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Environmental impacts by running an osmotic power plant

Norwegian Institute for Water Research
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REPORT

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Abstract

The possible environmental impact by running an osmotic power plant is assessed by using results from monitoring of the prototype plant at Tofte in the Oslofjord, where a water flow of approximately 13 L/s of freshwater is mixed with 20 L/s of saltwater and discharged at 2 m depth. The results from the biological investigations show no impact of the discharge water on the benthic communities in the area. Eutrophication effects near the discharge point are identified as the main environmental concern in an up-scaled power plant. Water samples from the saltwater intake indicate that the phosphorous concentration often is higher at 35 m depth than in the euphotic layer, and there will be a net supply of phosphorous to this layer. By diving the outlet plume below the euphotic zone, eutrophication effects as well as possible effects from use of chemicals and possible changed temperature and salinity in the surface layer is avoided.

4 keywords, Norwegian	4 keywords, English
Saltkraft	Osmotic Power
Miljøpåvirkning	Environmental impact
Oslofjorden	Oslofjord
Næringssalter	Nutrients

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Environmental impacts by running an osmotic power plant.

Preface

NIVA (Norwegian Institute for Water Research) has on behalf of Statkraft Development AS conducted surveys of the marine biological conditions in the area of the osmotic power plant at Tofte in the Oslofjord.

Contact persons at Statkraft have been Mari Roald Bern, Morten Stickler, Øystein Lund, Anette Nihlen Moritz and Geir Brekke.

Biological registrations were performed by Janne Gitmark, Norman Green Maia Røst Kile and Lise Tveiten (NIVA) in October 2010 and September 2011.

CTD measurements were conducted in August 2010, in June 2011 and in September 2011 by Jan Magnusson, André Staalstrøm and Norman Green (NIVA).

Water samples were collected in September 2010 by staff at the osmotic power plant, and in July 2011 by André Staalstrøm, and sent to the laboratories at NIVA for analysis.

Analyses of the hydrography and hydrochemistry have been performed by André Staalstrøm. Analyses of the biological registrations have been performed by Janne Gitmark.

Oslo, March 28th, 2012

Janne Gitmark

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Summary

This report assesses the possible environmental impacts by running an osmotic power plant. The assessment is based on results from the monitoring of the osmotic power prototype plant at Tofte in the Oslofjord. Biological, hydro-physical and hydro-chemical parameters are measured at several stations near the outlet of the plant in the period 2009 - 2011.

During normal operation approximately 20 L/s of seawater is pumped up from 35 m depth and mixed with approximately 13 L/s of freshwater to extract osmotic power. The water is discharged through a pipe with diameter 315 mm at 2 m depth. The discharge plume is estimated to be diluted approximately 5 times close to the discharge point. In a full scale osmotic power plant water flow will be considerably higher. In this report an upscaling to a water flow of 6 m^3/s is considered.

Eutrophication effects near the outlet are identified as the main environmental concern. This means increased biomass due to increase in nutrient load in the depth range where the light conditions are sufficient to maintain life (the euphotic zone). In the Oslofjord the euphotic zone is typically from the surface down to 10 - 20 m. With enhanced concentrations of nutrients in the water, small fast-growing opportunistic algae can increase drastically in abundance. The nutrient concentrations at the depth of the saltwater intake might be higher than in the euphotic zone, and in this case running an osmotic power plant means a net supply of nutrients. This nutrient pump effect will increase when the dimensions of the power plant increase, depending on the vertical distribution of nutrients in the water column.

At Tofte the volume flux of discharge water is approximately 33 L/s. A moderate current of 10 cm/s in the upper 3 meters of the water from the coastline and 10 meters out, will carry 3000 L/s past the discharge point, or 100 times the size of the discharge. Thus the impact at Tofte is expected to be negligible. The results from the biological investigations show no impact of the discharge water on the benthic communities in the area. There was a reduction in the number of species/taxa registered from 2009 to 2011. However, benthic communities are in constant change and the number and abundance of different species will vary during and between years. It is not likely that the registered reduction of species/taxa is a result of the discharged water. A comparison between the registered number of species/taxa at Tofte and a nearby station show little difference.

Nutrient concentrations are measured in the outlet basin at Tofte Osmotic power plant. Of the 14 measurements presented in this report the concentrations of total nitrogen, total phosphorus and phosphate are in the water quality class IV (bad environmental quality) or V (very bad environmental quality) 5, 6 and 2 times respectively. This shows that there would be a potential risk of eutrophication in the area close by the outlet pipe if the discharge gets large enough to dominate the water mass in the vicinity of the discharge point. If the volume transport in the outlet was increased 200 times from 30 L/s to 6 m^3/s, eutrophication in a limited area around the outlet pipe is probable. If we assume that the dilution and the thickness of the plume is the same, the outlet might influence locations that are about 14 times further away than would be the case with a discharge of 30 L/s. At Tofte traces of the discharge could be seen at station TOF-2 80 m from the discharge point, but not at station TOF-3 150 m away.

In two occasions when the total nitrogen and total phosphate concentrations are measured instantaneously in both the outlet basin, the saltwater intake and the freshwater intake, the high concentrations of nitrogen is caused by the river water and the high concentrations of phosphorus is caused by the seawater. Thus it’s likely that the occasions with high phosphorus concentrations in the outlet basin are due to a nutrient pump effect. For comparison, the phosphorus concentrations measured every second week at 4 m depth from the Ferrybox system at the ferry Color Fantasy show that the water quality in the waters surrounding Tofte is on every occasion in class I (very good environmental quality) or II (good environmental quality) during the summer in 2011.

To avoid eutrophication due to the nutrient pump effect in an upscaled osmotic power plant, measures can be taken to make sure that the outlet plume ends on a depth below the euphotic zone. This can be achieved by extending the outlet pipe down to an appropriate depth. Installing a diffusor to increase the dilution might also be considered. To assess if any of the measures mentioned above is necessary in the case of an upscaled power plant, the local conditions at the particular site in question must be evaluated.

Other possible environmental impacts are local change in salinity and temperature and possible effects of chemical substances used in the process. The risk of each chemical substance that will be used in an upscaled power plant must be assessed. Measures to reduce impact on local salinity and temperature would be exactly the same as the measures taken to avoid eutrophication effects, a deeper and more diluted discharge.

1. Introduction

Statkraft Development AS opened the world's first osmotic power prototype plant on November 24th 2009 (www.statkraft.com/energy-sources/osmotic-power/). The plant is located at the industrial area of Södra Cell at Tofte, Hurum. Tofte is located in the Oslofjord about 60 km south of Oslo. Freshwater and seawater are fed into the plant by separate pipes. Filters are used to remove humus and other particles. Saltwater (about 20 L / s) is taken from the fjord at 35 m depth, outside the industrial area. Freshwater (about 13 L / s) is taken from the local river Tofteelva (and sometimes when necessary from the river Sagende). In the future the freshwater intake will be changed from Tofteelva to a mix between the river Sagende and Tofteelva. The freshwater and seawater meet on either side of a membrane inside the plant. The natural phenomenon of osmosis will cause the freshwater to be drawn to the seawater side. The membrane only allows freshwater to flow through, but not the saltwater, thus creating a pressure of about 12 Bar on the seawater side which can be used to drive a turbine. After the water has passed the turbine, this, and any excess of seawater, is released into the fjord at about 2 m depth through a pipe with diameter 315 mm. To clean the filters, and to prevent fouling, some cleaning agents are used. **Figure 1** shows an overview of the location of the seawater intake and where the water mixture is discharged.

The objective of this report is to assess the possible environmental impact of running an osmotic power plant. The prototype power plant at Tofte will be used as an example. NIVA has monitored the environment at several hydrographical and biological stations (**Figure 1**) during the period the power plant has been running. During the preliminary survey (Walday et al. 2011) the following environmental risks was identified:

1. <u>Nutrient pump</u>: Saltwater for the plant is pumped up from 35 m, run through the plant and is released in the surface layer. Since the concentration of nutrients often increase with depth, especially during the summer months when nutrients are in demand by the algae community, pumping seawater from 35 m depth and releasing it in the surface layer may lead to local enhanced eutrophication (increased biomass due to addition of nutrients).
2. <u>Changed temperature conditions</u>: The temperature at 35 m depth is more stable than the temperature in the surface layer, so in winter the discharge is warmer than the ambient surface water and in summer the discharge relatively colder. This may lead to a change in the natural algal composition.

3. Possible effects of chemical substances used in the process: While cleaning the membranes in the power plant during regular operation certain chemical substances are used, and they may have an effect on the environment.

In the preliminary survey contaminants in filtered particles was also mentioned, but the operation of the power plant do not add any contaminants, and the concentration of contaminants in the filtered particles will reflect the concentrations found in the river and the fjord. This aspect is not evaluated in this report.

To evaluate the potential effect of the nutrient pump, nutrient concentrations are measured in the surface layer in the vicinity of the power plant, in the discharge water and in the intake water at 35 m. This is compared with concentrations measured in the water column in the fjord outside the power plant. To evaluate the potential effect of changed temperature conditions, temperature and salinity are measured at the intake water and in the surface layer in the vicinity of the plant. To evaluate the possible potential effects of chemicals, the actual use of substances during one year is assessed. The actual effect on the aquatic life is investigated with in situ registration.

The prototype plant at Tofte is designed for developing the technology. An economically profitable power plant will have a volume flow considerable higher than the present 0.03 m^3/s. A possible impact of upscaling to 2 m^3/s of freshwater and 4 m^3/s of saltwater is considered. This is the expected volume fluxes in a possible pilot osmotic power plant. A full scale plant will possibly have a SW volume flux of 20 m^3/s.

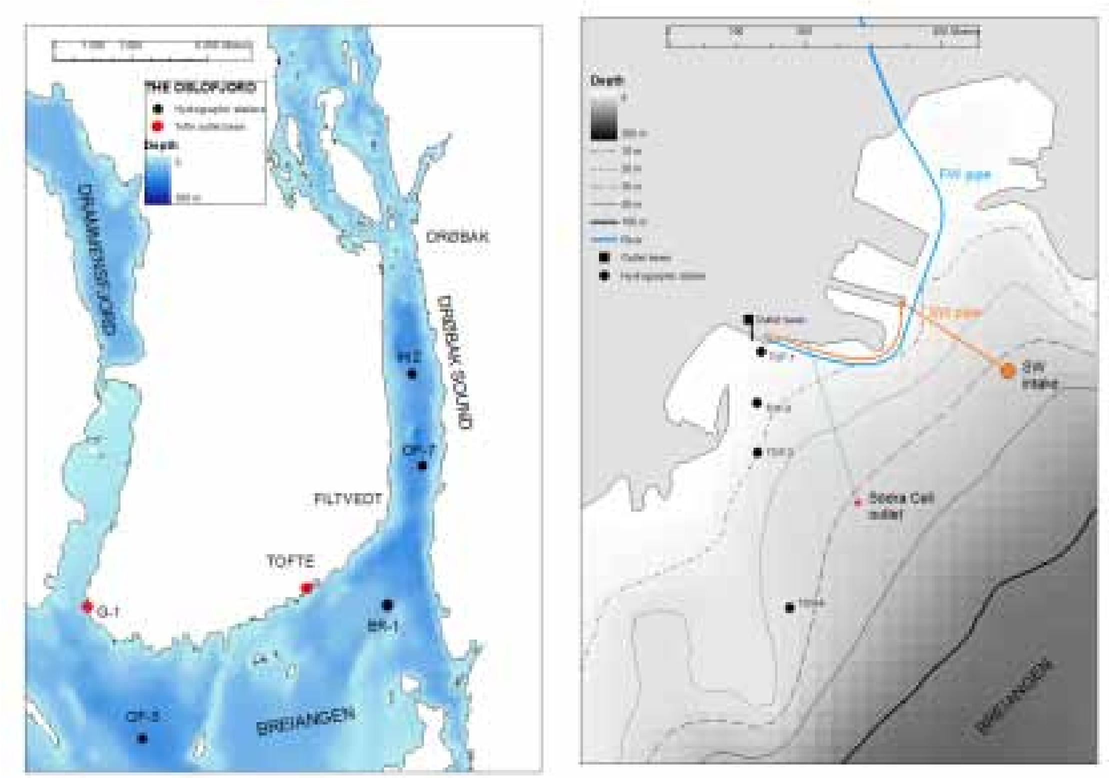

Figure 1. Location of Statkraft Energi at Tofte in mid-Oslofjord and station G1 from a monitoring program of the Outer Oslofjord (left) and detail of investigation area showing location of hydrographical stations (right).

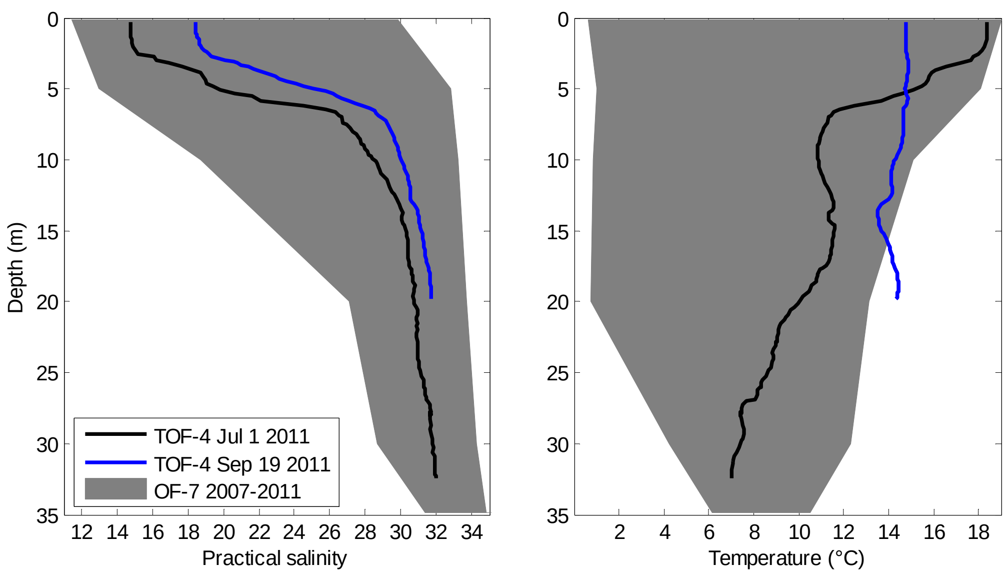

Figure 2. Vertical structure of salinity (left) and temperature (right) at station TOF-4 from 2011. The range of measurements from station OF-7 from 2007 to 2011 is indicated with grey colour.

2. Hydrography and hydrochemistry

In this chapter the results from measurements of salinity, temperature and nutrient concentrations will be presented. First we look at two active tracers in the sea, namely temperature and salinity. These two are called active tracers, because they determine the density of the seawater and are therefore important for the water movements. Secondly we look at another class of tracers, the nutrients. They are important building blocks for biological life. Discharge of nutrients in recipients where the biological life is limited by lack of nutrients, may lead to reduced environmental quality due to increased growth of algae, possibly also blooms of unwanted species. Finally we look at chemicals as a third class of tracers. The use of chemicals may have toxic effects on marine life.

2.1 Temperature and salinity

The water at 35 m depth generally has more stable temperature and salinity than the surface water. Moving water from this depth might change the conditions in the surface. Now we will examine how the osmotic power plant might impact the salinity and temperature in the surface layer. **Figure 2** shows two typical salinity and temperature profiles from the station TOF-4 near the plant. For comparison the variability from station OF-7 is shown in grey. Salinity higher than 30 psu is usually found below 15 - 20 m depth. In the summer the temperature below 30 m depth can be 10^{o}C colder than the surface water. Pumping up water from this depth might cool the surface waters in the summer and heat the surface waters in the winter. **Figure 3** show how the temperature varies at station TOF-1 at approximately 1 m depth. Note that daily mean (black line) can be up to 4 degrees different than the monthly mean (red line).

After the fresh- and saltwater is mixed inside the plant the resulting salinity will be approximately 18 – 21 psu. Depending on how far from the river mouth the discharge point from the power plant is situated, this might increase or decrease the salinity in the surface layer. At Tofte the salinity in the surface is measured to 15 and 19 in 2011, and the discharge will theoretically increase the surface salinity. The volume in the discharge is so small that this effect is not possible to observe.

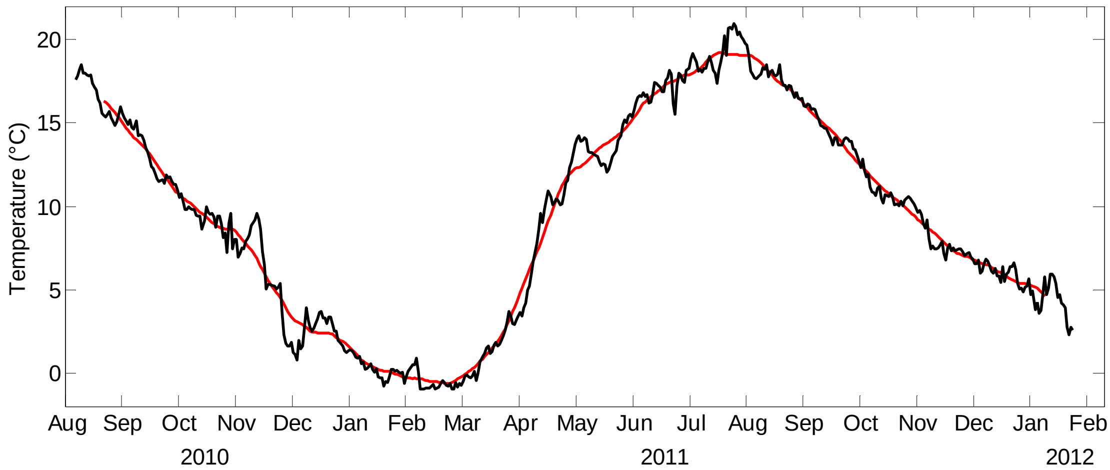

Figure 3. Temperature measured at 1 m depth at the station TOF-1. Daily running mean is shown in black and monthly running mean is shown in red.

It is necessary to see how the temperature and salinity vary at 35 m depth to be able to assess the possible effects. **Figure 4** gives an example of how the temperature and salinity can vary at 35 m depth. Temperature and salinity is measured in the seawater intake at the power plant. An outstanding downwelling is evident from approximately 17th to 27th of May. This can be explained by the strong southerly winds in the same period. Winds blowing from the south push surface water into the fjord and the thickness of the upper layer increases. The result is that the halocline is deepened and the salinity at 35 m decreases. The temperature is positively correlated with salinity from 11th to 22th of May, when the salinity is above 32.5 psu; there is a negative correlation in the period afterwards, when salinity is below 32.5 psu. There is a temperature minimum at salinity 32.5 psu during the observation period.

On a shorter time scale there is a semidiurnal oscillation in the salinity at 35 m depth with amplitude of approximately 0.15 salinity units that is almost in phase with the sea-level at Oscarsborg (**Figure 5**). This can be explained by the existence of internal tides in Breiangen. Below the halocline the salinity increases with about 2 salinity units per 15 m. Combining this vertical salinity gradients and the variation in salinity we can estimate that the amplitude of the internal waves is limited to approximately 1 m, so these variations should not be important for any environmental effects caused by differences between 35 m depth and surface waters.

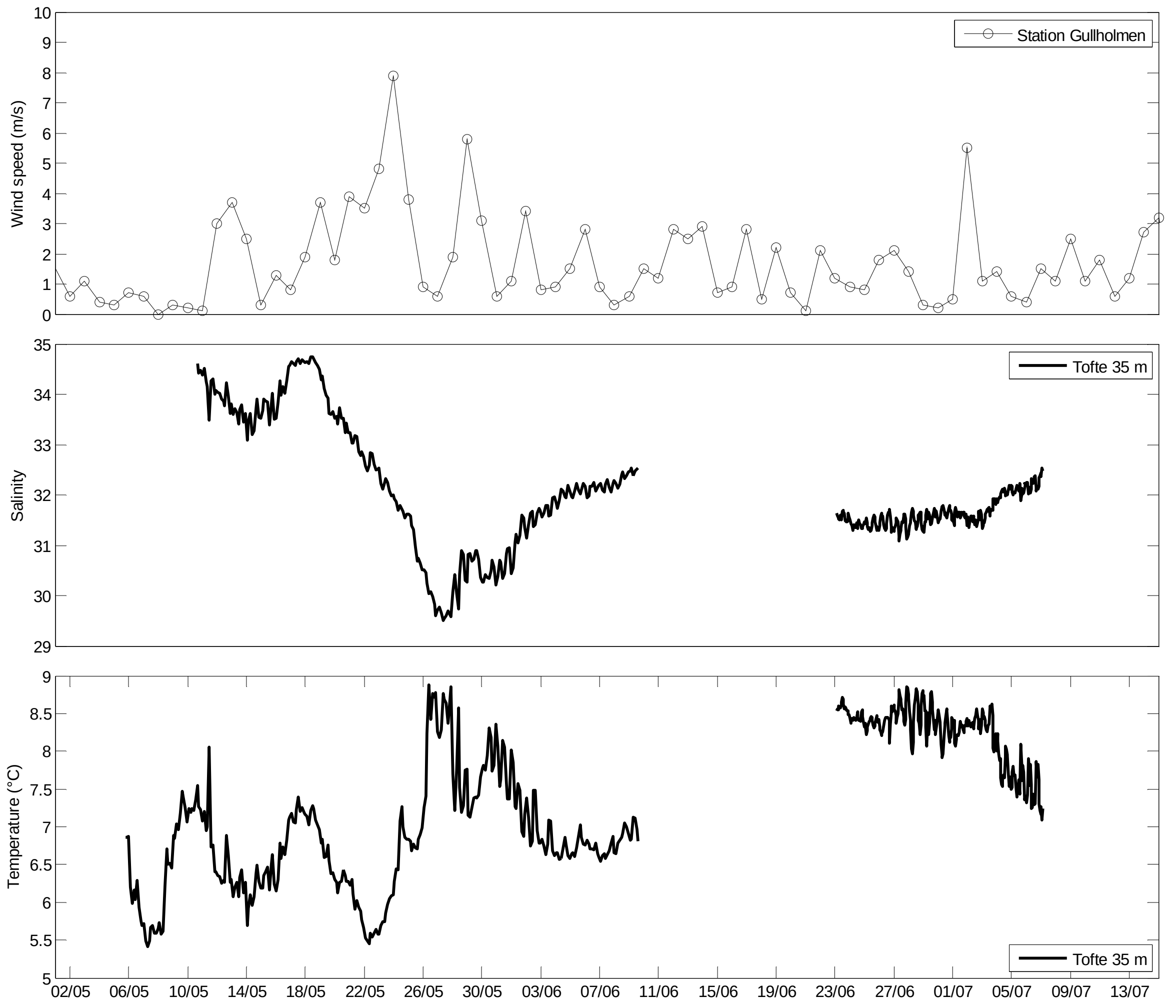

Figure 4. Variation in wind speed at station Gullholmen (N 59°26.11' E 10°34.68' about 12 km south of Tofte) (upper panel), salinity (middle panel) and temperature (lower panel) at 35 m depth at the saltwater intake (see **Figure 1**) during May – July 2011.

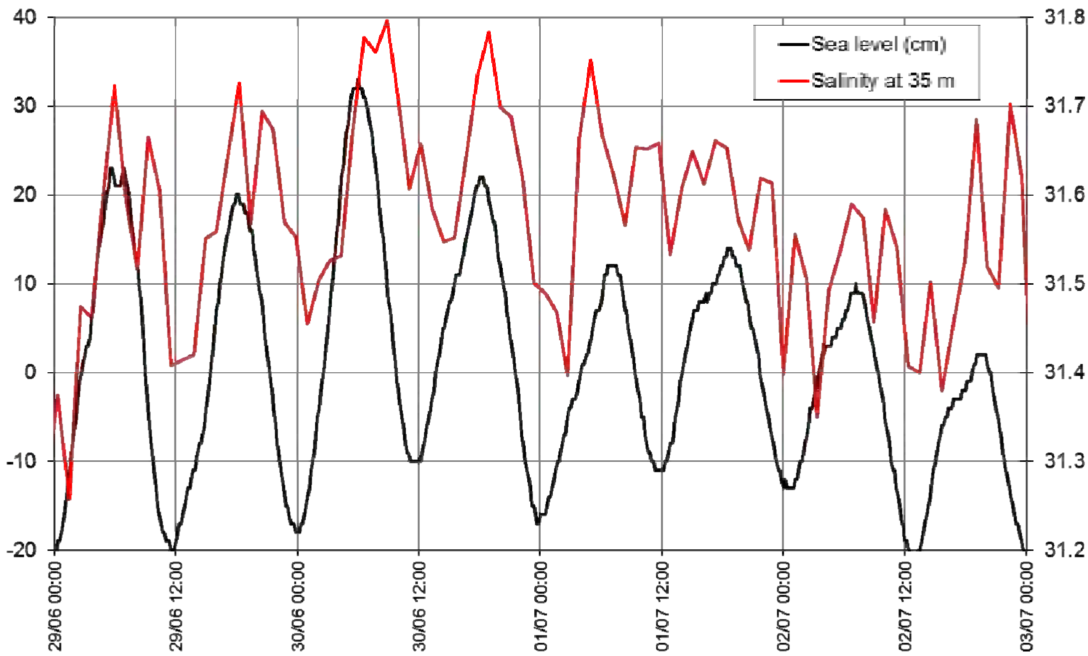

Figure 5. Salinity at 35 m depth at the seawater intake (red line) compared with sea level changes at Oscarsborg (black line) in a period of four days in the summer of 2011. The left vertical axis shows sea level in cm, and the right axis shows units of salinity.

2.2 Nutrients

In this subsection we look at how the discharge from the power plant might affect the nutrient concentrations in the vicinity of the outlet. First the framework and the general conditions in Breiangen is presented, then a method to estimate the over-concentrations of nutrients caused by the outlet plume is described. Finally, measurements of nutrients at the power plant and near the outlet is presented and it is discussed how this can be related to the nutrient pump effect.

Molvær et al. (2008) presented a proposal for water quality classes. The values in **Table 1** are limits for nutrient concentrations in sheltered waters. All measurements are compared to the water quality classification presented in **Table 1**. To give a picture of the general nutrient concentrations in the surface layer in the fjord outside Tofte, **Table 2** present measurements from the Ferrybox system on board the ferry Color Fantasy. The water sample is collected automatically at specified positions when the ferry passes through the fjord, one of them outside Tofte. The concentrations are in the water quality class 2 (Good environmental quality) or 1 (Very good environmental quality) except for one occasion when the total nitrogen concentration was in class 3 (Fair environmental quality).

Table 1. Water quality classification for sheltered waters (Molvær et al., 2008). Classification (upper limit for Classes I-IV).

Season	Parameter	Unit	Salinity	I Very good	II Good	III Fair	IV Bad	V Very bad
Winter	Tot P	µg/L	>18	<25	25-30	30-40	40-53	>53
	PO4	µg/L	>18	<20	20-26	26-35	35-45	>45
	Tot N	µg/L	>18	<370	370-460	460-555	555-740	>740
	Nitrate	µg/L	>18	<235	235-290	290-345	345-410	>410
Summer	Tot P	µg/L	>18	<10	10-13	13-17	17-25	>25
	Tot N	µg/L	>18	<215	215-250	250-290	290-370	>370

Table 2. Nutrient concentrations from station BR-1 at 4 m depth from the Ferrybox system on board Color Fantasy.

Date	Station	Tot-N (µg N/L)	NO_2+NO_3 (µg N/L)	Tot-P (µg P/L)	PO_4 (µg P/L)	SiO_2 (µg/L)	Kl-A (µg/L)
2011 Jun 2	BR-1	245	17	9	1	380	4.9
2011 Jun 6	BR-1	285	20	12	3	274	4.3
2011 Jul 10	BR-1	215	22	12	2	276	2.4
2011 Jul 13	BR-1	210	32	9	2	413	1.0
2011 Sep 6	BR-1		65	10	4	590	2.4

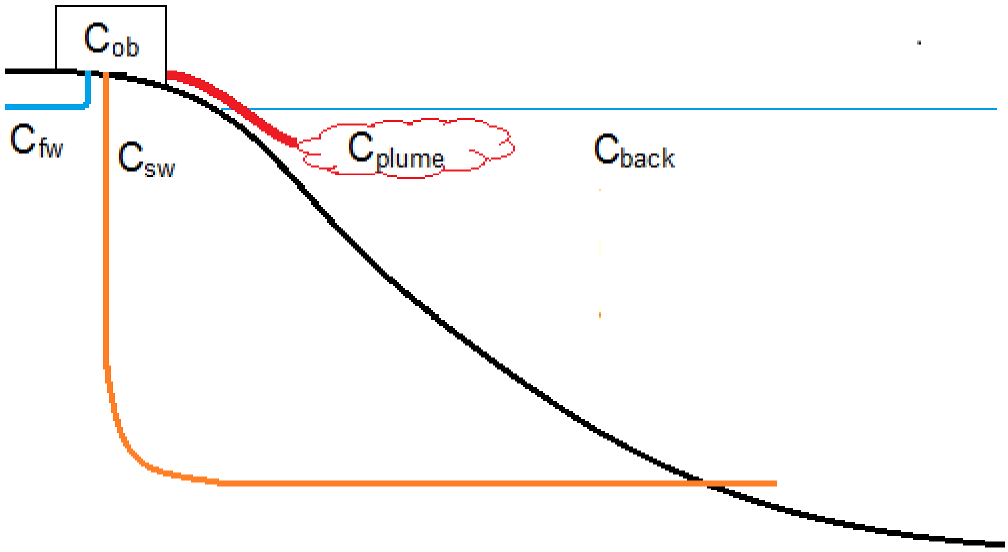

Figure 6. Sketch of the flow of water in and out of an osmotic power plant. Salt water with concentration C_{SW} is pumped up from 35 m depth. Fresh water with concentrations C_{fw} is supplied from a nearby river. C_{plume} is the concentration of the released water.

Consider one unit of volume with water from the outlet basin (OB), with nutrient concentration C_{ob}, mixed with d units of volume with seawater by mixing processes in the fjord outside the outlet (see **Figure 6**). We let C_{back} denote the background nutrient concentration of the water that the discharge is mixed with and C_{plume} the resulting concentration in the discharge plume when it has been diluted with seawater in proportion $d:1$. If we have a tracer for which the concentration differences can be measured and identified with reasonable precision, the dilution d can be estimated from

$$d = \frac{C_{ob} - C_{plume}}{C_{plume} - C_{back}} \tag{1}$$

From **Table 3** we can see that silicate (SiO_2) always have higher concentrations in the outlet basin than in the measurements in the fjord. On 4 out of 5 occasions the silicate concentrations at TOF-1 close to the outlet are higher than at TOF-3 about 200 m further south. The exception is 13th of September, when TOF-3 has a higher silicate concentration than at TOF-1. If we assume that for the other occasions TOF-1 and TOF-3 represents C_1 and C_3, respectively, and combines this with the measured outlet concentration C_0 (OB) in Equation (1), the result is an estimated dilution at TOF-1 varying from 10 to 50. It is possible that the concentration measured at TOF-1 is not only a result of the discharge from the outlet basin, but is also influenced by other sources. It is not likely that a water flow of 30 L/s can dominate an area of 10 x 10 meters in 2 m depth. A current speed of 10 cm/s along the shore in 10 m width and 3 m depth will carry 3 m^3/s past the area, or 100 times the discharge. To get a second estimate of the dilution the program JETMIX was set up to simulate a discharge of 30 L/s through a pipe with diameter 315 mm at 2.5 m depth. The resulting dilution was 5 which are lower than the silicate concentrations indicate. We regard the last result as a conservative estimate of the dilution, and will use this value in the further calculations. When the dilution d is known, the concentration at station TOF-1 of other parameters, in particular other nutrients, can be estimated as

$$C_{plume} = \frac{1}{d+1} C_{ob} + \frac{d}{d+1} C_{back} \tag{2}$$

and we can write the over-concentration $\Delta C = C_{plume} - C_{back}$ as

$$\Delta C \leq \frac{C_{ob}}{d} = \left(\frac{d+1}{d}\right) C_{plume} - C_{back} \tag{3}$$

Table 3. Nutrient concentrations from the outlet basin (OB), the saltwater (SW) and freshwater (FW) intake and at stations TOF-1, TOF-2, TOF-3 and TOF-4 at 0 - 2 m depth, May 2010 – July 2011. The color-coding is based on **Table 1**.

Date	Station	Tot-N (µg/L)	NO_2+NO_3 (µg/L)	Tot-P (µg/L)	PO_4 (µg/L)	SiO_2 (µg/L)	Kl-A (µg/L)	NH_4 (µg/L)
2010 May 10	OB	160	81	15	16			
2010 Jun 1	OB	593	82	35	28			
2010 Sep 2	OB	165	77	15	11	471	<0.16	
	TOF-1	210	16	12	3	325	1.5	
	TOF-3	306	14	9	3	306	1.7	
2010 Sep 6	OB	235	69	16	10	1124	0.71	
	TOF-1	180	9	14	3	407	2.3	
	TOF-3	190	2	15	1	285	2.2	
2010 Sep 8	OB	166	57	11	11			
2010 Sep 10	OB	265	64	16	4	1267	0.91	
	TOF-1	235	12	11	8	524	5.0	
	TOF-3	195	70	10	<1	584	4.8	
2010 Sep 13	OB	250	33	13	9	1260	0.91	
	TOF-1	225	30	11	5	469	3.3	
	TOF-3	210	41	10	3	424	3.3	
2010 Oct 13	OB	196	57	81	65			
2010 Nov 9	OB	274	80	43	43			
2011 Jan 12	OB	374	95	15	13			
2011 Mar 10	OB	320	128	23	23			
	SW intake	194	118	52	28			
	FW intake	409	134	9	8			
2011 Apr 7	OB	381	146	20	18			
	SW intake	239	106	72	22			
	FW intake	943	499	5	5			
2011 May 23	OB	199	126	95	33			
2011 Jul 1	OB	415	217	15	9	2067		12
	TOF-1	435	25	20	4	117		18
	TOF-2	305	15	15	3	106		10
	TOF-3	345	8	14	3	78		10
	TOF-4	315	6	14	3	80		10

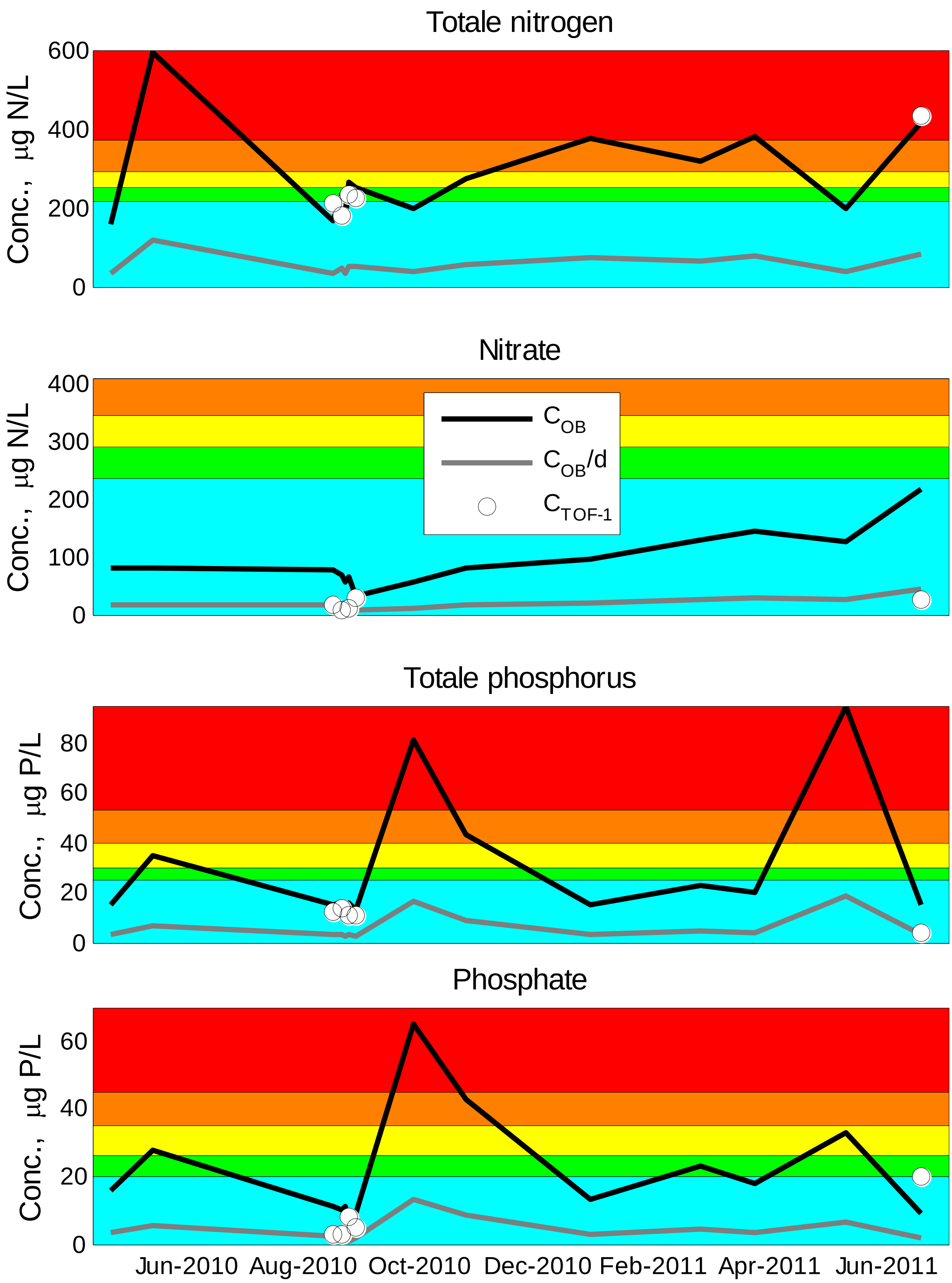

Figure 7. Concentration of total nitrogen, nitrate, total phosphorous and phosphate in the outlet basin from May 2010 to July 2011. The direct measurements from the outlet basin is plotted as a black line and the estimated over-concentrations in the outlet plume ($\frac{C_{ob}}{d}$) is plotted as a grey line. Water samples from station TOF-1 is plotted as white circles. The colour code indicates the water quality classes from **Table 1**.

Nutrient concentrations are measured in the outlet basin at Tofte Osmotic power plant (**Table 3** and **Figure 7**). Of the 14 measurements presented in this report the concentrations of total nitrogen, total phosphorus and phosphate are in the water quality class 4 (Bad environmental quality) or 5 (Very bad environmental quality) 5, 6 and 2 times respectively. At Tofte the volume flux is approximately 33 L/s. A moderate current of 10 cm/s in the upper 3 meters of the water from the coastline and 10 meters out, will carry 3000 L/s past the discharge point, or 100 times the size of the outlet. Thus the impact at Tofte is expected to be negligible.

The estimated over-concentrations due to the discharge from the plant is always in the water quality class 1 (Very good environmental quality). But there would be a potential risk of eutrophication in the area close by the outlet pipe if the discharge gets large enough to dominate the water mass in the vicinity of the discharge point. If the volume transport in the outlet was increased 200 times from 30 L/s to 6 m^3/s, eutrophication in a limited area around the outlet pipe is probable. If we assume that the dilution and the thickness of the plume is the same, the outlet might influence locations that are about 14 times further away. In the worst case scenario, with poor water exchange, the water quality for e.g. phosphorous might be reduced from good (class 2) to fair (class 3) or bad (class 4) due to this eutrophication effect. This eutrophication effect will be limited in both space and time. The volume of the saltwater supply will determine the size of the influence area. The duration of periods of increased nutrient concentration at 35 m depth determine the duration of the eutrophication effect.

Eutrophication means increased biomass due to increase in nutrient load in the depth range where the light conditions are sufficient to maintain life (the euphotic zone). With large over-concentrations of nutrients in the water, small fast-growing opportunistic algae can increase drastically in abundance. In the Oslofjord the euphotic zone is typically from the surface down to 10 - 20 m; it can roughly be estimated by multiplying the Secchi depth with a factor 2. The Secchi depth is the visibility in the water, and it is measured by lowering a white disc with diameter 25 cm in the water column until it is no longer visible.

The concentration in the outlet basin is not only a result of the concentration in the seawater intake, but also the concentration in the freshwater intake. The nutrients in the river would have ended up in the surface layer regardless of the osmotic power plant. To quantify the nutrient pump effect, it is necessary to analyse what causes high concentrations in the outlet basin. Unfortunately nutrient concentrations were only measured two times simultaneously in the outlet basin and in the fresh- and saltwater intake (**Table 3**). There was a third set of measurements in the water intakes, but they were contaminated (not shown). In two occasions when the total nitrogen and total phosphate concentrations are measured instantaneously in both the outlet basin, the saltwater intake and the freshwater intake, the high concentrations of nitrogen is caused by the riverwater and the high concentrations of phosphorus is caused by the sea water. Thus it’s likely that the occasions with high phosphorus concentrations in the outlet basin are due to a nutrient pump effect.

2.3 Chemicals

Chemicals are used to clean the membranes to prevent fouling. The cleaning agents that are being used do not accumulate in the environment, but there is a danger of local toxic effects if the concentration gets too high. During the period Sept. 2010 to Aug. 2011 none of the chemicals were used in volumes large enough to have any effect on the environment. The critical substance is chlorine dioxide. During the period a maximum of 2 L/day, with concentration 7 g/L was used. If this amount was released during one minute the concentration in the outlet basin would be less than 0.01 g/L. This will be further diluted when the water is discharged in the sea.

If the volume flow is increased and the volume of chemicals must be increased proportionally, great caution must be taken to prevent toxic concentrations locally. Since there should be no accumulating effects, dilution of the discharge would help to control the concentrations of the chemicals.

3. Surveys on benthic organisms

3.1 Data collection

Registrations of hard bottom organisms (macroalgae and sessile animals that live on rocks) were conducted to document any effects from the plant's discharge water on the marine life. Four stations in the vicinity of the plant's water discharge point were studied (**Figure 8**). GPS positions for these stations are given in **Appendix C**.

Figure 8. Location of the four intertidal stations (St. 1, 2, 3 and 4). Transect registrations were performed at station 1 and 2 (the transect direction is indicated by the dotted line). (Map from gulesider.no).

The occurrence of organisms was estimated using the following semi-quantitative scale:

1) single occurrence (< 5 % coverage / one individual)
2) spread occurrence (5-20 % coverage / ca. 2-4 individuals/m^2)
3) common occurrence (20-80 % coverage / ca. 5-50 individuals/m^2)
4) dominant occurrence (>80 % coverage / ca. >50 individuals/m^2)

Registrations were performed by a marine botanist and a marine zoologist (**Figure 9**). Organisms that could not be identified in the field were collected, and classified to species (or a higher taxa level) under a microscope or stereomicroscope at NIVA's laboratory.

The fieldwork was carried out October 7th 2010 and September 19th 2011. The stations were also examined October 14th 2009, in a preliminary survey before the plant began operation (Walday et al. 2010).

<u>Stations 1 – 4: Registrations in the intertidal zone.</u>

- Semi-quantitative registration of all benthic macroalgae and sessile animals along approximately 8 m of the shoreline (in the intertidal zone, down to about 1 m depth).
- The substrate at station 2 is smooth rocky surface.
- The substrate at station 1, 2 and 4 is large stones/rocks.

<u>Station 1: Transect registrations.</u>

- Semi-quantitative registration of readily visible benthic macroalgae and sessile animals along a transect line from the intertidal zone to approximately 18 m depth.
- The substrate consists of large stones/rocks in the upper 13 meters, and has a bottom slope between 50 and 80 degrees. The slope becomes progressively less steep deeper than 13 m, and at around 15 m depth the slope is about 10 degrees. From around 12 m and deeper the substrate is primarily soft bottom with some larger stones. Only stones were examined in the soft bottom area.

<u>Station 2: Transect registrations.</u>

- Semi-quantitative registration of readily visible benthic macroalgae and sessile animals along a transect from the intertidal zone to the point of discharge at about 3 m depth.
- The substrate consists of smooth rocky surface in the upper 2 meters, and has a bottom slope between 50 and 80 degrees. Below 2 m depth the substrate is soft bottom with some stones. The pipes for intake- and discharge water run across the transect line. The soft bottom has a slope of about 5 degrees. Only pipes and stones were examined in the soft bottom area.

Overview pictures were taken of all stations (**Figure 10)**.

Figure 9. A marine zoologist performing a transect registration of sessile animals at station 2

The statistical software package PRIMER was used for the processing of the data (Plymouth Routine In Multivariate Ecological Research) (Clarke & Gorley 2001). Differences in species communities between stations have been investigated using a classification method (Cluster analysis) which groups stations with relatively equal species composition. The results are presented as a dendrogram, a tree-like structure that shows the relationship among entities (species composition at each station in each survey). The similarities between the entities are shown as a percentage. These methods are primarily based on Bray-Curtis similarity index. The significant differences or similarities for the different species were calculated using the SIMPER analysis. Before the analysis of the results certain species and taxa were aggregated so that the comparison between the surveys would be more harmonized.

In the analyses of the biological data, results from 2010, 2011 and the preliminary study from 2009 were used.

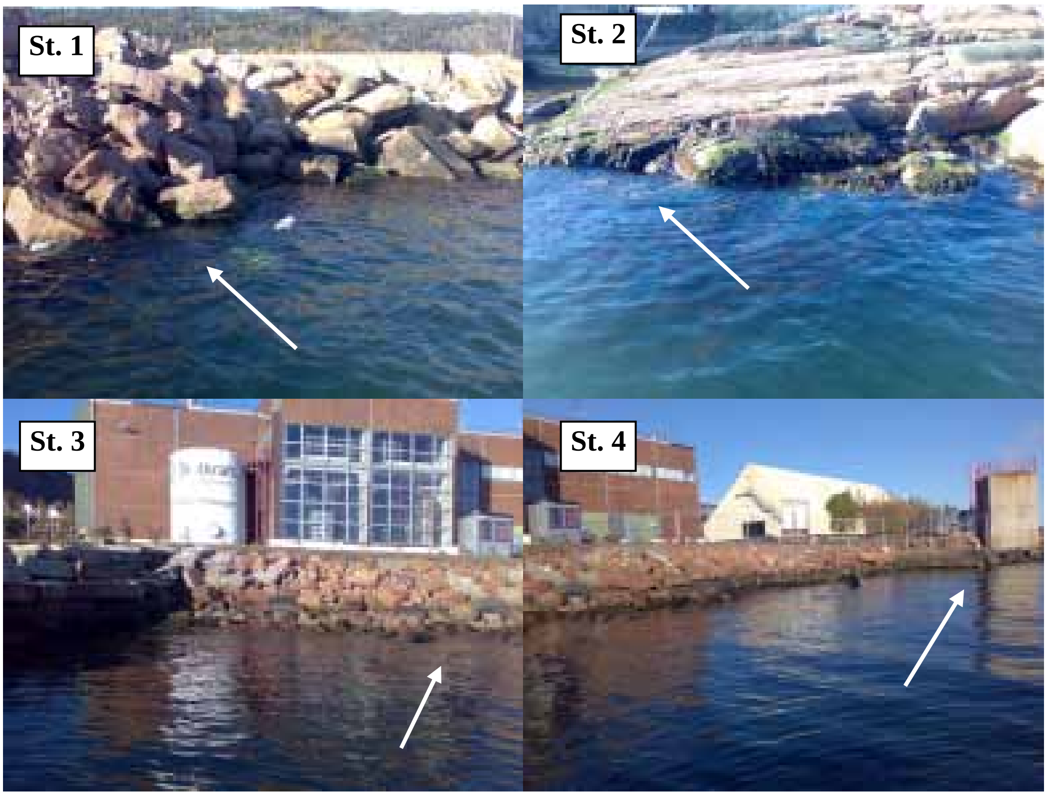

Figure 10. Overview photographs with arrows showing the locations of the biological stations 1, 2, 3 and 4. The intertidal was examined at all stations and transects were taken at stations 1 and 2.

3.2 Intertidal zone – results and analysis

In the 3 surveys a total of 48 species/taxa of algae and 23 species/taxa of animals were registered at the four intertidal stations. A complete list of species for the intertidal registrations is given in **Appendix A.**

There was a decrease in the total number of algae species/taxa at station 2 and 4 from 2009 to 2011. At station 3 there was a decrease in the total number of algae species/taxa between 2009 and 2010, but no change between 2010 and 2011. At station 1 there was an increase in the total number of algae species/taxa between 2009 and 2010, but a decrease from 2010 to 2011 (**Figure 11)**.

There was an increase in the total number of animal species/taxa between 2009 and 2010 at station 1 and 4, but a decrease in 2011. At station 3 there was a decrease in the total number of animal species/taxa between 2009 and 2010, but no change between 2010 and 2011. At station 2 there was a decrease in the total number of animal species/taxa from 2009/2010 to 2011 (**Figure 11)**.

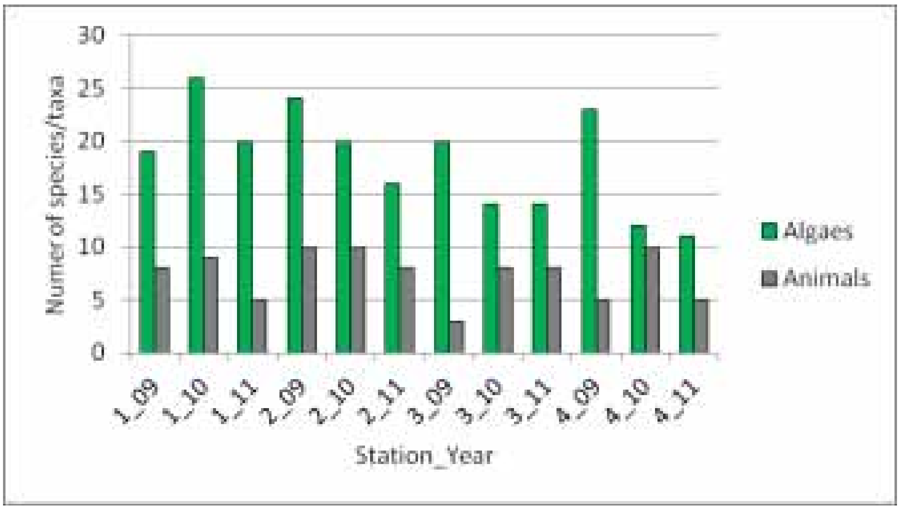

Figure 11. Total number of algae- and animal species/taxa registered at the 4 intertidal zone stations in 2009, 2010 and 2011.

A cluster analysis of the results shows that the species composition at each of the four stations is relatively similar in three surveys. The differences between any two stations, studied in any of the three years, are less than 50 % (**Figure 12**). Stations studied in the same year shows more similarity in species composition than studies at the same station performed in different years (e.g. the species composition at station 1 and 2 in 2011 are more similar than the species composition at station 1 in 2010 and in 2011).

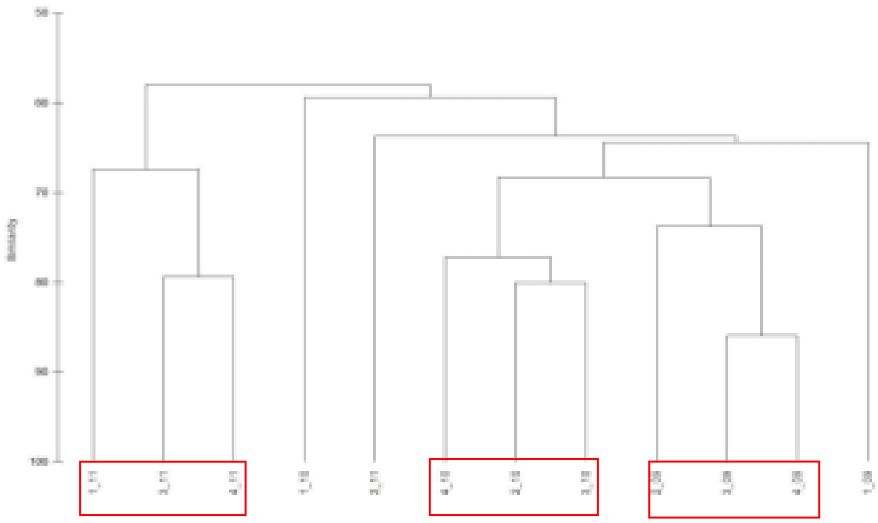

Figure 12. Cluster diagram. Similarities between the species composition in the intertidal zone at station 1 – 4 in 2009, 2010 and 2011 (for example, station 1 2011 is identified as 1_11 in the diagram). The red squares outline samples with similar species composition. The similarities between the entities are shown as a percentage on the y-axis.

Because the species composition at each of the four stations is relatively similar in three surveys, the results from the four stations were combined for a SIMPER analysis. The SIMPER analysis shows what species/taxa contribute most to the dissimilarities between the three surveys (**Table 4**). A complete list is given in **Appendix B**.

Table 4. The 3 algae- and animal species/taxa that contribute most to the dissimilarities in the intertidal zone at the 4 stations investigated in 2009, 2010 and 2011.

Avg. dissimilarity = 36,54	**2009**	**2010**		
Taxa	**Avg. Abund.**	**Avg. Abund.**	**Avg. Diss.**	**Contrib. (%)**
Semibalanus balanoides	0,00	2,00	1,83	5,01
Membranipora membranacea	0,50	2,00	1,37	3,74
Polysiphonia fibrillosa	2,00	0,50	1,35	3,70
Avg. dissimilarity = 43,54	**2010**	**2011**		
Taxa	**Avg. Abund.**	**Avg. Abund.**	**Avg. Diss.**	**Contrib. (%)**
Membranipora membranacea	2,00	0,00	2,05	4,72
Mytilus edulis	1,25	3,00	1,99	4,56
Brown encrusting algae	1,50	0,00	1,57	3,61

The barnacle *Semibalanus balanoides* was not registered in 2009, but was found in 2010 and 2011. The bryozoan *Membranipora membranacea* and brown encrusting algae was found in 2009 and 2010, but not in 2011. There was a lower abundance of the red algae *Polysiphonia fibrillosa* in 2010 compared to 2009 and 2011 (higher in 2009 compared to 2011). There was a higher abundance of the blue mussel, *Mytilus edulis*, in 2011 compared to 2009 and 2010.

3.3 Transect registrations – results and analysis

In the 3 surveys a total of 62 species/taxa of algae and 76 species/taxa of animals were registered at the two transect stations. A complete list of species from the transect registrations is given in **Appendix A**. **Figure 15** shows some pictures of common algae and animals observed during the transect registrations.

At station 1 there was a decrease in the total number of red algae- and animal taxa from 2009 to 2011. There was an increase in the total number of brown algae species/taxa from 2009 to 2010, but a decrease in 2011. There was a decrease in the total number of green algae species/taxa from 2009 to 2010, but an increase between 2010 and 2011 (**Figure 14**).

At station 2 there was a decrease in the total number of red algae taxa from 2009 to 2011. There was an increase in the total number of brown algae- and animal species/taxa from 2009 to 2010, but a decrease in 2011. There was a decrease in the total number of green algae species/taxa from 2009 to 2010, but an increase in 2011 **(Figure 14)**.

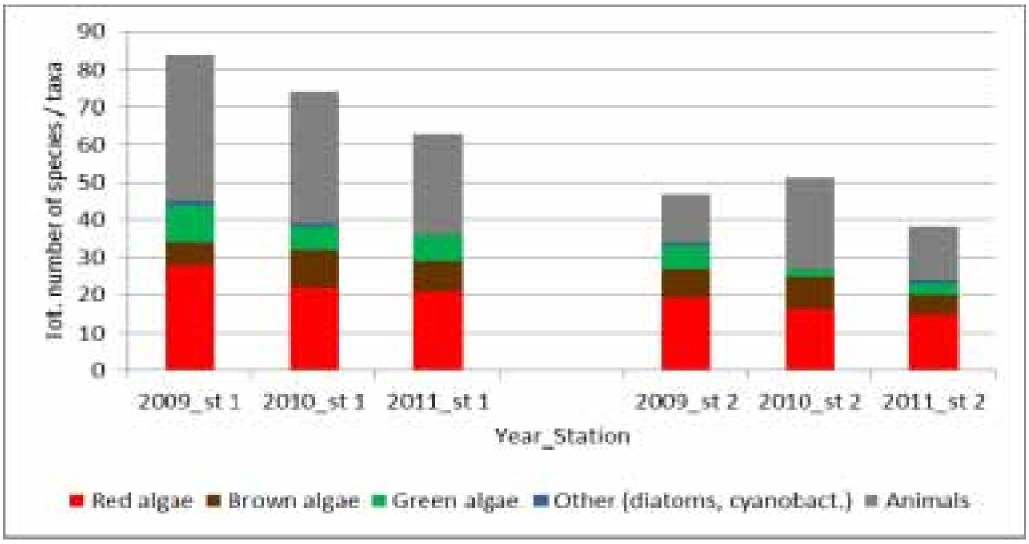

Figure 13. The number of species / taxa registered during transect-registrations at station 1 and station 2 in 2009, 2010 and 2011.

The species composition varies somewhat between the different water depths. The results from transect registrations from station 1 were therefore merged into 5 m depth intervals (except the deepest which is a 4 m interval) for the similarity analysis (Bray-Curtis). The depth intervals are: 0 - 4 m, 5 - 9 m, 10 - 14 m and 15 - 18 m. The total abundance of each species/ taxa in each of these intervals was added up.

A cluster analysis of the results from station 1 shows that the species compositions at each of the depth intervals were relatively similar in the three surveys. The differences between the same depth intervals at any of the three surveys are less than 50 % (**Figure 15**).

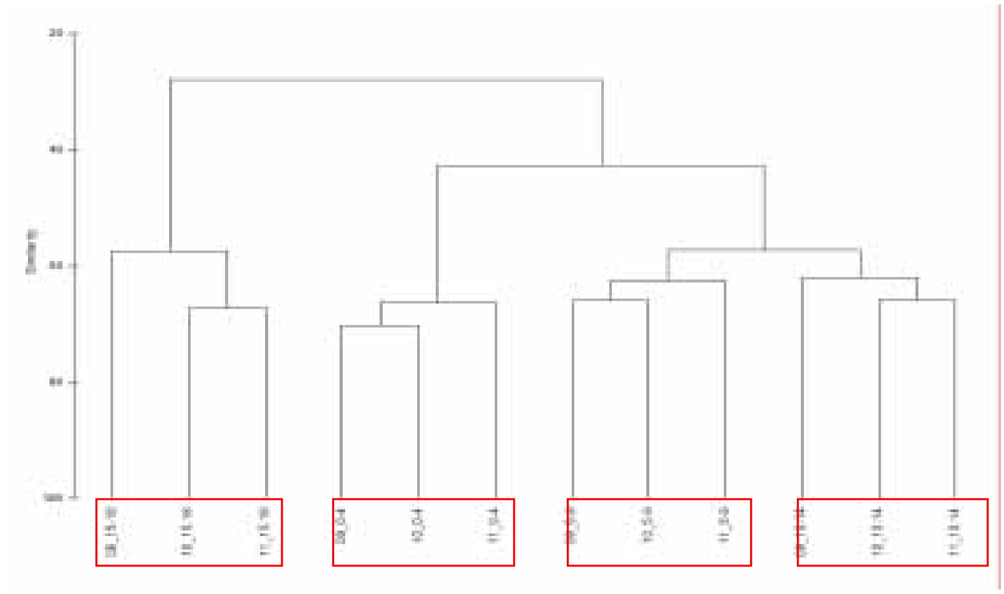

Figure 14. Cluster diagram. Similarities between the species composition at station 1 in 2009, 2010 and 2011, at 0 - 4 m, 5 - 9 m, 10 - 14 m and 15 - 18 m depth intervals (for example, 2011 15 - 18 m is identified as 11_15-18 in the diagram). The red squares outline samples with similar species composition. Note that these samples also have the same depth intervals. The similarities between the entities are shown as a percentage on the y-axis.

A SIMPER analysis was performed to identify what species/taxa caused the biggest differences between the registrations at the same depth intervals in the three surveys. The two largest contributors to the differences between the registrations at station 1 (between the same intervals) are shown in **Table 5**. A complete list is given in **Appendix B**.

The analysis shows that in the two upper depth intervals differences in the abundance of filamentous red algae such as *Heterosiphonia japonica* and *Pterothamnion plumula* and also encrusting bryozoans caused the biggest differences between the 2009 and 2010 surveys. Different abundance of encrusting bryozoans such as *Membranipora membranacea* and *Cryptosula pallasiana*, and also the calcareous polychaete-group *Spirorbis* spp., caused the biggest differences in the two upper intervals between the 2010 and 2011 surveys.

In the deepest interval the red alga *Phyllophora crispa* and *Phyllophora* sp. and the ascidian *Ciona intestinalis* caused the biggest differences between in the three surveys. In the 10–14 m interval the ascidian *Corella parallelogramma* and the gastropod *Buccinum undatum* caused the biggest differences between 2009 and 2010 surveys. The red algae *P. crispa* and the hydroid group *Laomedea* spp. caused the biggest differences between 2010 and 2011 surveys.

Table 5. The 2 algae- and animal species/taxa that contribute most to the dissimilarities in the different depth intervals (0 - 4 m, 5 - 9 m, 10 - 14 m and 15 - 18 m) in the transect registration at station 1 in 2009, 2010 and 2011.

Taxa	**Avg. Abund.**	**Avg. Abund.**	**Avg. Diss.**	**Contrib. (%)**
Avg. dissimilarity = 29,75	**2009_0-4m**	**2010_0-4m**		
Bryozoa indet. encrusting	0,00	6,00	1,26	4,23
Pterothamnion plumula	6,00	0,00	1,26	4,23
Avg. dissimilarity = 34,00	**2009_5-9m**	**2010_5-9m**		
Heterosiphonia japonica	0,00	10,00	1,89	5,57
Pterothamnion plumula	8,00	0,00	1,69	4,98
Avg. dissimilarity = 36,28	**2009_10-14m**	**2010_10-14m**		
Corella parallelogramma	8,00	0,00	1,85	5,09
Buccinum undatum	0,00	7,00	1,73	4,76
Avg. dissimilarity = 46,26	**2009_15-18m**	**2010_15-18m**		
Phyllophora crispa	4,00	0,00	4,44	9,60
Phyllophora sp.	4,00	0,00	4,44	9,60
Avg. dissimilarity = 35,24	**2010_0-4m**	**2011_0-4m**		
Membranipora membranacea	10,00	0,00	1,81	5,14
Spirorbis spp.	8,00	0,00	1,62	4,59
Avg. dissimilarity = 40,16	**2010_5-9m**	**2011_5-9m**		
Spirorbis spp.	10,00	0,00	2,18	5,43
Cryptosula pallasiana	8,00	0,00	1,95	4,85
Avg. dissimilarity = 34,14	**2010_10-14m**	**2011_10-14m**		
Phyllophora crispa	7,00	0,00	1,96	5,73
Laomedea spp.	0,00	6,00	1,81	5,31
Avg. dissimilarity = 32,86	**2010_15-18m**	**2011_15-18m**		
Phyllophora sp.	0,00	8,00	7,48	22,76
Ciona intestinalis	3,00	0,00	4,58	13,94

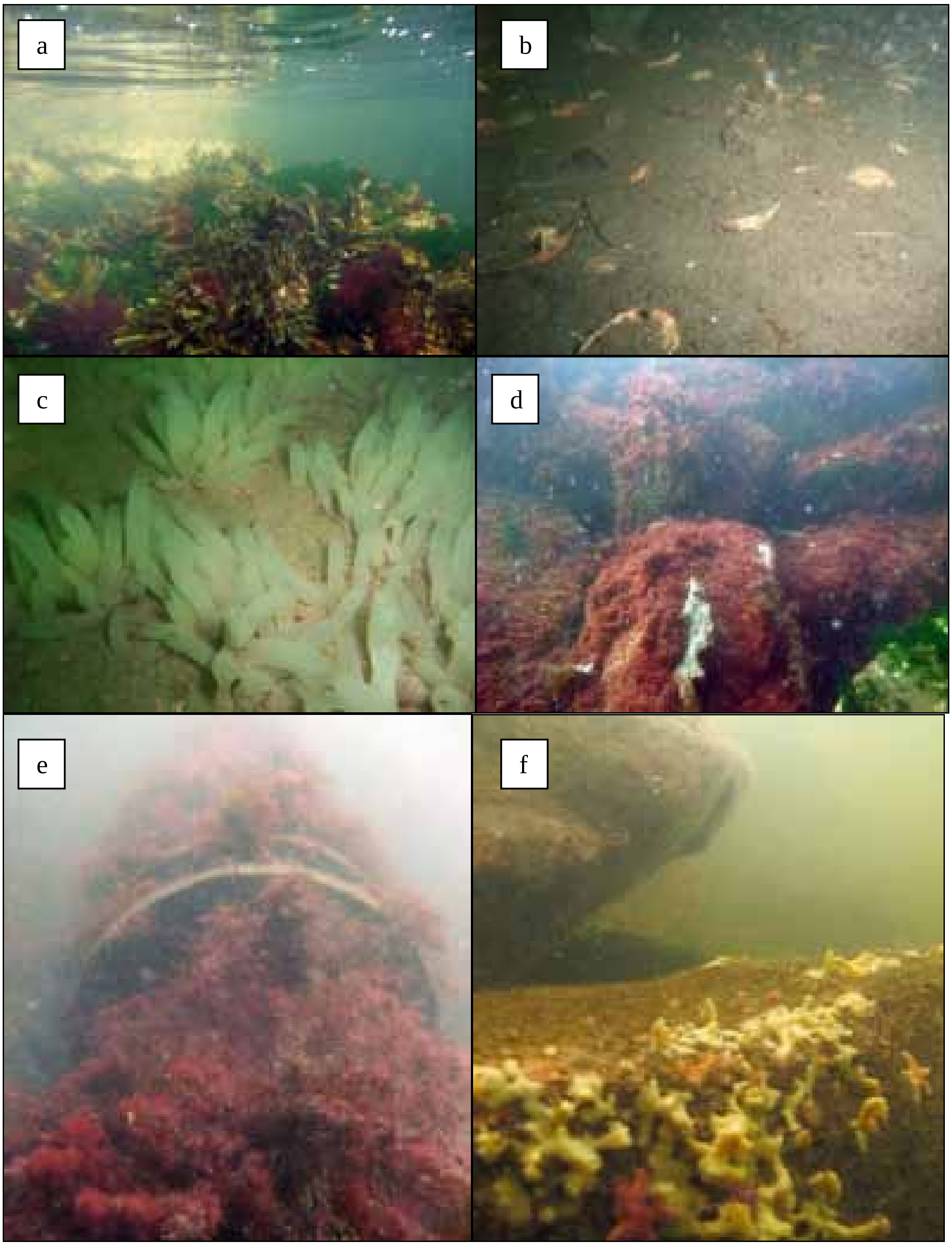

Figure 15. Pictures from the transect registrations. a. The brown seaweed, *Fucus serratus,* the green algae, *Ulva lactuca,* and the red algae, *Polysiphonia fucoides,* in the intertidal zone (St. 2_2010). b. Empty bivalve shells on soft bottom at 18 m depth (St. 1_2010). c. The ascidian, *Ciona intestinalis,* on sedimented rock at 14 m depth (St. 1_2010). d. Various filamentous red algae and *U. lactuca* on rocks at 3 m depth (St. 1_2010). e. Various filamentous red algae on a pipe at 4 m depth (St. 2_2010) f. The yellow sponge, *Halichondria panicea* and starfish (*Asterias rubens*) on sedimented rocks at 6 m depth (St. 1_2011).

In the analysis of the transect registrations from station 2, the results were merged into 2 m depth intervals (0 - 1m and 2 - 3 m). The total abundance of each species/taxa in each of these intervals was summed.

The cluster analysis shows that the species compositions at each of the depth intervals were relatively similar in the three surveys. The differences between the same depth intervals at any of the three surveys are less than 50 % (**Figure 16**).

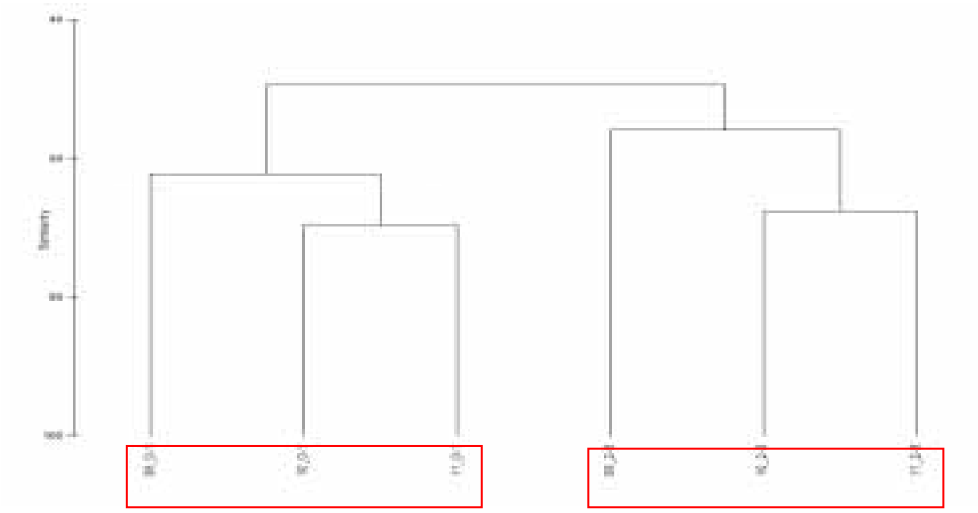

Figure 16. Cluster diagram. Similarities between the species composition at station 2 in 2009, 2010 and 2011 at 0 - 1 m and 2 - 3 m depth intervals (for example, 2010 0 - 1 m is identified as 10_0-1 in the diagram. The red squares outline the same depth intervals. The similarities between the entities are shown as a percentage on the y-axis.

A SIMPER analysis was performed to identify what species/taxa caused the biggest differences between the registrations at the same intervals in the three surveys. The two largest contributors to the differences between the surveys (between the same intervals) are shown in **Table 6**. A complete list is given in **Appendix B**.

The analysis shows that the polychaete *Pomatoceros triqueter* was registered in 2010 but not in 2009 or 2011. The green algae group *Ulva* spp. was registered in 2009 and 2011, but not in 2010. The red algae *Chondrus crispus* was registered in 2009 and 2010 but not in 2011. Barnacles (*Balanus* spp.) were registered in the lowest depth interval in 2011 but not in 2009 or 2010. They were however registered in the upper depth interval in 2010. The bryozoan *Membranipora membranacea* was registered in 2010, but not in 2009 or 2011, whereas the bryozoan *Electra pilosa* was registered in 2009 and 2010 but not in 2011.

Table 6. The 2 algae- and animal species/taxa that contribute most to the dissimilarities in the different depth intervals (0 - 1 m and 2 - 3m) in the transect registration at station 2 in 2009, 2010 and 2011.

Taxa	**Avg. Abund.**	**Avg. Abund.**	**Avg. Diss.**	**Contrib. (%)**
Avg. dissimilarity = 40,06	**2009_0-1m**	**2010_0-1m**		
Ulva spp.	5,00	0,00	2,50	6,24
Pomatoceros triqueter	0,00	4,00	2,24	5,59
Avg. dissimilarity = 47,63	**2009_2-3m**	**2010_2-3m**		
Membranipora membranacea	0,00	4,00	2,00	4,20
Pomatoceros triqueter	0,00	4,00	2,00	4,20
Avg. dissimilarity = 30,36	**2010_0-1m**	**2011_0-1m**		
Pomatoceros triqueter	4,00	0,00	2,61	8,59
Chondrus crispus	4,00	0,00	2,61	8,59
Avg. dissimilarity = 40,52	**2010_2-3m**	**2011_2-3m**		
Balanus spp.	0,00	5,00	2,48	6,13
Electra pilosa	4,00	0,00	2,22	5,48

The maximum depth at which there is sufficient light for macroalgae to grow (compensation depth) is a good measure of water quality. The lower growth limit of algae provides a cumulative measure of water clarity. The deeper the light penetrates, the deeper the algae can grow. There are other factors that may limit the lower growth limit, such as availability of suitable substrate and sea urchin grazing that also must be taken into account.

The lower growth limit for 4 readily visible algae species/genus' found at station 1 was compared (**Table 7**). It must be noted that the registrations were done at maximum 18 – 20 m depth due to the lack of suitable substrate at the station.

The lower growth limit for *Phyllophora* sp. and *Laminaria saccharina* increased from 2009 to 2011, but it decreased for *Delesseria sanguinea and Phycodrys rubens*.

Table 7. Lower growth limit (m) for 4 species/genus' registered at station 1 in 2009, 2010 and 2011.

Species /Genus	2009	2010	2011
Phyllophora spp.	16	14	18
Delesseria sanguinea	14	14	12
Phycordys rubens	14	14	12
Laminaria saccharina	8	8	12

3.4 Comparison of the transect registrations to a nearby, similar study

The Outer Oslofjord is a heavily studied area in regards to benthic flora and fauna. In a monitoring program of the Outer Oslofjord, transect registrations of benthic communities have been performed at a number of stations. Station G1, in this program, is located near Rødtangen at Hurum (**Figure 1**), and it is investigated down to 18 m depth. The station's GPS position is given in **Appendix C**. Transect registrations were performed at this station in 2010 (Walday et. al. 2010).

There is little difference in the number of species/taxa registered at station 1 in 2010 compared to that registered at the nearby G1 station (**Figure 17**). There were a larger number of animal- and green algae species/taxa, and fewer red- and brown algae species/taxa, at station 1 in 2010 compared to G1.

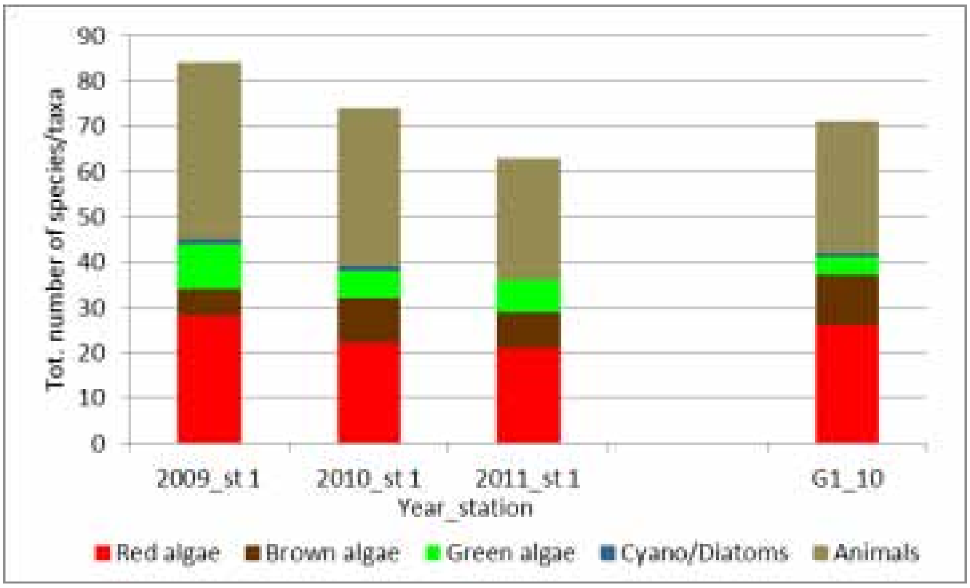

Figure 17. The number of species/taxa registered at station 1 in 2009, 2010 and 2011, and at station G1 (a station in the monitoring program of the Outer Oslofjord) in 2010.

A comparison of the lower growth limit for the four algae species/genus' also shows that there is not much differences between the two stations. Most species/genus' were registered a few meters deeper at station G1 compared to station 1 in 2010 (**Table 8**).

Table 8. Lower growth limit (m) for 4 species/genus' registered at station 1 in 2009, 2010 and 2011, and at station G1 (stations in the monitoring program of the Outer Oslofjord) in 2010

	St1_2009	St1_2010	St1_2011	G1_2010
Phyllophora spp.	16	14	18	18
Delesseria sanguinea	14	14	12	16
Phycordys rubens	14	14	12	16
Laminaria saccharina	8	8	12	8

It must be noted that the substrate at station G1 consists of sedimented smooth rocky surface. The substrate at station 1 is larger stones/rocks and soft bottom, so bottom conditions suggest that the biology will be somewhat poorer here than in an area consisting primarily of hard bottom.

3.5 Conclusions

The results from the biological investigations show no impact of the discharge water on the benthic communities in the area. There was a reduction in the number of species/taxa registered from 2009 to 2011, but it is not likely that the registered reduction of species/taxa is a result of the discharge water. Benthic communities are in constant change, and the number and abundance of different species will vary during, and between, years. A comparison of the number of species/taxa registered at station 1 with a nearby station (G1) showed little difference. The lower depth limits for growth of benthic algae varied little over the three surveys, and there was not much difference in the lower depth limits between station 1 and station G1, so the water clarity does not seem to have been impacted by the discharge water.

The amount of discharge water from the prototype plant at Tofte is too insignificant to have an impact on the benthic communities in and around the point of discharge. A larger plant, with greater amount of discharge water, may have an impact in the benthic communities in the area; this is further discussed in chapter 4.3.

4. Discussion

4.1 Possibility of changed conditions in the surface layer

One of the questions posed in the introduction were if running an osmotic power plant might alter the temperature and salinity conditions in the surface layer. There will be a net upward flux of salt all throughout the year since the salinity always increase with depth. The temperature generally increases with depth during the winter and decrease during the summer. During the winter relatively warmer water is supplied to the surface. During the summer relatively cooler water is supplied to the surface.

The key figure to scale these effects is the volume of the water flow. This must be compared with the retention time for the water mass that the discharge plume flow into. Let's consider a triangle that goes from the discharge point and 200 metres south and east. If we look at the upper 3 metres, the volume will be 30000 m^3. A moderate current of 10 cm/s in the upper 3 meters of the water from the coastline and 10 meters out, will carry 3 m^3/s in and out of this volume. The retention time for the water in this volume will be 2 to 3 hours (10000 s), and during this time a volume of 200 m^3 will be pumped up from 35 m depth and discharged into the volume. This means that the conditions in the surface possibly can be altered 0.6 % of the difference in salinity or temperature between the surface layer and the water at 35 m depth. This is negligible.

If on the other hand the volume flow was 200 times larger the conditions in the surface could possibly be altered 50 % of the difference in salinity or temperature between the surface layer and the water at 35 m depth. In the case where this difference is large, it can be as much as 10 degrees or salinity units, this effect must be considered. This is only a crude estimate, and the result will depend on geometry and local conditions of the recipient of the discharge water. But in general we can say that an upward flow of water of 4 m^3/s will probably alter the conditions in the surface layer, and the effect will be that the salinity will be increased and the seasonal temperature variability will be reduced.

4.2 Possibility of eutrophication effects

Another important question posed in the introduction was if running an osmotic power plant might lead to a net supply of nutrients to the euphotic zone. In the 14 measurements from the outlet basin presented in this report the concentrations of total nitrogen, total phosphorus and phosphate are in the water quality class 4 (Bad environmental quality) or 5 (Very bad environmental quality) 5, 6 and 2 times respectively. This shows that there would be a potential risk of eutrophication in the area close by the outlet pipe if the discharge gets large enough to dominate the water mass in the vicinity of the discharge point. As long as the volume flow is only 30 L/s the effect is most likely negligible. If the volume transport in the outlet was increased 200 times from 30 L/s to 6 m^3/s, eutrophication in a limited area around the outlet pipe is probable. If we assume that the dilution and the thickness of the plume is the same, the outlet might influence locations that are about 14 times (square root of 200) further away.

The concentration in the outlet basin is not only a result of the concentration in the sea water intake, but also the concentration in the freshwater intake. The nutrients in the river would have ended up in the surface layer regardless of the osmotic power plant. In two occasions when the total nitrogen and total phosphate concentrations were measured instantaneously in both the outlet basin, the saltwater intake and the freshwater intake, the high concentrations of nitrogen is caused by the river water and the high concentrations of phosphorus is caused by the seawater. Thus it’s likely that the occasions with high phosphorus concentrations in the outlet basin are due to a nutrient pump effect.

4.3 Possible effects on benthic organisms from discharge water

Pumping seawater from e.g. 35 m depth and releasing it in the surface layer could lead to eutrophication effects near the point of discharge. Possible eutrophication effects could be a shift in the species composition and dominance of a few species of small fast-growing opportunistic algae. The opportunistic algae could possibly outcompete and also suffocate other algae/animals.

Moving seawater from 35 m depth to the surface could cause changes in the temperature and/or salinity of the surface water. Species have different tolerances for changes in salinity and temperature. Different species have different upper and lower lethal levels of temperature and salinity, and also upper/lower temperature limits for reproduction. If the discharge water cause changes in temperature and/or salinity in the water masses in the area, there could be a shift in the species composition.

The severity of a possible shift in the species composition depends on the species present in the area, and their ecological importance.

4.4 Measures to prevent environmental impacts

As long as not all of the water in the fresh water source is used, the best way to prevent any impacts from running an osmotic power plant is to make sure that the discharge plume will end up at a depth where biological growth is limited by light. In the Oslofjord the euphotic zone typically extends 10 - 20 m. Whether or not this measure is necessary depends on the water flow in the power plant and the local conditions; the phosphate concentration for instance varies from place to place. If the concentration is low the effect might be negligible. To dive the outlet plume is also a remedy for the other possible environmental impacts mentioned in this report.

Increased dilution by installing a diffusor at the outlet pipe will make it more likely that the plume end up at the depth where it is discharged, and increased dilution will make possible toxic effects from chemical cleaning substances less likely.

5. Further work

Prior to the placement of a larger plant it is advisable to perform a preliminary study of the biological diversity to identify any possible vulnerable habitat types in the area.

The plant needs a large input of freshwater and it is likely to be placed near a large river mouth. In these areas there are often large soft-bottom areas where Zostera– and/or other sea-grass meadows can be found. Zostera/sea-grass meadows are very productive areas and are regarded as important marine ecosystems worldwide. They are often important nursery and feeding grounds for fishes and birds.

When looking at potentially new locations, it will also be beneficial to study the area for possible effects on the biology from already present industrial facilities. Areas where there already are industrial emissions are potentially more vulnerable to increased emissions. Pristine areas may be more resistant.

The most important measurements to assess the effect of a nutrient pump from the monitoring at Tofte is the concentration of phosphorous and nitrate in the fresh- and saltwater intake, and it is recommended that this is measured in the future. Measurements in the outlet basin and in the surface waters outside the power plant are also recommended. To assess a completely new site, measurement from the potential seawater intake depth is necessary. It would be useful to measure the Secchi depth to estimate the depth of the euphotic zone.

It is possible to model the eutrophication effect on a long range of different basins with a relatively simple box model. The water exchange with the outside waters, the hydro physical and hydro chemical profiles, the depth of the outlet plume, the depth of the intake water and the general supply of nutrients to the basin can then be altered to study the possible environmental impacts.

References

Clarke, K. R. 1993. *Non-parametric multivariate analyses of changes in community structure*. Australian Journal of Ecology. 18: 117-143.

Isaacs, J. D. and Seymour, R. J. 1973. *The Ocean as a power resource*. Interna. J. Environmental Studies. 4: 201-205.

Molvær, J., Magnusson, J., Pedersen, A. and Rygg, B. 2008. *Water Framework Directive; Development of a system for marine classification. Progress report autumn 2008* (in Norwegian). NIVA-report 5700-2008, 33 p.

Walday, M., Gitmark, J., Naustvoll, L. (HI), Norling, K., Selvik, J. R. and Sørensen K. 2011. *Monitoring of the Outer Oslofjord. Annual report* (in Norwegian). NIVA-report 6184-2011, 77 p.

Walday, M., Berge, J., Gitmark, J. and Green, N. 2011. *Pilotanlegg for produksjon av saltkraft på Hurum - Registrering av marin fauna og flora i fjæra og på grunt vann*. NIVA-report 5925-2011, 27 p.

Appendix A.

Table 9. Species list and abundance of algae in the intertidal zone at station 1 – 4, 2009-2011.

Table 10. Species list and abundance of animals in the intertidal zone at station 1 – 4, 2009-2011.

Table 11. Species list and abundance of benthic algae and animals from the transect registrations at station 1 in 2009, 2010 and 2011.

Table 12. Species list and abundance of benthic algae and animals from the transect registrations at station 2 in 2009, 2010 and 2011.

Table 9. Species list and abundance of algae in the intertidal zone at station 1 – 4, 2009-2011.

1=single occurrence, 2=spread occurrence, 3=common occurrence, 4=dominant occurrence

Species / Station	1_09	2_09	3_09	4_09	1_10	2_10	3_10	4_10	1_11	2_11	3_11	4_11
Ahnfeltia plicata		2	2	2		1	2			2	2	
Brogniartella byssoides					1							
Brun skorpeformet alge på fjell og blåsk	2	2	2	2		2	2	2				
Bryopsis cf. hypnoides		1										
Callithamnion corymbosum	2			2		2				2		
Callithamnion sp	2		1									
Ceramium rubrum	4	3	3	3	2	2	2	2		2	2	2
Ceramium cf. tenuicorne		2	2	2					1	1		
Chaetomorpha linum		2										
Chaetomorpha melagonium	2				2				2		2	2
cf Chaetomorpha sp									2			
Chondrus crispus	2	3	3	3	2	2	2	2			3	3
Chordaria flagelliformis	2				1				1			2
Cladophora albida		2		2						2	2	1
Cladophora rupestris	2	2			2					2		
Cladophora sericea					1							
Cladophora sp									1			
Cyano/Kisel		2	2	2	2	2	2	2		2		
Cystoclonium purpureum									1	1		
Delesseria sanguinea	2				2				1			
Dumontia contorta		2	2	2		2						
Ectocarpus fasciculatus		2	2	2		2			2			
Ectocarpales	2											
Elachista fucicola		2		2	2	2			2	2	2	
Fucus serratus	2	3	3	3	2	3	3	4	2	2	3	3
Fucus vesiculosus	2	3	3	3	2	3	2	4	2	3	2	2
Heterosiphonia japonica					1							
Hildenbrandia rubra	2	3	2	2	2	3	2	3	2	3	2	2
Laminaria sp juvenil					1				1			
Lithothamnion sp	2	2	2	2	2	2	2			2		
Phyllophora pseudoceranoides					2							
Polysiphonia elongata					1							
Polysiphonia fibrillosa	2	2	2	2				2	2		2	
Polysiphonia fucoides	2	2	2	2	2	2	2	2	1	2		
Polysiphonia stricta	2								2			
Porphyra cf purpurea			2									
Porphyra sp					2	2	2	2				
Porphyra umbilicalis									1		1	
Pylaiella littoralis					2		2			1	2	2
Ralfsia verrucosa				2		2						
Rhodomela confervoides		2	2	2	2				1			
Sargassum muticum					1							
Sphacelaria cirrosa		2		2	2	2						
Trailiella intricata					2	2						
Ulva intestinalis	3	3	2	2		2			2	2	2	3
Ulva lactuca	2	2	2	2	2	2	2	2	2		2	2
Ulva cf. linza		2	2	2								
Ulva sp							3	2				

Table 10. Species list and abundance of animals in the intertidal zone at station 1 – 4, 2009-2011. 1=single occurrence, 2=spread occurrence, 3=common occurrence, 4=dominant occurrence

Species / Station	1_09	2_09	3_09	4_09	1_10	2_10	3_10	4_10	1_11	2_11	3_11	4_11
Alcyonidium hirsutum		2										
Alcyonidium sp											2	
Asterias rubens	2	2			2	2	2		2	2	2	2
Balanus balanoides					2	2	2	2	3	3	3	3
Balanum improvisus	2		3	2	3	2	3	2	2	3	3	3
Campanularia johnstoni		2										
Cryptosula pallasiana		2										
Dynamena pumila		2				2	2	2			2	
Electra pilosa	2	2	2	3	2	2	2	2		2		
Halicondria panicea	2	2								2	2	
Hydroides norvegica					2							
Laomedea flexuosa	2								2			
Laomedea geniculata				2								
Laomedea sp						2		2				
Leptasterias mulleri		2										
Littorina littorea	1	2	2	2		2	2	2		2	2	2
Membranipora membranacea	2				2	2	2	2				
Metridium senile pallidus								2				
Mytilus edulis	2	3		2	2	3			2	4	3	3
Rissoa sp							2	2				
Sagartiidae										1		
Spirorbis sp					2							
Skorpeformet bryozo på fjell					2	2		2				

Table 11. Species list and abundance of benthic algae and animals from the transect registrations at station 1 in 2009, 2010 and 2011.

1=single occurrence, 2=spread occurrence, 3=common occurrence, 4=dominant occurrence

St. 1 - Algae transect - 2009	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Algecover		100	100	100	95		90		75		75		30		10						
Lithothamnion sp		2	2	2	2	3	3	4	4	4	4	2	2	2	2	2	2	2	2	2	2
Brunt på fjell - mørkt					2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Ubestemt rød skorpe															2	2	2	2	2	2	2
Cruoria pellita							2	2	2	2	2	2	2	2	2	2	2				
Phyllophora sp.									2				2	2	2	2	2				
Phyllophora truncata									2	2	2	2	2	2	2						
Delesseria sanguinea				2			3	2	2	2	2	2	2	2	2						
Phycodrys rubens							2	3	3	3	3	3	3	2	2						
Phyllophora cf.crispa													2	2	2	2	2				
Chondrus crispus	1												1		1						
Bonnemaisonia hamifera: sporp.				4	4	4	4	3	3	3	3	2	2								
Rhodomela confervoides				2	2	2	2	2	2		1										
Polysiphonia elongata									2												
Laminaria saccharina				1			2		1												
Phyllophora pseudoceranoides				2	2	2	2	2	2						1						
Pterothamnion plumula			2	2	2	2	2	2	2												
Furcellaria lumbricalis					2	2	2	2	2												
Sargassum muticum					2		1														
cf.Ulva lactuca			2	2	2		1														
Monostroma cf.grevillei					1																
Polysiphonia fucoides		2	2	2	2	2	2														
Ceramium rubrum	2	4	4	3	2																
Chaetomorpha melagonium				2	2																
Cladophora rupestris	1		1		2																
Cladophora sericea			2	2	2																
Bryopsis cf. plumosa			2		1																
Beggiatoa sp.																2					
Brongniartella byssoides					1																
Enteromorpha intestinalis	2	3	2	3																	
Enteromorpha compressa	2	2	2	2																	
Callithamnion corymbosum		2	2	2																	
Dasya baillouviana				1																	
Porphyra cf.purpurea			2																		
Cladophora albida			1																		
Fucus sp. juv.			2																		
Ectocarpus sp.		2	2																		
Chaetomorpha linum			2																		
Callithamnion byssoides							1														
Heterosiphonia japonica				2	2																
diatome-kjede på fjell				2	2																
Audouniella sp.				2	2																
Ceramium strictum			2	2																	
Ulva lactuca		2	2																		
Callithamnion sp.		2					2														
Polysiphonia urceolata		2																			
Fucus serratus	2	2																			
Hildenbrandia rubra	2																				
Fucus vesiculosus	2																				
Polysiphonia violacea	2																				

Table 11. cont.

St1. - animal transect - 2009	**0**	**1**	**2**	**3**	**4**	5	**6**	7	**8**	9	**10**	11	**12**	13	**14**	15	**16**	17	**18**	19	**20**
Bare rock surface	10	20	20	10	10		10		10		20		20		10				5		5
Sediment: unclassified	0	0	10	10	10		60		60		70		70		80				90		90
Hydroides norvegica							2	2						2	2			2	2		2
Leptasterias mulleri juv.							1			2	2			2	2			2	2		2
Alcyonium digitatum										2	2	2	2	2	2				1		
Caryophyllia smithii														2	2			2	2		
Laomedea longissima							2	2		2	2	2	2					2	2		
Leptasterias mulleri			2	2					2		1							2	2		
Metridium senile			2	2	2	2	2	2	2	2	2			2	2			2	2		
Ciona intestinalis														3	3			2	2		
Spirorbis spirillum				2		2	2	2	2	2	2	2	2	2	2			2	2		
Echinus acutus																			1		
cf.Protanthea simplex															2				1		
Gibbula cineraria															1				1		
Macropodia rostrata																			1		
Pomatoceros triqueter		2	2	2				2	2		2	2		2	2						
Asterias rubens		2	2	2	2	2	2	2	2	2	2			2	2						
Corella parallelogramma												2	2	2	2						
Amphipoda indet.: tube															2						
Homarus gammarus															1						
Gonactinia prolifera															2						
Littorina littorea	2														1						
cf.Beggiatoa sp.									2				2	2	2						
Sabella penicillus														2	2						
Mytilus edulis	2	2	2	2											1						
Sagartiidae indet.					2	2				2	2	2	2								
Halichondria panicea		2	1	3	2	3	3	2	2	2	2		1								
Tritonia hombergi							1				1										
Prostheceraceus vittatus									1												
Laomedea flexuosa				2	2	2	2														
Membranipora membranacea		2	2	2	2	2	2	2				2	2								
Electra pilosa		2	2	2	2	2	2	2													
Dendrodoa grossularia				2	2	2	2														
Bryozoa indet. encrusting						2	2														
Psammechinus miliaris							1														
Asterias rubens juv.	2	1	1																		
Balanus improvisus	2																				
Disporella hispida						2	2					2	2								
Cryptosula pallasiana						2	2					2	2								
Escharella immersa												2	2								
Eudendrium arbuscula												2	2								
Crisiella producta												2	2								
Callopora aureum							1														
Laomedea gracilis					2	2	2														

Table 11. cont.

St. 1 - Algae transect - 2010	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Algedekke	60	100	95	100	90		90		90		60		30		10				
Brunt på fjell - mørkt			2				2	3	3	3	3	3	3	2	2	2	2	2	2
Lithothamnion sp		2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3		
Cruoria pellita					2	2	2	2	2	2	2	2	2	2	2	2	2		
Phyllophora truncata											2	2	2		1				
Delesseria sanguinea		2	2	2	2	3	3	2	2	2	2	2	2	2	2				
Phyllophora sp.									2	2	2	2	2	2	2				
Phyllophora crispa											2	2	2		1				
Phycodrys rubens									2	2	2	2	2	2	2				
Bonnemaisonia hamifera: sporp.		2	2	4	4	4	4	4	4	3	3	2	2	2	2				
Chondrus crispus	2	2					2	2	2	2	2								
Heterosiphonia japonica		1	2	2	2	2	2	2	2	2	2								
Audouniella sp.							2	2	2	2	2								
Laminaria saccharina			2	2	2	2	2		1										
Dilsea carnosa									1										
Phyllophora pseudoceranoides		2	2				2	2	2										
Rhodomela confervoides		2	2	2	2				1										
Sargassum muticum		1	2	2	2		1												
Ceramium rubrum	2	2	3	2	2														
Chaetomorpha melagonium	2	2	2	2	2														
Ulva lactuca	2	3	3	2															
Porphyra sp.	2				1														
Callithamnion corymbosum				2															
Dasya baillouviana			1	2															
Fucus serratus	2			2															
Cladophora rupestris	2	2	2																
Rhizoclonium riparium			2																
Cladophora sericea		2	2																
Brongniartella byssoides		1	2																
Chordaria flagelliformis	1	2	1																
Laminaria digitata		1																	
Polysiphonia elongata		1																	
Polysiphonia fucoides	2	2																	
Hildenbrandia rubra	2																		
Enteromorpha sp.	2																		
Fucus vesiculosus	2																		
Cyanophycea div. indet i SLAM	2																		
Pilayella littoralis		2																	
Elachista fucicola	2																		
Laminaria saccharina juv.	1																		
Sphacelaria cirrosa	2																		

Table 11. cont.

St1. - animal transect - 2010	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Sediment: unclassified	0	0	0	0	0		20		20		30		20		50	20			60	60
Bare rock surface	10	5	10	10	10		0		0		10		10		20	40			20	90
Buccinum undatum				1					1		1		2	2	2	2			2	2
Metridium senile			1	1			1		2	2	2				1				1	2
Pagurus sp.					1															1
Asterias rubens	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1			2	2
Ciona intestinalis									2	3	3	4	4	3	3	3			3	2
Pomatoceros triqueter			2	2	2	2	2	2	2	2	2	2	2	2	2	2			2	2
Caryophyllia smithii																			2	
Echinus esculentus																			1	
Asterias rubens juv.	2	2													1				2	
Ophiura albida															2	1			1	
Hydroides norvegica	2						2	2	2				2			2				
Sagartiidae indet.							2	2	2	2	2	2	2	3	3					
Marthasterias glacialis															1	1				
Alcyonium digitatum													2							
Porifera indet.: encrusting													1							
Leptasterias mulleri							1				2									
Styela rustica				2	1		1		1		1									
Halichondria panicea			2	2	2	2	2	2	2		1									
Bryozoa indet. encrusting									2		1									
Crisiella producta											2									
Spirorbis tridentata							2													
Spirorbis sp.		2	2	2	2	2	2	2	2	2	2									
Hydroida indet.											2									
Electra pilosa	2	2	2	2	2	2	2	2	2											
Skorpeformet bryozo på lamina				2					2											
Membranipora membranacea	2	2	2	2	2	2	2													
Cryptosula pallasiana							2	2	2	2	2									
Spirorbis spirillum									2											
Disporella hispida									1											
cf.Prostheceraceus vittatus							1													
Laomedea geniculata		2	2	2	2		1													
Skorpeformet bryozo på fjell			2		2															
Mytilus edulis	2	2																		
Porifera indet.: encrusting - white		1																		
Balanus improvisus	3																			
Escharella immersa							2													
Tubularia sp.							2													
Anomoniidae indet.							2													
Polyplacophora indet.							1													

Table 11. cont.

St. 1 - Algae transect - 2011	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Algedekke	40	70	20	30	90		70		80		80		20		1		<1		<1
Lithothamnion sp			2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Brunt på fjell - mørkt							2	2	2	2	2	2	2	2	2	2	2	2	2
Phyllophora sp.									2	2	2	2	2	2	2	2	2	2	2
Cruoria pellita							2	2	2	2	2	2	2	2	2	2	2		
Phyllophora truncata											2	2	2		1				
Phycodrys rubens				2					2	2	2	2	2						
Pterothamnion plumula									2	2	2	2	2						
Heterosiphonia japonica									2	2	2	2	2						
Delesseria sanguinea		1	1	2	2	2	2	3	3	3	3	2	2						
Laminaria sp. juv.		2											1						
Laminaria saccharina				2	2	2	2	2	2	2	2		1						
Phyllophora pseudoceranoides			2	2					2	2	2								
Polysiphonia stricta											2								
Ceramium strictum		2									1								
Rhodomela confervoides			2	2	2	2	2	2	2		1								
Bonnemaisonia hamifera: sporp.				2	3	2	2	2	2	2	2								
Brongniartella byssoides							2												
Cladophora rupestris			2	2			2												
Ulva lactuca		2	2	2	2	2	2												
Polyides rotundus				2	2	2	2												
Cystoclonium purpureum		1					2												
Sargassum muticum				2	2														
Chaetomorpha melagonium	1	2	2	2	2														
Chondrus crispus					2														
Callithamnion corymbosum					2														
Polysiphonia fucoides			2	2	2														
Rhizoclonium riparium				2	1														
Fucus serratus			2	2															
Bryopsis hypnoides			2																
Polysiphonia fibrillosa		2																	
Fucus vesiculosus		2																	
Chordaria flagelliformis	1																		
Elachista fucicola	2																		
Cladophora sp.	1																		
Hildenbrandia rubra	2																		
Ulva cf intestinalis		2																	

Table 11. cont.

St1. - animal transect - 2011	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Sediment: unclassified	0	0	5	5	5		10		60		80		90		80				##
Sabella penicillus																			2
Asterias rubens		2	2	2	2	2	2		1		2	2	2						1
Metridium senile				2	2	2	2	2	2				2	2	2				2
Pomatoceros triqueter				2	2	2	2				1		2	2	2				2
Leptasterias mulleri				1					2	2	2	2	2	2	2				1
Laomedea longissima		2					2	2	2				2	2	2				2
Ophiura albida															2				1
Echinus esculentus																			1
Ciona intestinalis													2	2	2				
Sagartiidae indet.			2	2	2				2	2	2	2	2		1				
Leptasterias mulleri juv.									1						2				
Buccinum undatum											1				2				
Nassarius reticulatus															1				
Alcyonium digitatum											2				2				
Mytilus edulis					2								2						
Spirorbis borealis													2						
Styela rustica													1						
Halichondria panicea			2	2	2	2	2	2	2	2	2	2	2						
Urticina felina									1		1								
Tubularia larynx									2						2				
Electra pilosa					2	2	2												
Laomedea geniculata					2	2	2												
Mytilus edulis juv.		2	3	2	3														
Balanus sp.					2														
Botryllus schlosseri				2															
Balanus balanoides	2	2	3	2															
Balanus improvisus		2			2	2	2												
Littorina littorea							1												
Prosobranchia indet. juv.													1						

Table 12. Species list and abundance of benthic algae and animals from the transect registrations at station 2 in 2009, 2010 and 2011.

1=single occurrence, 2=spread occurrence, 3=common occurrence, 4=dominant occurrence

St. 2 - Algae transect - 2009	0	1	2	3
Algedekke		90	50	20
Ahnfeltia plicata	2		2	
Audouniella sp.			2	
Bonnemaisonia hamifera: sporp.			2	
Brunt på fjell - mørkt			2	
Callithamnion corymbosum			2	2
Ceramium rubrum	3	3	4	2
Ceramium strictum	2	2	2	
Chaetomorpha linum		2		
Chondrus crispus		2	2	2
Cladophora albida		2		
Cruoria pellita			2	
Dasya baillouviana				2
Delesseria sanguinea				1
diatome-kjede på fjell	2	2		
Dumontia contorta	2			
Ectocarpus fasciculatus		2		
Ectocarpus sp.			1	
Elachista fucicola	2	2		
Enteromorpha cf.flexuosa-gruppen			1	
Enteromorpha intestinalis	3	2		
Enteromorpha sp.				2
Erythrothrichia carnea			2	2
Fucus serratus	2	3	2	1
Fucus vesiculosus	2	3		
Heterosiphonia japonica		2	2	
Hildenbrandia rubra	3	2	2	
Laminaria saccharina			1	1
Lithothamnion sp	2	2	3	
Phycodrys rubens			1	
Phyllophora pseudoceranoides			2	
Pilayella littoralis			1	
Polysiphonia fucoides			2	2
Rhodomela confervoides		2		
Ulva lactuca		2		1

St2. - animal transect - 2009	**0**	**1**	**2**	**3**
Bare rock surface	30	40	40	50
Sediment: unclassified	10	40	40	50
Littorina littorea	3	2		2
Electra pilosa	2	3	2	2
Mya truncata død				2
Carcinus maenas				1
Asterias rubens juv.				2
Pagurus sp.			1	
Mytilus edulis	3	3		
Halichondria panicea		2		
Asterias rubens		2		
Leptasterias mulleri juv.		2		
Alcyonidium mamillatum			1	
Campanularia johnstoni		2	2	
Alcyonidium hirsutum		2		
Dynamena pumila		2		
Cryptosula pallasiana	2			

Table 12. cont

St. 2 - Algae transect - 2010	0	1	2	3	4	5
Algedekke	20	100	100	100	90	100
Brunt på fjell - mørkt					1	
Heterosiphonia japonica			2	2	2	3
Laminaria sp. kimplanter				2	2	2
Ceramium rubrum		2	2	2	3	3
Laminaria saccharina			2			2
Dasya baillouviana				2	3	2
Delesseria sanguinea				2	1	2
Bonnemaisonia hamifera: sporp.		2	2	3	2	2
Rhodomela confervoides			2	2	2	2
Polysiphonia elongata				2	2	2
Sargassum muticum				2	2	2
Laminaria juv				2	2	
Ulva lactuca	2	2	2	2	2	2
Chondrus crispus	2	2	3	2	2	
Polysiphonia fucoides	2	2	2	2	2	
Cruoria pellita		2	2	2	2	
Heterosiphonia plumosa				2	2	
Callithamnion corymbosum		2	2	2	2	
Fucus serratus	3	4	2	2		
Furcellaria lumbricalis				1		
Lithothamnion sp		2	2	2		
Ahnfeltia plicata			2			
Rhizoclonium riparium			1			
Fucus vesiculosus	2	2				
Ectocarpus fasciculatus		2				
Elachista fucicola	2	2				
Hildenbrandia rubra	2	2				
Sphacelaria cirrosa		2				

St2. - animal transect - 2010	<1	0	1	2	3	4	5
Bare rock surface				5			
Sediment: unclassified				0			
Asterias rubens juv.		1		2	2	2	2
Littorina littorea		2	2	2			
Asterias rubens				2	2	2	2
Electra pilosa		2	2	2			
Dynamena pumila			2	2			
Mytilus edulis		3	2	2			
Botryllus schlosseri				1	2	2	2
Membranipora membranacea			2	2	2	2	2
Bryozoa indet. encrusting				2	2	2	
Metridium senile				2			
Spirorbis sp.				2			
Halichondria panicea				2			
Alcyonidium mamillatum			2				
Sagartiidae indet.			1				
Balanus improvisus			2	2	2		
Pomatoceros triqueter		2	2	2	2	2	2
Balanus balanoides		2					
Littorina saxatilis	2						
Cryptosula pallasiana			2				
Hydroida indet.						2	2
Arenicola marina							2
Ciona intestinalis							2
Ascidiacea indet.					2		2
Buccinum undatum							2
Balanus cf.balanus						2	2
Empty bivalve shell					2		

Table 12. cont

St. 2 - Algae transect - 2011	<1	0	1	2	3	4
Algedekke			20	90	60	60
Laminaria saccharina					1	2
Delesseria sanguinea				2	2	2
Chondrus crispus				2	2	2
Bonnemaisonia hamifera: sporp.				2	2	2
Pterothamnion plumula				1	1	1
Ceramium rubrum		2	2	2	2	2
Heterosiphonia japonica					2	2
Brunt på fjell - mørkt				2	2	2
Lithothamnion sp			2	2	2	2
Polysiphonia fucoides			2	2	2	2
Cruoria pellita				2	2	2
Phyllophora pseudoceranoides						2
Ulva lactuca				1		2
Fucus serratus			2	2	2	
Callithamnion corymbosum			2	2	2	
Ahnfeltia plicata			2	2	1	
Polysiphonia stricta					1	
Furcellaria lumbricalis				2		
Enteromorpha sp.	2	2	2	1		
Fucus vesiculosus		3	2			
Hildenbrandia rubra	2	3	2			
Cladophora rupestris		2				
Cyanophycea div. indet i SLAM	4	2				
Elachista fucicola		2	2			

St2. - animal transect - 2011	0	1	2	3	4
Electra pilosa	2	2			2
Littorina littorea	2	2	2	2	2
Pomatoceros triqueter			2	2	2
Leptasterias mulleri juv.					2
Asterias rubens juv.				2	1
Balanus improvisus		3	3	2	1
Bittium reticulatum					2
Halichondria panicea		2	1	1	
Mytilus edulis juv.	2	4	3		
Asterias rubens		2	2		
Sagartiidae indet.		1			
Mytilus edulis		3			
Alcyonidium gelatinosum				2	2
Botrylloides leachi				2	2
Campanularia johnstoni				2	2
Dynamena pumila		2	2		
Balanus improvisus	2	2			

Appendix B.

SIMPER ANALYSIS

```
Standardise data: No, Transform: Square root, Cut off for low
contributions: 90,00%
```

Table 13. SIMPER analysis. Algae- and animal species/taxa that contribute most to the dissimilarities in the intertidal zone at the 4 stations investigated in 2009, 2010 and 2011.

Table 14. SIMPER analysis. Algae- and animal species/taxa that contribute most to the dissimilarities in the different depth intervals (0-4 m, 5-9 m, 10-14 m and 15-18 m) in the transect registration at station 1 in 2009, 2010 and 2011.

Table 15. SIMPER analysis. Algae- and animal species/taxa that contribute most to the dissimilarities in the different depth intervals (0-1 m and 2-3m) in the transect registration at station 2 in 2009, 2010 and 2011.

Table 13. SIMPER analysis. Algae- and animal species/taxa that contribute most to the dissimilarities in the intertidal zone at the 4 stations investigated in 2009, 2010 and 2011.

Groups 2009 & 2010

Average dissimilarity = 36,54

Species	**Group 2009 Av.Abund**	**Group 2010 Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Semibalanus balanoides	0,00	2,00	1,83	10,34	5,01	5,01
Membranipora membranacea	0,50	2,00	1,37	1,64	3,74	8,75
Polysiphonia fibrillosa	2,00	0,50	1,35	1,65	3,70	12,44
Skorpeformet bryozo på fjell	0,00	1,50	1,34	1,65	3,67	16,12
Porphyra sp	0,50	2,00	1,33	1,66	3,64	19,75
Mytilus edulis	1,75	1,25	1,26	1,20	3,44	23,20
Dynamena pumila	0,50	1,50	1,18	1,24	3,24	26,44
Dumontia contorta	1,50	0,50	1,15	1,23	3,16	29,60
Rhodomela confervoides	1,50	0,50	1,15	1,23	3,15	32,75
Ceramium rubrum	3,25	2,00	1,15	2,65	3,14	35,89
Callithamnion corymbosum	1,25	0,50	1,05	1,29	2,88	38,77
Ahnfeltia plicata	1,50	0,75	1,02	1,23	2,79	41,56
Rissoa sp	0,00	1,00	0,97	0,96	2,65	44,21
Asterias rubens	1,00	1,50	0,94	0,96	2,56	46,77
Laomedea sp	1,00	1,00	0,92	0,96	2,50	49,27
Sphacelaria cirrosa	1,00	1,00	0,91	0,97	2,49	51,76
Elachista fucicola	1,00	1,00	0,91	0,97	2,49	54,25
Cladophora rupestris	1,00	0,50	0,89	0,96	2,44	56,69
Ulva spp	2,50	1,75	0,88	1,00	2,41	59,10
Cladophora sp	1,00	0,25	0,88	1,11	2,40	61,50
Halicondria panicea	1,00	0,00	0,87	0,96	2,38	63,88
Balanus improvisus	1,75	2,50	0,87	1,02	2,37	66,25
Trailiella intricata	0,00	1,00	0,86	0,96	2,36	68,61
Fucus vesiculosus	2,75	2,75	0,70	1,27	1,91	70,52
Chondrus crispus	2,75	2,00	0,68	1,64	1,87	72,39
Delesseria sanguinea	0,50	0,50	0,68	0,75	1,85	74,24
Chaetomorpha melagonium	0,50	0,50	0,68	0,75	1,85	76,09
Fucus serratus	2,75	3,00	0,58	0,99	1,58	77,68
Chordaria flagelliformis	0,50	0,25	0,57	0,76	1,56	79,24
Littorina littorea	1,75	1,50	0,56	0,79	1,52	80,76
Metridium senile pallidus	0,00	0,50	0,48	0,56	1,31	82,07
Ectocarpales	2,00	1,50	0,48	0,56	1,31	83,38
Lithothamnion sp	2,00	1,50	0,48	0,56	1,31	84,69
Polysiphonia stricta	0,50	0,00	0,46	0,56	1,27	85,96
Cyano/Kisel	1,50	2,00	0,46	0,56	1,27	87,23
Hildenbrandia rubra	2,25	2,50	0,46	0,96	1,25	88,47
Hydroides norvegica	0,00	0,50	0,43	0,56	1,19	89,66
Spirorbis sp	0,00	0,50	0,43	0,56	1,19	90,84

Table 13. cont

Groups 2010 & 2011

Average dissimilarity = 43,54

Species	Group 2010 Av.Abund	Group 2011 Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Membranipora membranacea	2,00	0,00	2,05	11,95	4,72	4,72
Mytilus edulis	1,25	3,00	1,99	1,34	4,56	9,28
Brunt på fjell	1,50	0,00	1,57	1,66	3,61	12,89
Electra pilosa	2,00	0,50	1,56	1,66	3,59	16,48
Cyano/Kisel	2,00	0,50	1,56	1,66	3,59	20,07
Porphyra sp	2,00	0,50	1,55	2,71	3,56	23,63
Chondrus crispus	2,00	1,50	1,53	2,93	3,52	27,15
Skorpeformet bryozo på fjell	1,50	0,00	1,50	1,66	3,45	30,60
Dynamena pumila	1,50	0,50	1,31	1,24	3,01	33,61
Chaetomorpha melagonium	0,50	1,50	1,31	1,24	3,01	36,62
Polysiphonia fucoides	2,00	0,75	1,30	1,44	2,99	39,61
Lithothamnion sp	1,50	0,50	1,28	1,24	2,94	42,56
Cladophora sp	0,25	1,50	1,28	1,87	2,93	45,49
Rissoa sp	1,00	0,00	1,09	0,97	2,51	48,00
Elachista fucicola	1,00	1,50	1,06	0,97	2,42	50,42
Semibalanus balanoides	2,00	3,00	1,03	11,95	2,36	52,78
Laomedea sp	1,00	0,50	1,02	0,96	2,35	55,13
Polysiphonia fibrillosa	0,50	1,00	1,02	0,96	2,34	57,47
Ahnfeltia plicata	0,75	1,00	1,02	1,09	2,34	59,81
Halicondria panicea	0,00	1,00	0,98	0,96	2,26	62,07
Sphacelaria cirrosa	1,00	0,00	0,96	0,97	2,21	64,28
Trailiella intricata	1,00	0,00	0,96	0,97	2,21	66,48
Ulva spp	1,75	2,25	0,89	0,93	2,03	68,52
Chordaria flagelliformis	0,25	0,75	0,80	0,93	1,84	70,36
Fucus vesiculosus	2,75	2,25	0,78	0,93	1,80	72,15
Fucus serratus	3,00	2,50	0,78	1,08	1,79	73,94
Littorina littorea	1,50	1,50	0,76	0,75	1,74	75,69
Cladophora rupestris	0,50	0,50	0,74	0,75	1,70	77,39
Callithamnion corymbosum	0,50	0,50	0,74	0,75	1,70	79,09
Ectocarpales	1,50	1,75	0,66	0,75	1,51	80,60
Rhodomela confervoides	0,50	0,25	0,62	0,79	1,43	82,03
Delesseria sanguinea	0,50	0,25	0,62	0,79	1,43	83,46
Metridium senile pallidus	0,50	0,00	0,54	0,56	1,24	84,70
Asterias rubens	1,50	2,00	0,54	0,56	1,24	85,94
Polysiphonia stricta	0,00	0,50	0,52	0,56	1,20	87,14
cf Chaetomorpha sp	0,00	0,50	0,52	0,56	1,20	88,34
Balanus improvisus	2,50	2,75	0,51	0,96	1,17	89,51
Hildenbrandia rubra	2,50	2,25	0,51	0,96	1,17	90,68

Table 14. SIMPER analysis. Algae- and animal species/taxa that contribute most to the dissimilarities in the different depth intervals (0-4 m, 5-9 m, 10-14 m and 15-18 m) in the transect registration at station 1 in 2009, 2010 and 2011.

Groups 09_0-4 & 10_0-4

Average dissimilarity = 29,75

	Group 09_0-4	Group 10_0-4				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Bryozoa indet. encrusting	0,00	6,00	1,26	#######	4,23	4,23
Pterothamnion plumula	6,00	0,00	1,26	#######	4,23	8,46
Leptasterias mulleri	4,00	0,00	1,03	#######	3,45	11,92
Dendrodoa grossularia	4,00	0,00	1,03	#######	3,45	15,37
Audouniella sp.	4,00	0,00	1,03	#######	3,45	18,83
Chordaria flagelliformis	0,00	4,00	1,03	#######	3,45	22,28
Ulva spp	10,00	2,00	0,90	#######	3,02	25,30
Styela rustica	0,00	3,00	0,89	#######	2,99	28,29
Bryopsis sp	3,00	0,00	0,89	#######	2,99	31,28
Laminaria saccharina	1,00	7,00	0,85	#######	2,84	34,13
Sagartiidae indet.	2,00	0,00	0,73	#######	2,44	36,57
Spirorbis spp.	2,00	8,00	0,73	#######	2,44	39,01
Littorina littorea	2,00	0,00	0,73	#######	2,44	41,45
Hydroides norvegica	0,00	2,00	0,73	#######	2,44	43,90
Polysiphonia stricta	2,00	0,00	0,73	#######	2,44	46,34
Rhizoclonium riparium	0,00	2,00	0,73	#######	2,44	48,78
Sphacelaria cirrosa	0,00	2,00	0,73	#######	2,44	51,23
Polysiphonia fibrillosa	2,00	0,00	0,73	#######	2,44	53,67
Delesseria sanguinea	2,00	8,00	0,73	#######	2,44	56,11
Elachista fucicola	0,00	2,00	0,73	#######	2,44	58,55
Furcellaria/Polyides	2,00	0,00	0,73	#######	2,44	61,00
Cruoria pellita	0,00	2,00	0,73	#######	2,44	63,44
Sargassum muticum	2,00	7,00	0,63	#######	2,13	65,57
Metridium senile	6,00	2,00	0,53	#######	1,79	67,35
Callithamnion spp	6,00	2,00	0,53	#######	1,79	69,14
Porifera indet.: encrusting	0,00	1,00	0,51	#######	1,73	70,87
Pagurus sp.	0,00	1,00	0,51	#######	1,73	72,60
Buccinum undatum	0,00	1,00	0,51	#######	1,73	74,32
Laminaria digitata	0,00	1,00	0,51	#######	1,73	76,05
Polysiphonia elongata	0,00	1,00	0,51	#######	1,73	77,78
Chondrus crispus	1,00	4,00	0,51	#######	1,73	79,51
Mytilus edulis	8,00	4,00	0,43	#######	1,43	80,94
Laomedea spp	4,00	8,00	0,43	#######	1,43	82,37
Rhodomela confervoides	4,00	8,00	0,43	#######	1,43	83,80
Polysiphonia fucoides	8,00	4,00	0,43	#######	1,43	85,23
Dasya baillouviana	1,00	3,00	0,38	#######	1,26	86,49
Brongniartella byssoides	1,00	3,00	0,38	#######	1,26	87,76
Chaetomorpha spp	6,00	10,00	0,37	#######	1,23	88,99
Heterosiphonia japonica	4,00	7,00	0,33	#######	1,12	90,11

Table 14. cont.

Groups 09_5-9 & 10_5-9

Average dissimilarity = 34,00

Species	Group 09_5-9 Av.Abund	Group 10_5-9 Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Heterosiphonia japonica	0,00	10,00	1,89	#######	5,57	5,57
Pterothamnion plumula	8,00	0,00	1,69	#######	4,98	10,55
Furcellaria/Polyides	8,00	0,00	1,69	#######	4,98	15,53
Audouniella sp.	0,00	8,00	1,69	#######	4,98	20,51
Chondrus crispus	0,00	8,00	1,69	#######	4,98	25,48
Ciona intestinalis	0,00	5,00	1,34	#######	3,94	29,42
Dendrodoa grossularia	4,00	0,00	1,20	#######	3,52	32,94
Phyllophora truncata	4,00	0,00	1,20	#######	3,52	36,46
Polysiphonia fucoides	4,00	0,00	1,20	#######	3,52	39,98
Laomedea spp	8,00	1,00	1,09	#######	3,22	43,20
Rhodomela confervoides	8,00	1,00	1,09	#######	3,22	46,42
Styela rustica	0,00	2,00	0,85	#######	2,49	48,91
Tubularia sp.	0,00	2,00	0,85	#######	2,49	51,40
Escharella immersa	0,00	2,00	0,85	#######	2,49	53,89
Alcyonium digitatum	2,00	0,00	0,85	#######	2,49	56,38
Anomoniidae indet.	0,00	2,00	0,85	#######	2,49	58,87
Polysiphonia elongata	2,00	0,00	0,85	#######	2,49	61,36
Callithamnion spp	2,00	0,00	0,85	#######	2,49	63,85
Phycodrys rubens	11,00	4,00	0,79	#######	2,32	66,17
Leptasterias mulleri	5,00	1,00	0,74	#######	2,18	68,34
Pomatoceros triqueter	4,00	10,00	0,70	#######	2,05	70,39
Lithothamnion sp	18,00	10,00	0,65	#######	1,90	72,29
Psammechinus miliaris	1,00	0,00	0,60	#######	1,76	74,05
Tritonia hombergi	1,00	0,00	0,60	#######	1,76	75,81
Polyplacophora indet.	0,00	1,00	0,60	#######	1,76	77,57
Disporella hispida	4,00	1,00	0,60	#######	1,76	79,33
Buccinum undatum	0,00	1,00	0,60	#######	1,76	81,09
Callopora aureum	1,00	0,00	0,60	#######	1,76	82,85
Ulva lactuca	1,00	0,00	0,60	#######	1,76	84,61
Dilsea carnosa	0,00	1,00	0,60	#######	1,76	86,38
Metridium senile	10,00	5,00	0,55	#######	1,63	88,01
Sagartiidae indet.	4,00	8,00	0,50	#######	1,46	89,46
Cryptosula pallasiana	4,00	8,00	0,50	#######	1,46	90,92

Groups 09_10-14 & 10_10-14

Average dissimilarity = 36,28

Species	Group 09_10-14 Av.Abund	Group 10_10-14 Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Corella parallelogramma	8,00	0,00	1,85	#######	5,09	5,09
Buccinum undatum	0,00	7,00	1,73	#######	4,76	9,85
Laomedea spp	6,00	0,00	1,60	#######	4,41	14,26
Sabella penicillus	4,00	0,00	1,31	#######	3,60	17,85
Membranipora membranacea	4,00	0,00	1,31	#######	3,60	21,45
Disporella hispida	4,00	0,00	1,31	#######	3,60	25,05
Escharella immersa	4,00	0,00	1,31	#######	3,60	28,65
Eudendrium arbuscula	4,00	0,00	1,31	#######	3,60	32,25
Caryophyllia smithii	4,00	0,00	1,31	#######	3,60	35,85

Table 14. cont.

Spirorbis spp.	10,00	2,00	1,14	#######	3,15	38,99
Alcyonium digitatum	10,00	2,00	1,14	#######	3,15	42,14
Ciona intestinalis	6,00	17,00	1,09	#######	3,01	45,15
cf.Protanthea simplex	2,00	0,00	0,92	#######	2,54	47,69
Ophiura albida	0,00	2,00	0,92	#######	2,54	50,24
Gonactinia prolifera	2,00	0,00	0,92	#######	2,54	52,78
Hydroida indet.	0,00	2,00	0,92	#######	2,54	55,33
Amphipoda indet.: tube	2,00	0,00	0,92	#######	2,54	57,87
Heterosiphonia japonica	0,00	2,00	0,92	#######	2,54	60,41
Audouniella sp.	0,00	2,00	0,92	#######	2,54	62,96
Leptasterias mulleri	6,00	2,00	0,68	#######	1,86	64,82
Sagartiidae indet.	6,00	12,00	0,66	#######	1,83	66,65
Porifera indet.: encrusting	0,00	1,00	0,65	#######	1,80	68,45
Styela rustica	0,00	1,00	0,65	#######	1,80	70,24
Tritonia hombergi	1,00	0,00	0,65	#######	1,80	72,04
Littorina littorea	1,00	0,00	0,65	#######	1,80	73,84
Marthasterias glacialis	0,00	1,00	0,65	#######	1,80	75,64
Mytilus edulis	1,00	0,00	0,65	#######	1,80	77,44
Gibbula cineraria	1,00	0,00	0,65	#######	1,80	79,24
Homarus gammarus	1,00	0,00	0,65	#######	1,80	81,04
Bryozoa indet. encrusting	0,00	1,00	0,65	#######	1,80	82,84
Rhodomela confervoides	1,00	0,00	0,65	#######	1,80	84,64
Phyllophora pseudoceranoides	1,00	0,00	0,65	#######	1,80	86,44
Halichondria panicea	3,00	1,00	0,48	#######	1,32	87,75
Metridium senile	6,00	3,00	0,47	#######	1,29	89,05
Asterias rubens	6,00	10,00	0,47	#######	1,28	90,33

Groups 09_15-18 & 10_15-18

Average dissimilarity = 46,26

	Group 09_15-18	**Group 10_15-18**				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Phyllophora crispa	4,00	0,00	4,44	#######	9,60	9,60
Phyllophora sp.	4,00	0,00	4,44	#######	9,60	19,19
Spirorbis spp.	2,00	0,00	3,14	#######	6,79	25,98
Leptasterias mulleri	2,00	0,00	3,14	#######	6,79	32,77
Pomatoceros triqueter	0,00	2,00	3,14	#######	6,79	39,55
Hydroides norvegica	2,00	0,00	3,14	#######	6,79	46,34
Laomedea spp	2,00	0,00	3,14	#######	6,79	53,13
Asterias rubens	0,00	2,00	3,14	#######	6,79	59,91
Buccinum undatum	0,00	2,00	3,14	#######	6,79	66,70
cf.Protanthea simplex	1,00	0,00	2,22	#######	4,80	71,50
Macropodia rostrata	1,00	0,00	2,22	#######	4,80	76,30
Ophiura albida	0,00	1,00	2,22	#######	4,80	81,10
Gibbula cineraria	1,00	0,00	2,22	#######	4,80	85,89
Alcyonium digitatum	1,00	0,00	2,22	#######	4,80	90,69

Table 14. cont.

Groups 10_0-4 & 11_0-4

Average dissimilarity = 35,24

	Group 10_0-4	Group 11_0-4				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Membranipora membranacea	10,00	0,00	1,81	#######	5,14	5,14
Spirorbis spp.	8,00	0,00	1,62	#######	4,59	9,73
Heterosiphonia japonica	7,00	0,00	1,51	#######	4,30	14,03
Sagartiidae indet.	0,00	6,00	1,40	#######	3,98	18,01
Bryozoa indet. encrusting	6,00	0,00	1,40	#######	3,98	21,98
Furcellaria/Polyides	0,00	4,00	1,14	#######	3,25	25,23
Ceramium spp	11,00	2,00	1,09	#######	3,09	28,32
Electra pilosa	10,00	2,00	1,00	#######	2,84	31,16
Styela rustica	3,00	0,00	0,99	#######	2,81	33,97
Porphyra sp	3,00	0,00	0,99	#######	2,81	36,79
Dasya baillouviana	3,00	0,00	0,99	#######	2,81	39,60
Brongniartella byssoides	3,00	0,00	0,99	#######	2,81	42,41
Balanus spp.	3,00	11,00	0,91	#######	2,57	44,99
Hydroides norvegica	2,00	0,00	0,81	#######	2,30	47,28
Botryllus schlosseri	0,00	2,00	0,81	#######	2,30	49,58
Sphacelaria cirrosa	2,00	0,00	0,81	#######	2,30	51,88
Laminaria sp. juv.	0,00	2,00	0,81	#######	2,30	54,18
Phycodrys rubens	0,00	2,00	0,81	#######	2,30	56,47
Polysiphonia fibrillosa	0,00	2,00	0,81	#######	2,30	58,77
Ectocarpales	2,00	0,00	0,81	#######	2,30	61,07
Kisel/Cyano på fjell	2,00	0,00	0,81	#######	2,30	63,36
Brunt på fjell - mørkt	2,00	0,00	0,81	#######	2,30	65,66
Bryopsis sp	0,00	2,00	0,81	#######	2,30	67,96
Cruoria pellita	2,00	0,00	0,81	#######	2,30	70,25
Bonnemaisonia hamifera: sporp.	12,00	5,00	0,70	#######	1,99	72,25
Mytilus edulis	4,00	10,00	0,67	#######	1,89	74,14
Porifera indet.: encrusting	1,00	0,00	0,57	#######	1,62	75,76
Leptasterias mulleri	0,00	1,00	0,57	#######	1,62	77,38
Pagurus sp.	1,00	0,00	0,57	#######	1,62	79,01
Buccinum undatum	1,00	0,00	0,57	#######	1,62	80,63
Laminaria digitata	1,00	0,00	0,57	#######	1,62	82,26
Polysiphonia elongata	1,00	0,00	0,57	#######	1,62	83,88
Cystoclonium purpureum	0,00	1,00	0,57	#######	1,62	85,50
Chordaria flagelliformis	4,00	1,00	0,57	#######	1,62	87,13
Cladophora sp	4,00	1,00	0,57	#######	1,62	88,75
Laomedea spp	8,00	4,00	0,47	#######	1,35	90,10

Groups 10_5-9 & 11_5-9

Average dissimilarity = 40,16

	Group 10_5-9	Group 11_5-9				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Spirorbis spp.	10,00	0,00	2,18	#######	5,43	5,43
Cryptosula pallasiana	8,00	0,00	1,95	#######	4,85	10,28
Audouniella sp.	8,00	0,00	1,95	#######	4,85	15,14
Chondrus crispus	8,00	0,00	1,95	#######	4,85	19,99
Hydroides norvegica	6,00	0,00	1,69	#######	4,20	24,20
Ciona intestinalis	5,00	0,00	1,54	#######	3,84	28,04

Table 14. cont.

Membranipora membranacea	4,00	0,00	1,38	#######	3,43	31,47
Balanus spp.	0,00	4,00	1,38	#######	3,43	34,90
Pterothamnion plumula	0,00	4,00	1,38	#######	3,43	38,33
Ulva lactuca	0,00	4,00	1,38	#######	3,43	41,77
Furcellaria/Polyides	0,00	4,00	1,38	#######	3,43	45,20
Laomedea spp	1,00	8,00	1,26	#######	3,14	48,34
Rhodomela confervoides	1,00	8,00	1,26	#######	3,14	51,48
Styela rustica	2,00	0,00	0,97	#######	2,43	53,90
Escharella immersa	2,00	0,00	0,97	#######	2,43	56,33
Bryozoa indet. encrusting	2,00	0,00	0,97	#######	2,43	58,76
Anomoniidae indet.	2,00	0,00	0,97	#######	2,43	61,19
Cystoclonium purpureum	0,00	2,00	0,97	#######	2,43	63,61
Brongniartella byssoides	0,00	2,00	0,97	#######	2,43	66,04
Cladophora rupestris	0,00	2,00	0,97	#######	2,43	68,47
Bonnemaisonia hamifera: sporp.	19,00	10,00	0,82	#######	2,05	70,52
Pomatoceros triqueter	10,00	4,00	0,80	#######	2,00	72,52
Heterosiphonia japonica	10,00	4,00	0,80	#######	2,00	74,51
Prostheceraceus vittatus	1,00	0,00	0,69	#######	1,72	76,23
Urticina felina	0,00	1,00	0,69	#######	1,72	77,95
Leptasterias mulleri	1,00	4,00	0,69	#######	1,72	79,66
Littorina littorea	0,00	1,00	0,69	#######	1,72	81,38
Polyplacophora indet.	1,00	0,00	0,69	#######	1,72	83,10
Disporella hispida	1,00	0,00	0,69	#######	1,72	84,81
Buccinum undatum	1,00	0,00	0,69	#######	1,72	86,53
Sargassum muticum	1,00	0,00	0,69	#######	1,72	88,24
Dilsea carnosa	1,00	0,00	0,69	#######	1,72	89,96
Asterias rubens	10,00	5,00	0,64	#######	1,59	91,55

Groups 10_10-14 & 11_10-14

Average dissimilarity = 34,14

	Group 10_10-14	Group 11_10-14				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Phyllophora crispa	7,00	0,00	1,96	#######	5,73	5,73
Laomedea spp	0,00	6,00	1,81	#######	5,31	11,04
Pterothamnion plumula	0,00	6,00	1,81	#######	5,31	16,34
Bonnemaisonia hamifera: sporp.	11,00	2,00	1,41	#######	4,12	20,46
Leptasterias mulleri	2,00	10,00	1,29	#######	3,79	24,25
Laminaria saccharina	0,00	3,00	1,28	#######	3,75	28,00
Ciona intestinalis	17,00	6,00	1,24	#######	3,63	31,63
Halichondria panicea	1,00	6,00	1,07	#######	3,14	34,77
Tubularia sp.	0,00	2,00	1,05	#######	3,06	37,83
Mytilus edulis	0,00	2,00	1,05	#######	3,06	40,89
Hydroides norvegica	2,00	0,00	1,05	#######	3,06	43,96
Hydroida indet.	2,00	0,00	1,05	#######	3,06	47,02
Crisiella producta	2,00	0,00	1,05	#######	3,06	50,08
Cryptosula pallasiana	2,00	0,00	1,05	#######	3,06	53,15
Polysiphonia stricta	0,00	2,00	1,05	#######	3,06	56,21
Phyllophora pseudoceranoides	0,00	2,00	1,05	#######	3,06	59,27
Audouniella sp.	2,00	0,00	1,05	#######	3,06	62,34
Chondrus crispus	2,00	0,00	1,05	#######	3,06	65,40
Heterosiphonia japonica	2,00	6,00	0,77	#######	2,24	67,64
Porifera indet.: encrusting	1,00	0,00	0,74	#######	2,17	69,81

Table 14. cont.

Prosobranchia indet. juv.	0,00	1,00	0,74	#######	2,17	71,98
Urticina felina	0,00	1,00	0,74	#######	2,17	74,14
Marthasterias glacialis	1,00	0,00	0,74	#######	2,17	76,31
Nassarius reticulatus	0,00	1,00	0,74	#######	2,17	78,47
Bryozoa indet. encrusting	1,00	0,00	0,74	#######	2,17	80,64
Rhodomela confervoides	0,00	1,00	0,74	#######	2,17	82,81
Laminaria sp. juv.	0,00	1,00	0,74	#######	2,17	84,97
Ceramium spp	0,00	1,00	0,74	#######	2,17	87,14
Buccinum undatum	7,00	3,00	0,68	#######	1,98	89,12
Sagartiidae indet.	12,00	7,00	0,61	#######	1,77	90,89

Groups 10_15-18 & 11_15-18

Average dissimilarity = 32,86

	Group 10_15-18	**Group 11_15-18**				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Phyllophora sp.	0,00	8,00	7,48	#######	22,76	22,76
Ciona intestinalis	3,00	0,00	4,58	#######	13,94	36,70
Sabella penicillus	0,00	2,00	3,74	#######	11,38	48,09
Laomedea spp	0,00	2,00	3,74	#######	11,38	59,47
Buccinum undatum	2,00	0,00	3,74	#######	11,38	70,85
Caryophyllia smithii	2,00	0,00	3,74	#######	11,38	82,23
Leptasterias mulleri	0,00	1,00	2,64	#######	8,05	90,28

Table 15. SIMPER-analysis. Algae- and animal species/taxa that contribute most to the dissimilarities in the different depth intervals (0-1 m and 2-3m) in the transect registration at station 2 in 2009, 2010 and 2011.

Groups 09_0-1 & 10_0-1

Average dissimilarity = 40,06

	Group 09_0-1	Group 10_0-1				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Ulva spp.	5,00	0,00	2,50	#######	6,24	6,24
Pomatoceros triqueter	0,00	4,00	2,24	#######	5,59	11,83
Balanus spp	0,00	4,00	2,24	#######	5,59	17,41
Kisel/Cyano på fjell	4,00	0,00	2,24	#######	5,59	23,00
Polysiphonia fucoides	0,00	4,00	2,24	#######	5,59	28,58
Halichondria panicea	2,00	0,00	1,58	#######	3,95	32,53
Leptasterias mulleri	2,00	0,00	1,58	#######	3,95	36,48
Membranipora membranacea	0,00	2,00	1,58	#######	3,95	40,43
Rhodomela confervoides	2,00	0,00	1,58	#######	3,95	44,38
Sphacelaria cirrosa	0,00	2,00	1,58	#######	3,95	48,33
Campanularia johnstoni	2,00	0,00	1,58	#######	3,95	52,28
Heterosiphonia spp	2,00	0,00	1,58	#######	3,95	56,23
Ahnfeltia plicata	2,00	0,00	1,58	#######	3,95	60,18
Bonnemaisonia hamifera: sporp.	0,00	2,00	1,58	#######	3,95	64,13
Callithamnion corymbosum	0,00	2,00	1,58	#######	3,95	68,08
Chaetomorpha linum	2,00	0,00	1,58	#######	3,95	72,03
Cladophora albida	2,00	0,00	1,58	#######	3,95	75,98
Cruoria pellita	0,00	2,00	1,58	#######	3,95	79,93
Dumontia contorta	2,00	0,00	1,58	#######	3,95	83,88
Ceramium spp	6,00	2,00	1,16	#######	2,89	86,77
Sagartiidae indet.	0,00	1,00	1,12	#######	2,79	89,56
Ulva lactuca	2,00	4,00	0,66	#######	1,64	91,19

Groups 09_2-3 & 10_2-3

Average dissimilarity = 47,63

	Group 09_2-3	Group 10_2-3				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Membranipora membranacea	0,00	4,00	2,00	#######	4,20	4,20
Pomatoceros triqueter	0,00	4,00	2,00	#######	4,20	8,39
Rhodomela confervoides	0,00	4,00	2,00	#######	4,20	12,59
Balanus spp	0,00	4,00	2,00	#######	4,20	16,79
Bryozoa indet. encrusting	0,00	4,00	2,00	#######	4,20	20,99
Erythrothrichia carnea	4,00	0,00	2,00	#######	4,20	25,18
Ulva spp.	3,00	0,00	1,73	#######	3,63	28,82
Botryllus schlosseri	0,00	3,00	1,73	#######	3,63	32,45
Dynamena pumila	0,00	2,00	1,41	#######	2,97	35,42
Halichondria panicea	0,00	2,00	1,41	#######	2,97	38,39
Metridium senile	0,00	2,00	1,41	#######	2,97	41,36
Mytilus edulis	0,00	2,00	1,41	#######	2,97	44,33
Spirorbis sp.	0,00	2,00	1,41	#######	2,97	47,29
Sargassum muticum	0,00	2,00	1,41	#######	2,97	50,26
Ascidiacea indet.	0,00	2,00	1,41	#######	2,97	53,23

Table 15. cont.

Campanularia johnstoni	2,00	0,00	1,41	#######	2,97	56,20
Hildenbrandia rubra	2,00	0,00	1,41	#######	2,97	59,17
Phyllophora pseudoceranoides	2,00	0,00	1,41	#######	2,97	62,13
Polysiphonia elongata	0,00	2,00	1,41	#######	2,97	65,10
Audouniella sp.	2,00	0,00	1,41	#######	2,97	68,07
Brunt på fjell - mørkt	2,00	0,00	1,41	#######	2,97	71,04
Ectocarpales	2,00	0,00	1,41	#######	2,97	74,01
Carcinus maenas	1,00	0,00	1,00	#######	2,10	76,10
Pagurus sp.	1,00	0,00	1,00	#######	2,10	78,20
Rhizoclonium riparium	0,00	1,00	1,00	#######	2,10	80,30
Ulva lactuca	1,00	4,00	1,00	#######	2,10	82,40
Alcyonidium spp	1,00	0,00	1,00	#######	2,10	84,50
Furcellaria lumbricalis	0,00	1,00	1,00	#######	2,10	86,60
Phycodrys rubens	1,00	0,00	1,00	#######	2,10	88,70
Bonnemaisonia hamifera: sporp.	2,00	5,00	0,82	#######	1,72	90,42

Groups 10_0-1 & 11_0-1

Average dissimilarity = 30,36

	Group 10_0-1	**Group 11_0-1**				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Pomatoceros triqueter	4,00	0,00	2,61	#######	8,59	8,59
Chondrus crispus	4,00	0,00	2,61	#######	8,59	17,17
Cryptosula pallasiana	2,00	0,00	1,84	#######	6,07	23,24
Halichondria panicea	0,00	2,00	1,84	#######	6,07	29,31
Membranipora membranacea	2,00	0,00	1,84	#######	6,07	35,38
Sphacelaria cirrosa	2,00	0,00	1,84	#######	6,07	41,45
Alcyonidium spp	2,00	0,00	1,84	#######	6,07	47,52
Kisel/Cyano på fjell	0,00	2,00	1,84	#######	6,07	53,60
Ahnfeltia plicata	0,00	2,00	1,84	#######	6,07	59,67
Bonnemaisonia hamifera: sporp.	2,00	0,00	1,84	#######	6,07	65,74
Cladophora rupestris	0,00	2,00	1,84	#######	6,07	71,81
Cruoria pellita	2,00	0,00	1,84	#######	6,07	77,88
Ectocarpales	2,00	0,00	1,84	#######	6,07	83,95
Fucus serratus	7,00	2,00	1,60	#######	5,29	89,24
Polysiphonia fucoides	4,00	2,00	0,76	#######	2,51	91,75

Groups 09_2-3 & 11_2-3

Average dissimilarity = 40,52

	Group 09_2-3	**Group 11_2-3**				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Balanus spp	0,00	5,00	2,48	#######	6,13	6,13
Electra pilosa	4,00	0,00	2,22	#######	5,48	11,61
Pomatoceros triqueter	0,00	4,00	2,22	#######	5,48	17,09
Erythrothrichia carnea	4,00	0,00	2,22	#######	5,48	22,57
Mytilus edulis	0,00	3,00	1,92	#######	4,75	27,32
Ulva spp.	3,00	0,00	1,92	#######	4,75	32,07
Dynamena pumila	0,00	2,00	1,57	#######	3,88	35,94
Halichondria panicea	0,00	2,00	1,57	#######	3,88	39,82

Table 15. cont.

Botrylloides leachi	0,00	2,00	1,57	#######	3,88	43,69
Furcellaria lumbricalis	0,00	2,00	1,57	#######	3,88	47,57
Hildenbrandia rubra	2,00	0,00	1,57	#######	3,88	51,44
Phyllophora pseudoceranoides	2,00	0,00	1,57	#######	3,88	55,32
Audouniella sp.	2,00	0,00	1,57	#######	3,88	59,20
Dasya baillouviana	2,00	0,00	1,57	#######	3,88	63,07
Ectocarpales	2,00	0,00	1,57	#######	3,88	66,95
Carcinus maenas	1,00	0,00	1,11	#######	2,74	69,69
Pagurus sp.	1,00	0,00	1,11	#######	2,74	72,43
Pterothamnion plumula	0,00	1,00	1,11	#######	2,74	75,17
Sphacelaria cirrosa	0,00	1,00	1,11	#######	2,74	77,91
Phycodrys rubens	1,00	0,00	1,11	#######	2,74	80,65
Polysiphonia stricta	0,00	1,00	1,11	#######	2,74	83,39
Delesseria sanguinea	1,00	4,00	1,11	#######	2,74	86,13
Littorina littorea	2,00	4,00	0,65	#######	1,61	87,74
Asterias rubens	2,00	4,00	0,65	#######	1,61	89,34
Bonnemaisonia hamifera: sporp.	2,00	4,00	0,65	#######	1,61	90,95

Appendix C.

GPS positions for the biological stations (WGS 84)

Station	Latitude	Longitude
St. 1	N59° 32.538’	E10° 33.875’
St. 2	N59° 32.626’	E10° 33.887’
St. 3	N59° 32.631’	E10° 33.911’
St. 4	N59° 32.630’	E10° 33.925’
G1	N59° 32.318’	E10° 24.691’

GPS positions for the CTD stations (WGS 84)

Station	Latitude	Longitude
TOF-1	N59° 32.618’	E10° 33.924’
TOF-2	N59° 32.553’	E10° 33.937’
TOF-3	N59° 32.538’	E10° 33.929’
TOF-4	N59° 32.416’	E10° 33.996’
Im2	N59° 37.322’	E10° 37.693’
OF-5	N59° 29.22’	E10° 27.48’
OF-7	N59° 35.4’	E10° 38.4’

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