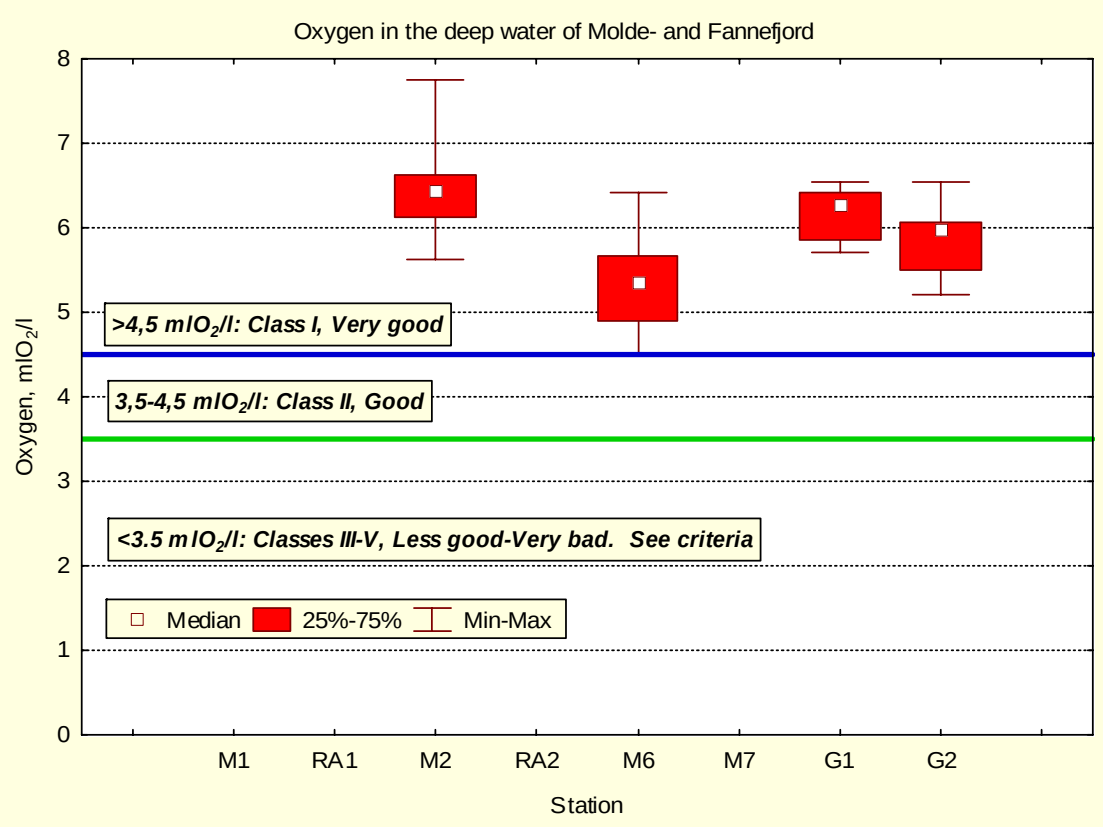


Figure 5. Measurements of oxygen conditions in Moldefjord (M3), Fannefjord (M6) and near by the fish-farm in Grønnes (G1 and G2).

3.2 Benthic biota

3.2.1 Rocky bottom

Investigation of fixed benthic algae and fauna in shallow water is an efficient mean to characterise environmental status. Algae and animal communities change according to environmental conditions and mirror how the situation has been in the past.
Benthic communities have been investigated, following Norwegian standard of investigation of hard-bottom flora and fauna (NS 9424, 1998) through quantitative and semi-quantitative routine analyses at 9 stations at low tide, and 2 semi-quantitative scuba-diving transects from a maximum depth of 30 m to the surface (st. 4 and Ref3). In addition 16 locations in fannefjord were investigated at low tide for algal belt, dominant species and eutrophication status (**Figure 6**).

Results from the biodiversity analysis are shown in **Table 1**.

Registration of macroscopic benthic algae and invertebrates done *in situ* showed only few indications of eutrophication. However, compared to the reference station the biological communities at Moldeholmen (st. 4) showed some indications of increased nutrient and organic load.

Station 7 nearby the fish-farm shows significant differences in communities in the mixed-kelp belt compared to the other stations. The main difference was found to be due to smaller number of species present at this station. But the occurrence of the present species is also lower, in particular *Patella vulgata*), *Fucus vesiculosus* and *Littorina obtusata*.

Figure 6. Localisation of the stations investigated for rocky biological communities. Observations by scuba diving were conducted at stations 2 and ref 3. Triangles show stations for observations at low tide. FO3 is the location of the fish-farm.

Table 1. Number of taxa (S), summed occurence (N), species richness (d (Margalef)), smoothness (J') and diversity (H' (Shannon-Wiener)) at 10 stations, at low tide outside of Molde.

Index	Belt	11	12	13	1	3	4	5	6	7	8
S	Egg wrack	35	29	36	25	28	34	39	26	28	31
	Mixed kelp	25	20	22	15	18	31	15	21	9	22
N	Egg wrack	288,5	226,55	182,15	231,05	243,15	273,3	277,65	188,45	172,45	209,25
	Mixed kelp	292,40	179,35	212,70	82,05	203,55	239,15	208,70	144,85	21,50	206,70
d	Egg wrack	6,00	5,16	6,72	4,41	4,91	5,88	6,75	4,77	5,24	5,61
	Mixed kelp	4,23	3,66	3,92	3,18	3,20	5,48	2,62	4,02	2,61	3,94
J'	Egg wrack	0,59	0,53	0,53	0,60	0,54	0,68	0,70	0,51	0,47	0,49
	Mixed kelp	0,75	0,62	0,67	0,65	0,58	0,75	0,77	0,47	0,85	0,65
H'	Egg wrack	2,12	1,79	1,92	1,94	1,81	2,38	2,57	1,65	1,56	1,68
	Mixed kelp	2,42	1,87	2,08	1,76	1,66	2,58	2,10	1,44	1,86	2,02

Communities in the tidal zone inside Fannefjord shows caharacteristics typical of environment under freahwater influence: *Pelvetia canaliculata* was not present in the inner part of the fjord and increased occurrence of grenn algae.

Compared to an earlier investigation back in 1985 (Nilsen et al., 1987), we also found that station 8 was the most disturbed, but we assign this state to non-communal discharges near Molde's shipyard.

Comparison of the two stations investigated by mean of scuba-diving shows little differences on number of species registered, but we observed much higher occurrence at Ref3 than St.4. High occurrence of species that characterised polluted areas was observed at St.4, e.g. the green algae

Enteromorpha sp., blue-green algae, sea urchin, etc. Comparison of community indexes species richness (d), smoothness (J) and diversity (H) shows little difference between the two stations.

The study of biological communities in the littoral zone showed in general good conditions, and except from stations close to RA2 there were few indications of any nutrient load. The inner parts of Fannefjord showed some symptoms from nutrients, but probably enhanced by the influence of fresh water.

3.2.2 Soft bottom

Fauna and animal communities on soft bottom have also been investigated, following Norwegian standard of investigation of soft-bottom fauna NS 9423 (1998).
Sediment samples were taken at each station, using a 0.1 m^2 vanVeen grab.
Eleven stations were investigated, including two stations (M6 and M8) that had been already investigated in 1985 (**Figure 7**). Bottom depth varies between ca. 30 m (M23) and 80 m (M17).

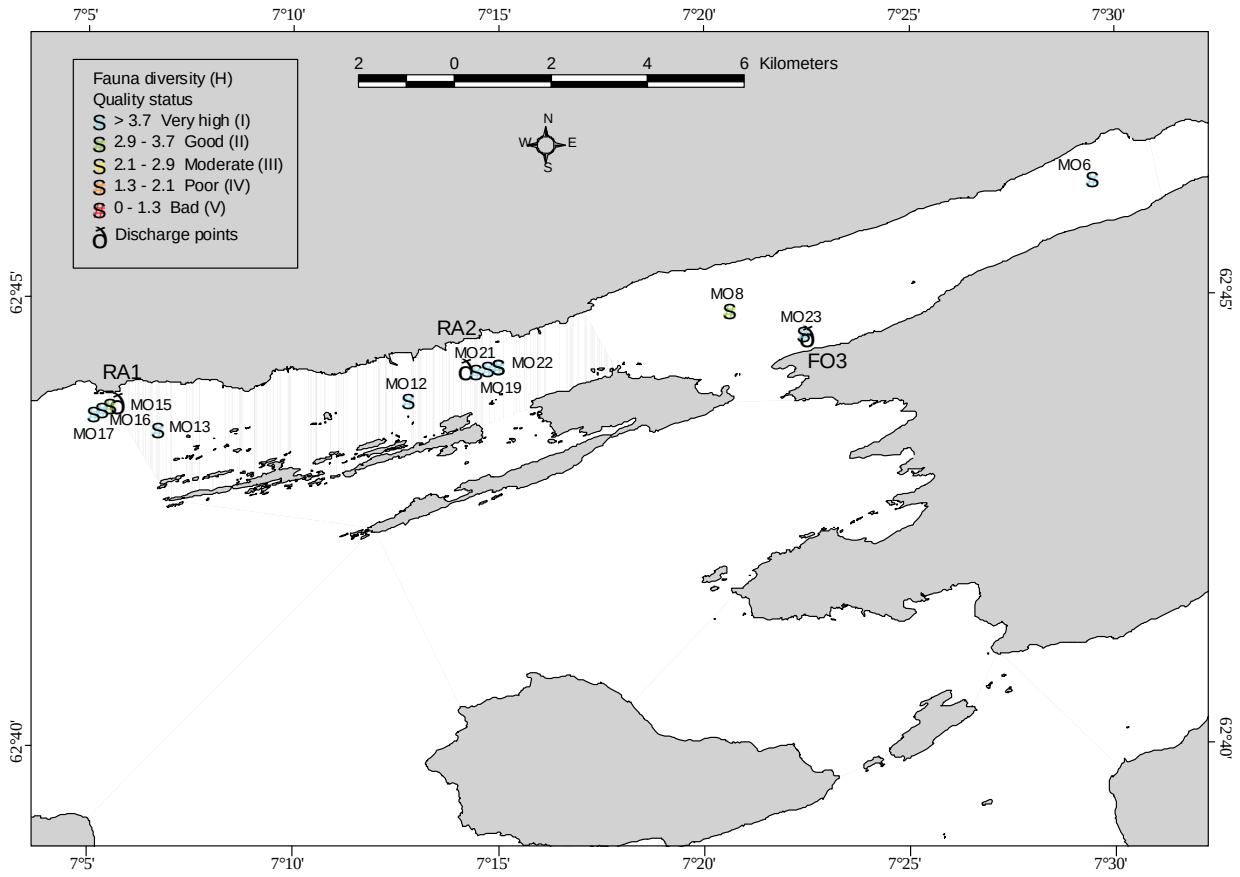


Figure 7. Location of the eleven soft-bottom stations. Stations M6 and M8 were also investigated in 1985. The colour scale indicates the fauna diversity (H) according to the Norwegian classification system.

Biodiversity (H(log2) (Shannon & Weaver, 1963), Hurlberts index – ES100 (Hurlbert, 1971), ISI (Rygg, 2002)) was assessed together with sediment granulometry and concentration of organic carbon and nitrogen. The results were also assessed with reference to the Norwegian classification system for soft-bottom fauna (Molvær et al., 1997), which is based upon species diversity and organic materiel content (TOC) (**Table 2** and **Table 3**).

Table 2. Station parameters. S04 = Number of species per 0.4 m^2; ES100 and H = diversity indices; H_{63} = H normalised to grain size < 63µm; ISI = Indicator species index; $ISI_{depth200}$ = ISI normalised to depth200m; TTS% = sediment dry content; P = sediment phosphorous (g/kg); TN = total nitrogen (g/kg); TOC = total organic carbon (g/kg); TOC_{63} = TOC normalised to grain size < 63µm; TOC/TN = ratio; CU = copper (mg/kg); ZN = zink (mg/kg).

2003																			
Station	Depth	Areal	Number species	S04	Occurrence	%<63µm	ES100	H	H_{63}	ISI	$ISI_{depth200}$	TTS%	P	TN	TOC	TOC_{63}	TOC/ TN	CU	ZN
MO6	70	0.4	77	77	821	89.3	30.9	4.60	4.41	8.88	9.55	26.3	1.32	5.70	56.1	58.0	9.8		
MO8	69	0.4	80	80	1134	57.1	27.8	3.98	3.39	9.23	9.93	39.4	1.06	2.90	25.6	33.3	8.8	19.8	57.5
MO12	53	0.4	113	113	2804	63.3	30.7	4.51	3.92	8.96	9.94	41.8	1.07	2.40	23.2	29.8	9.7		
MO13	60	0.4	106	106	1632	69.8	33.7	4.60	4.09	9.38	10.25	51.4	1.01	2.00	13.8	19.2	6.9		
MO15	60	0.1	75	143	592	32.4	32.7	4.48	3.51	9.29	10.16	59.6	0.76	1.20	7.8	20.0	6.5		
MO16	70	0.1	65	124	349	55.6	35.9	4.56	3.85	9.24	9.93	53.1	0.90	1.00	9.1	17.1	9.1		
MO17	80	0.1	56	106	367	58.8	35.3	4.84	4.13	9.05	9.59	55.2	0.88	1.00	8.3	15.7	8.3		
MO19	46	0.1	73	139	489	42.2	35.5	4.93	3.98	8.83	9.96	51.9	0.89	1.70	14.7	25.1	8.6		
MO21	42	0.1	55	105	509	60.9	30.5	4.58	3.94	8.52	9.72	50.6	0.96	1.70	15.1	22.1	8.9		
MO22	44	0.1	72	137	445	38.3	37.0	4.96	3.95	8.52	9.66	55.6	0.83	1.40	11.4	22.5	8.1		
MO23	28	0.2	87	117	751	69.5	33.8	4.63	4.11	8.77	10.47	57.3	1.01	1.20	9.4	14.9	7.8	7.27	24.0
1985																			
MO3	50	0.4	95	95	694	ingen data	39.8	5.28		8.90	9.94								
MO6	70	0.4	59	59	437	89.3*	28.3	4.18	4.00	7.92	8.51								
MO8	69	0.4	71	71	595	57.1*	30.9	4.26	3.62	8.47	9.11								
MO9	68	0.4	54	54	184	ingen data	36.8	4.78	+	9.48	10.22								

*) values from 2003; +) expected %<63µm not lower than 30

TOC_{63}, CU og ZN were classifised following SFT (Molvær et al., 1997); H_{63} and $ISI_{depth200}$ following Olsgard et al., 2004 (**Table 3.**).

Table 3. Suggested class intervals for normalised parameters (Olsgard et al., 2004).

Class	**V**	**IV**	**III**	**II**	**I**
H_{63}	0-1.3	1.3-2.1	2.1-2.9	2.9-3.7	>3.7
$ISI_{depth200}$	0-4.8	4.8-6.6	6.6-8.3	8.3-9.4	>9.4

With one exception all soft bottom stations in the Molde-Fannefjord area were classified as Very Good. This also included stations 250-750 m from the outfalls from RA1 and RA2. One station in the western part of Fannefjord (M8) was classified as Good, according to the index H_{63}.

4. Conclusions

4.1 Impacts of the municipal waste water discharges

In general the environmental conditions in the Molde- and Fannefjord were classified as Very Good. This classification corresponds to the fact that the nutrient load from municipal sewage contributes a small part of the total load for the fjord system. At RA2 the hard bottom flora and fauna showed local indications of increased nutrient load. Except from these local effects this study did not show any negative effects on the marine environment from the outfalls from RA1 and RA2.

From the above description follows that the Moldefjord and the Fannefjord are not adversely affected by the present discharges of municipal sewage.

4.2 Environmental conditions near the fish farm at Grønnes

The present discharge of nutrients and organic matter from the fish farm is not known. However, the concentrations of nutrients and chlorophyll_a in the surface layer and oxygen concentration in the bottom layer both corresponded to class I (Very Good) with reference to Norwegian classification system.

The biological community in the littoral zone included relatively few species, but this may be caused by natural conditions and not an effect from the fish-farm. However, some rapid-growing algal species may indicate a certain effect from nutrients from the aquaculture settlement. The soft bottom fauna was classified as Very Good, and did not show any effects from the fish-farm.

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Appendix A. Norwegian system for classification of environmental status

	Parametre	Classification				
		I Very Good	II Good	III Intermediate	IV Bad	V Very Bad
Surface layer Summer (June-August)	Total phosphorus (µg P/l)*	<12	12-16	16-29	29-60	>60
	Phosphate- phosphorus (µg P/l)*	<4	4-7	7-16	16-50	>50
	Total nitrogen (µg N/l)*	<250	250-330	330-500	500-800	>800
	Nitrate-nitrogen (µg N/l)*	<12	12-23	23-65	65-250	>250
	Ammonium-nitrogen (µg N/l)*	<19	19-50	50-200	200-325	>325
	Chlorophyll *a* (µg/l)	<2	2-3.5	3.5-7	7-20	>20
	Secchi depth (m)	>7.5	7.5-6	6-4.5	4.5-2.5	<2.5
Surface layer Winter (december-February)	Total phosphorus (µg P/l)*	<21	21-25	25-42	42-60	>60
	Phosphate- phosphorus (µg P/l)*	<16	16-21	21-34	34-50	>50
	Total nitrogen (µg N/l)*	<295	295-380	380-560	560-800	>800
	Nitrate-nitrogen (µg N/l)*	<90	90-125	125-225	225-350	>350
	Ammonium-nitrogen (µg N/l)*	<33	33-75	75-155	155-325	>325
Deep Water	Oxygen (ml O_2/l)**	>4.5	4.5-3.5	3.5-2.5	2.5-1.5	<1.5
	Oxygen saturation (%)	>65	65-50	50-35	35-20	<20

* Conversion factor from µg/l to µg-at/l is 1/31 for phosphorus and 1/14 for nitrogen.
** Conversion factor from mlO_2/l to mgO_2/l er 1.42

The classification of hygienical water quality is base don criteria from the Norwegian Institute for Human health (ref. the two following tables).

Parametre	Good	Intermediate	Not acceptable
Thermo-tolerante coliform bacteria/100 ml	< 100	100-1000	> 1000

Result of water sampling	Bedømmelse av badeplassens bakteriologiske standard
>90% of samples has concentration < 100 TKB/100 ml, and not more than 10% of samples classified as intermediate	Good
> 90% of samples classified as Good or Intermediate	Intermediate
> 10% of samples classified as ”not acceptable”	Not suitable for bathing