Potential influence of effluents from Longyearbyen on the benthic fauna in Adventfjorden, Svalbard

Jan Wiggo Dahl

Master's thesis in Fishery Sciences discipline fisheries biology

(60 credits)

Department of Aquatic BioSciences

Norwegian College of Fisheries Science

University of Tromsø

Spring 2007

Abstract

Benthic macrofaunal communities, sampled in 1998 end 2005 in Adventfjorden, a small side-arm to the Isfjord-complex on Svalbard, were compared. The samples were collected in various distances from the main sewage discharge point from the settlement of Longyearbyen. Four locations were sampled each year in order to investigate if the increased organic effluents from Longyearbyen had affected benthic community structure. The results showed that diversity indexes were generally low with the lowest values at the innermost locality in 2005. An inner community was recognised with high abundance of especially the opportunistic polychaetes *Capitella capitata* and *Chaetozone* sp.. *Capitella capitata* disappear and the abundance of opistobranch *Cylichna* sp., the polychaete *Thyasira gouldi* and the contaminant sensitive polychaete *Maldane sarsi* increases towards the fjord mouth. The innermost station in 2005 showed higher influence of organic pollution compared to 1998 indicated by the considerably higher abundance of *Capitella capitata.*

Keywords: Arctic, benthic macrofauna, organic pollution, *Capitella capitata, Chaetozone* sp.

Introduction

Pollution in the Arctic has in the recent years received much attention (Gabrielsen & Henriksen 2001). Different pollutants can be carried long distances by air - and water-currents and end up in Arctic environments (Burkow & Kallenborn 1998) , and/or they may come from local sources (AMAP 2002). Community structure is often used to evaluate the condition of ecosystems and it is well known that studies of the composition of marine benthic communities can give information about the impacts of pollution on the environment. Also, some benthic species with certain characteristics have been used as indicator species of pollution. Such species are among others found within the polychaetes (Pearson & Rosenberg 1978). Examples of such polychaetes from Arctic areas are found within the genera *Capitella* and *Chaetozone* (Holte et al. 1996; Holte & Gulliksen 1998). The families Capitellidae and Spionidae are also known to be abundant in organically enriched areas (Pearson & Rosenberg 1978). However, it is difficult to separate the effects of natural variation on community parameters from variation due to pollution and other man-made impacts. Both physical (e.g sedimentation, water temperature, salinity) and biological factors (e.g predation and competition for space) may cause variation in community composition (Cochrane et al. 1998).

In 1996 the governor of Svalbard initiated and financed studies of benthic communities in Isfjorden on the west side of Svalbard. The main objective was to evaluate the effect of marine pollution on benthic communities. The Tromsø-based firm Akvaplan-niva was given the commission, and several sites in the Isfjord were investigated (Cochrane et al. 2001). In 2005, a follow-up study was performed in Adventfjorden . The present paper is based on data from sampling sites in Adventfjorden, a side-arm of Isfjorden where the settlement Longyearbyen is located. The aim of this study was to assess if effluents from Longyearbyen influence the marine environment and if there had been changes (natural or anthropogenic) in the benthic fauna from 1998 to 2005.

Materials and methods

Study site

The Adventfjord (Fig.1) is a side-arm to the relatively wide and 120 km long Isfjord. It hosts the settlement Longyearbyen. The about 8 km long Adventfjorden has no significant sill and the maximum depth is approximately 80 m.

The lack of a sill in Adventfjorden promotes good water circulation in the fjord, and good connection with the outside Isfjorden, even though a large input of fresh water in the melting season can reduce the vertical circulation in Adventfjorden (Holte et al. 1996). The water masses in Isfjorden are influenced both by the West Spitsbergen Current (Atlantic water) and the South Cape Current (Arctic water) (Loeng 1991, Berge et al. 2005).

The fjords on Svalbard are known to have high inorganic sedimentation. Sedimentation rates up to 35 cm/ year have been measured close to glaciers (Holte & Gulliksen 1998; Gorlich et al. 1987). High amounts of inorganic particles are brought to Advendtfjorden via the rivers from Longyearbreen and Advendtdalen, and by wind from Advendtdalen (pers.obs), but exact measurements of this transport are unfortunately not available. Adventfjorden receives sewage from the Longyearbyen settlement.

Longyearbyen has increased its population from about 1500 in 1998 to about 1900 in 2005. The number of overnight stays per year has increased from about 46000 in 1998 to approximately 77000 in 2005 (Personal communication from Svalbard Reiseliv), due to increased tourism. The untreated sewage from Longyearbyen had four outlets in the fjord during the period of investigation. After September 2005, it was changed to two outlets.

Sampling and Environment

Sampling was performed in September 1998 and 2005 with a van Veen $0.1 m^2$ grab at four stations (Table 1), in a gradient from near the main sewage discharge point in the inner part of the fjord to the outer part (Fig.1). Depth on the various sampling stations varied from 29 to 80 m (Table 1). The temperature in Adventfjorden in September 2005 at the investigated four sampling stations (Fig.1) was from 1 ° - 2,5°C and the salinity between 33,5 to 34,5 ppt (Velvin et al. 2006). The water-masses were quite homogeneous with little variation with depth (CTD-measurements, Velvin et al. 2006). This indicates good mixing of water in the whole water column. The velocity of the water current was measured near station 13 (Fig. 1), and recorded values at ca 25 and 10 m depth varied between 2,3 cm/s to 13 cm/s with a main water current going in south-west direction (Velvin et al. 2006).

Sampling was done in accordance with Norwegian Standard (NS 9423 1998). Three grab-samples were taken from each of the sampling stations in 1998 (totally 12 samples). In 2005, this number was increased to four samples at each station, giving a total of 16 samples. The grab-samples were sieved through sieves with a mesh size of 1.0 mm (round holes), thus only the macrofauna was retained. After sieving, the samples were transferred to buckets with seawater, before formaldehyde (neutralized with borax) was added to conserve the samples.

Rose Bengal was added to separate the benthic macrofauna from inorganic particles (the Rose Bengal was dissolved in the added formaldehyde). Sampling was carried out from the ships Polarsyssel (1998) and Nordsyssel (2005), and the exact positions of sampling stations were found using the GPS equipment of the ships.

Treatment of samples

In the laboratory, the fauna was first sorted out from the sediment and separated in main phyla. The organisms were then identified to the lowest taxonomic taxa possible.

Analysis of granulometry and total organic carbon (TOC)

Analysis of grain size was carried out by splitting the samples in a coarse (>0.063 mm) and a fine (< 0.063 mm) subsample by wet sieving. These subsamples were then dried and weighed. The total organic carbon (TOC) was found by using a carbonanalyser on the dry samples. The carbon content was calculated by measuring the CO_2 content that emitted during the combustion process. Both analyses were conducted by GeoGruppen Tromsø.

Statistical analyses

Univariate analysis was performed using the Primer program (Clarke & Warwick 1994). The following parameters were calculated:

- Shannon-Wiener index (H`), which indicates faunal diversity.
- Pielou index, which indicates faunal evenness.
- Hurlbert ES 100, which indicates the expected number of species in a hypothetical sample of 100 individuals

Multivariate analyses on replicate level were conducted in full using the program R (www.r.project.org). The datasets from 1998 and 2005 were combined in the same analysis. Environmental data was standardized to eliminate effect of differences, e.g. weight and depth.

Species that amounted less to than 5 % of the total number were left out from the multivariate analyses in an attempt to limit the number of species because several species were only recorded once or twice.

A Bray-Curtis analysis (presented as a dendrogram) was conducted in order to get a biological interpretation of the stations combined. 3-D nonmetric multidimensional scaling (NMDS) was used with the Bray-Curtis index as distance measure, showing the dispersion of the stations, according to fauna, with the most similar closest together.

A Correspondence Analysis (CA) was based on the species abundance data. A Canonical Correspondence Analysis (CCA) was conducted to combine both species and all the environmental data. The environmental data included depth, mud (% < 0.063 mm), and total organic carbon (TOC). Since (CCA) is based on the correspondence analysis (CA), it is natural that (CA) is also included in a such study (Fieler et. al 1994, Cochrane et al. 1998). Canonical correspondence analysis (CCA) was used to assess the relationship between species abundance and the chemical and physical characteristics of the sediment.

An ANOVA analysis was carried out in “R”, using the Monte Carlo permutation test to test the null hypothesis of no difference between the sites from 1998 to 2005.

Results

Fauna

1998

Totally, 72 taxa and 9745 individuals were identified from the twelve samples (= 1.2m$^{2)}$ in 1998 (Appendix 1). Polychaeta was the most abundant class, and comprised 42 % of the identified taxa and 82 % of the individuals. Bivalves made up 23 % of the taxa and 14 % of the individuals. Polychaetes comprised from 88 % of the individuals on station 14 to 76 % on station 13. Bivalves ranged from 19 % on station 15 to 7 % on station 14.

Fewest taxa (32 taxa) were recorded at the innermost station, station.13 (Appendix 1) near the main sewage outlet from Longyearbyen. Most abundant here were the polychaetes *Chaetozone* sp. and *Cossura longocirrata.* On station 14, 37 taxa were found and *Chaetozone* sp. and *Cossura longocirrata* were also most abundant on this station*.* On station 15, 40 taxa were found and the two most abundant taxa were *Chaetozone* sp. and the bivalve *Axinopsida orbiculata.* On station 16, 50 taxa were recorded and the two most abundant taxa were the polychates *Chaetozone* sp. and *Aphelochaeta* sp. Thus, the polychaete *Chaetozone* sp. was most abundant on all stations. The polychaetes *Cossura longocirrata, Aphlochaeta* sp., *Heteromastus filiformis,* and the bivalve *Axinopsida orbiculata* were also represented among the top ten most abundant taxa on all stations (Tab.3).

The highest number of individuals was found on station 15 with 3328 individuals and lowest on station 16 with 1805 individuals. Station 16 comprised 70 % of the total number of taxa reported in 1998 and station 13 comprised 45 %.The four most abundant taxa on station

15 comprised 87 % of the individuals on that station while the four most abundant taxa on station 16 comprised fewest individuals with 70 % on that station (Appendix 1).

The Shannon-Wiener diversity index varied between 2.3 to 3.4 (Table 2). The highest value was recorded at the outermost sampling station in the fjord (Station 16) while the index varied between 2.3 – 2.8 at the three other stations. The Pielou coefficients were quite low, ranging from 0.4 to 0.6 with the highest values on the innermost and outermost stations. The Hurlbert ES 100 increased from 12 on the innermost station to 20 on the outermost station.

2005

The 16 samples (=1.6 $m^{2)}$ from 2005 contained totally 74 taxa and 8762 individuals (Appendix 2). As in 1998, polychaetes were most abundant with 43 % of the taxa and 74 % of the individuals. Bivalves contributed to 23 % of the taxa and 14 % of the individuals. Polychaetes comprised from 87 % of the individuals on station 13 to 53 % of the individuals on station 15. Bivalves ranged from 27 % of the individuals on station 16 to 10 % of the individuals on station 14. Malacostracan crustaceans and opistobranchs contributed respectively 8 % and 3 % of the total taxa. However, malacostracans only contributed to less than 1 % of the total individuals while opistobranchs constituted 9 % of the total individuals (where *Cylichna* sp. was the dominating species).

Station 13 yielded 39 taxa, and most abundant were the polychaetes *Capitella capitata* followed by *Chaetozone* sp. On station 14, fewest taxa (25) were recorded, with *Chaetozone* sp. and the opistobranch *Cylichna* sp. as the most abundant species (Tab 3, Appendix 2). On station 15, most taxa (45) were found, and most abundant were *Chaetozone* sp. and *Cylichna* sp. On station 16, 41 taxa were recorded and most abundant were the two polychaetes

Chaetozone sp. (as at station 14 and 15) and *Maldane* sarsi. The bivalve *Macoma calcarea* was among the top ten most abundant species at all station, but not within the top five at any of the stations. The two polychaetes *Maldane sarsi* and *Axionice flexuosa* were only recorded at the two outer localities in the fjord.

The number of individuals varied from 4187 on station 13 to 1235 on station 16 (Appendix 2). Station 15 comprised 61 % of the total taxa and station 14 comprised 34 % of the total taxa. The four most abundant taxa on station 13 comprised 90 % of the individuals on that station and there was a decreasing gradient to station 16, where the four most abundant taxa accounted for 61 % of the individuals on that station.
Shannon-Wiener index increased from 1.9 on station 13 to 3.7 on station 16 (Table 2). Pielou increased from 0.4 on station 13 to 0.7 on station 16. Hurlbert ES 100 increased from 11 on station 13 to 20 on station 16. It has increased from 13 in 1998 to 17 in 2005 on station 15 although the positions on these two stations are not exactly the same these two years.

Comparison between 1998 and 2005

Capitella capitata have had a huge increase in abundance on station 13 from 1998 to 2005. *Chaetozone* sp. have had a decline in abundance on all stations from 1998 to 2005. *Aphelochaeta* sp. was found in huge abundance in 1998, especially on station 16, and was on the top ten lists on all stations in 1998, but decreased significantly in abundance from 1998 to 2005. Only 16 specimens were found on the outermost station in 2005 and on the other stations it was found from five to eleven specimens. The bivalve *Axinopsida orbiculata* was a top ten species on every station in 1998, but only a top ten on station 13, 14 and 16 in 2005, and have had a huge decrease on station 15. *Macoma calcarea* was represented as a top ten abundant on every station in 2005, but only on the top ten lists on the two innermost stations in 1998, even thought the number is pretty stable.

Heteromastus filiformis was represented on the top ten lists on all stations in 1998 and on the top ten lists of the three innermost stations in 2005. *Cossura longocirrata* was represented as a top ten abundant on every station in 1998, but had a huge decrease in abundance in the period 1998 - 2005, though it was still a top ten on station 14 in 2005. There were much less of the polychaetes *Aphelochaeta* sp. and *Cossura longocirrata* in 2005. It seems to be an increase in the abundance of opistobranch (*Cylichna* sp.*)* and an increase in the taxa of bivalves (*Thyasira gouldi,,Yoldia hyperborean, Ennucula tenuis*) towards the fjord mouth. Such pattern is not so obvious in the dataset from 1998 (Appendix 1 and 2). The species of *Cylichna* is called *Cylichna alba* in 1998 and *Cylichna* sp. in 2005. *Cylichna* was a top ten on station 13 and 14 in 1998 and a top ten on the three outermost stations in 2005, but were only recorded with three specimens on st.13, 2005. The polychaete *Caulleriela zetlandica* was on the top ten list on station 13,14 and 16, 1998. This species was not found in 2005. The bivalve *Ennucula tenuis* was on the top ten lists on station 14 and 15 in 2005. It was not found in 1998.

The Bray-Curtis cluster analysis (Fig.2) showed that the final merge of all samples into a single cluster took place at a dissimilarity level at about 95 %. Three main station groups can be discerned. Station 13, 1998, separated from the rest of the stations with about 95 % dissimilarity. Station 13, 2005, separated with a dissimilarity of about 90 %, and the rest of the stations fused together with a dissimilarity of about 83 %.There were a high degree of variation between the replicates collected on each station. The replicate four from station 13, 2005 had the highest dissimilarity from the other replicates on that station with more than 70 % dissimilarity and replicate one from station 13, 1998 with about 45 % dissimilarity, and replicate one from station 13, 2005, with about 40 % dissimilarity. Station 14, 15 and 16, 2005, fully clustered according to sampling stations, though replicate four from station 14 showed approximately 40 % dissimilarity. Station 14, 15 and 16, 1998, did not cluster in full, according to their respective stations. Replicate four from station 13, 2005, is also showed as an isolated replicate in the MDS plot (Fig.3). The MDS plot showed the dispersion between the stations (faunal dissimilarity). The more faunal dissimilarity, the more distance between the replicates. The replicates from station 13, 2005 showed the highest dispersion, followed by the replicates from station 13, 1998. The replicates from station 16, 2005 showed least dispersion.

The plot of the MDS is showing that there is a considerable degree of dissimilarity between the stations. The samples of station 15, 2005 group together, also station 16, 2005 group together. Most scattered are the samples from station 13, both in 1998 and 2005, station 16, 1998 and station 14 from 2005, indicating that there is a considerable faunal dissimilarity between the stations.

Correspondence analysis (CA) is showing the species relative to the stations (Fig.4). Each species is given a weight proportional to the overall abundance of the species. The Correspondence analysis emphasises that station 13, 2005 stands out from the rest of the stations. The first axis explains 32.6 % of the variations in the species data and that the second axis explains 21.6 % of the variation. Axis one is probably mud and TOC and axis two is probably depth. Station 13, 2005 follow axis one and the other stations follow axis two.

The Canonical Correspondence Analysis (CCA) shows that *Capitella capitata* is negatively correlated with both, depth, MUD and TOC (Fig.5). The replicates from station 13, 2005, stand out from the rest of the stations in both years. Both the CA and the CCA shows the same pattern regarding station 13, 2005. Axis one correlated with mud, TOC and depth.

Axis two is correlated with year, depth and TOC. The first axis explains 29.2 % of the variation in the species data and the second axis explains 12.8 % of the variation (Fig.5)

The ANOVA Monte Carlo permutation test showed a p-value of less than 0,005.This indicates that is a statistical ground to state that there has been a change in the fauna from 1998 to 2005.

Sediment

There were little variance between stations in grain size and TOC in the samples from 1998. (Tab.1). The percentage values for TOC ranged from a minimum of 2.19 % on station 14 to a maximum of 3.45 % on station 15. The values for mud varied from 93.14 % on station 16 to 99.30 % on station14.

In 2005 the values for mud ranged from 35.97 % on the innermost station to 98.75 % on station 14, and the values for TOC ranged from 0.89 % on the innermost station to 2.27 % on station 14.

Discussion

Comparison of 1998 &2005

Polychaetes were most abundant, both regarding number of taxa and number of individuals in both 1998 and 2005. *Chaetozone* sp. was most abundant at all stations in 1998 and at three of the four stations in 2005. However, at the innermost station (station 13), *Capitella capitata* was most numerous in 2005 with a density as high as 6545 individuals per m^2, and no other species showed higher density at any of the sampled stations in 2005. *Capitella capitata* was also recorded at this locality in 1998, but only with a mean of 213 individuals per m^2. *Capitella capitata* is often regarded as an opportunist (Pearson & Rosenberg 1978) and may occur in high numbers in environments with environmental stress. The occurrence of high numbers of *Capitella capitata* on station 13 may therefore indicate that a change in the environment may have taken place here between 1998 and 2005, and this is related to increased sewage discharges. The difference is clear, according to the permutation test ($p<0.005$).This change is also supported by the lower value of Shannon-Wiener diversity at station 13, a value of 1.9 in 2005 compared to 2.8 in 1998. TOC was low on station 13, but this station also had the coarsest sediment. It is known that coarse sediment may influence TOC. Organic material has a tendency to bind to finer sediment. It is expected higher TOC values in habitats influenced by sewage (Webber et al. 2003).

The diversity values at the outer station in Adventfjord, station 16, were 3.4 in 1998 and 3.7 in 2005. Values above 3.7 were not recorded at any of the other stations in any of the two years (Table 2). The relatively high values at station 16 indicate that the bottom organisms in the outer part of the fjord encounter a less stressful environment than organisms further into the fjord. This is also supported by the occurrence of species like *Maldane sarsi* and *Pectinaria hyperborea* on station 16. These species are more sensitive to environmental stress than other species, like the opportunist *Capitella capitata* (Pearson & Rosenberg 1978). The diversity indexes are relatively low and there is a gradient of decreasing diversity in the benthic community towards the fjord head in the results from 2005. This is not so obvious in the 1998 data except from the ES 100 index that shows the same pattern in both years (Tab.1). Hurlbert index (ES 100) below 18 and Shannon-Wiener index (H) below 3 is regarded as indications of poor environmental condition (Molvær et al.1997). It is also interesting to note that station 16 is the deepest station (80 m depth). Usually diversity decrease with depth in Arctic areas (Zenkevich 1963).

The tube-building polychaete *Maldane sarsi* was not found on the two innermost stations in 2005. In 1998, it was only on station 13 that it was not found. This may be due to high sedimentation rates, or the increased organic effluent. The grain size is maybe also a factor here. Station 13, 2005, had the coarsest sediment.

The results from the Bray-Curtis analysis (Fig.2) are showing the cluster grouping of individual replicates. Three main station groups can be identified and in particular station 13, both in 1998 and 2005, are separated from the other stations. There was a huge range in the inter-replicate variations at the stations, ranging from about 10 % (replicate 3 and 4 on station 15, 2005) to about 75% (replicate 4, which stands out on station 13, 2005). The replicates from st. 14, 15 and 16, 2005 clustered according to sampling stations. This indicates faunal similarity between the replicates on these stations. Two of the three replicates from both stations 14 and 15 in 1998 group together. This indicates faunal evenness among these. It is interesting to note that the station with the coarsest sediment type (st.13, 2005) showed the highest inter-replicate variations.

In 2005 the lowest diversity was found on the shallowest station, where it was a great majority of *Capitella capitata.* It is earlier found a lot of *Capitella capitata* and *Chaetozone* sp. on shallow areas in Adventfjorden (Holte et al. 1996). This species is probably well adapted to environmentally perturbations, which often occur in shallow water. Different types of stress (e.g organic enrichment, sedimentation, salinity) can reduce the fauna to species that are particular robust against such influence (Pearson & Rosenberg 1978). The innermost station had the coarsest sediment, which maybe can be explained by relatively strong currents and wind transported sand from land (pers.obs.). It can be considerably variation from year to year regarding this. The most coarse and heavy particles will not be transported as far as the finer particles regarding wind-blown sand. It has been reported that wind can transport huge amounts of particles from Longyearbyen (Holte et al.1996). Sejr et al. (2000) found that with the shift from sandy sediment on shallow parts to silty sediment on deeper parts in a fjord on east-Greenland the fauna structure changed gradually from filter-feeders to more deposit-feeders.

It is striking that the total organic carbon displayed the lowest value on the innermost station near the outlet with the highest value on the second outermost station. Low organic content in the sediment due to high inorganic sedimentation can contribute to reduced benthic fauna. Chareonpanich et al.(1994) found that *Capitella capitata* efficiently decomposed organic matter in the sediment. The digestible food supply is diluted by the inorganic deposition (Gorlich et al. 1987). Fjords in Arctic that are influenced by inorganic sedimentation have been reported to have a reduced benthic fauna in the innermost areas (Holte & Gulliksen 1998), even though it is also reported that areas in open waters east of Svalbard have reduced benthic fauna (Cochrane et al.1998). *Capitella capitata* was found in high abundance in samples collected in the same area of Adventfjorden as the samples in the present study in 1992. A high abundance of *Chaetozone/Tharyx* sp. was also recorded in 1992 (Holte et al.1996). There was a low abundance of *Capitella capitata* in the 1998 samples and a huge abundance in the 2005 dataset. Holte et al. (1996) found a high abundance of the bivalvia *Nuculoma tenuis* at depths of 18 and 26 m. A few individuals of this species were found in 1998, but no individuals were found in the samples from 2005. Holte et al. (1996) found highest abundance of the opistobranch *Cylichna sp.* on the outermost station. In Adventfjorden in 2005, it was found most of this species on the second outermost station. Holte et al. (1996) also found a high number of the bivalve *Thyasira dunbari* at 50 m, but there were few of this species in samples from both 1998 and the 2005. The polychaete

Scoloplos armiger was counted over hundred in Adventfjorden in 1992 (Holte et al. 1996), but was only found in 1 and 8 specimens in 1998 and 2005, respectively. This may indicate environmental change and more perturbations.

Weslawski et al. (1999) found high abundance of the polychaetes *Chaetozone/Tharyx* sp., *Cossura longocirrata* and the opistobranchi *Cylichna occulta* at depths from 45 to 67 m in Adventfjorden. On another site of the Isfjord-complex (Yoldiabukta glacial bay), Wlodarska et al. (1999) found that the bivalve *Yoldiella fraterna* was the dominating species, but that also *Chaetozone setosa* were abundant. In samples collected outside the abandoned settlement Pyramiden , the bivalve *Yoldiella solidula* and the polychaete *Caulleriella zetlandica* were found in highest abundance, whereas outside Barentsburg *Chaetozone setosa*, *Maldane sarsi* and *Thyasira gouldi* was dominating (Cochrane et al. 2001). Sampling from Forlandsundet and Sassenfjorden showed highest abundance of the polychaete *Lumbrineris mixochaeta. Capitella capitata* is also found elsewhere in “non-human impacted” fjords in arctic, but not in high abundance (Wlodarska et al.1999, Cochrane et al.2001).
Gulliksen et al. (1985) found severe reduced complexity in fauna in the inner part of the Van Mijenfjord, a Svalbard fjord with a very high sedimentation rate. The most dominant species in the inner part of this fjord was the bivalve *Portlandia arctica.* Only four individuals of this species were found on the stations samples in Adventfjorden in 2005 and only one was found in 1998. This can be due to less sedimentation in Adventfjorden. Further out in the Van Mijenfjord, *Lumbrinereis* spp., *Chaetozone* sp. and *Scoloplos armiger* were most abundant. Only eight individuals of the polychaete *Scoloplos armiger* was only found in Adventfjorden in 2005 and one in 1998. The polychaete *Lumbrinereis mixochaeta* was only found in eleven specimens in Adventfjorden in 1998. In Raudfjord on the north west of Svalbard the situation was different, since the highest density was found at the innermost station, and there *Maldane sarsi* was dominating. Holte & Gulliksen (1998) suggested that the very low proportion of

tube-building polychates (e.g. *Maldane sarsi)* and the low occurrence of suspensivore species in the inner part of Van Mijenfjord were caused by a high inorganic sedimentation from the nearby glacier. Highest abundance was found of the polychaetes *Lumbrineris* sp. and *Chaetozone* spp. in both Van Mijenfjord and Raudfjord (Holte & Gulliksen 1998). Wlodarska-Kowalczuk & Pearson (2004) found two faunal communities in Kongsfjord (Spitsbergen), an inner and an outer community where the inner community was dominated by small bivalves (*Yoldiella solidula)* and *Chaetozone* group, and the outer group was dominated by larger, tube-dwelling polychaetes (among others *Maldane sarsi* and *Heteromastus filiformis*). *Yoldiella solidula* was only found in one specimen in Adventfjorden in 1998.Wlodarska-Kowlazcuk et al. (2005) found the lowest biomass in the fjord head of Kongsfjorden, closest to the glacier. The inner basin was dominated by small motile bivalves and polychaetes. They suggested that species composition were influenced to a considerable extent by the proximity to the glacier and not to depth. The tube-dwelling, burrowing polychaete *Maldane sarsi* was found in high abundance in the central basin. Wlodarska-Kowalczuk et al. (2004) found that species diversity decreased with depth in the Kongsfjordrenna and at depths below 1500 m it was not found over 20 species. The most abundant species at depth below 1500 m was the bivalve *Thyasira dunbari,* a species which also was found in a glacial bay in Kongsfjord (Wlodarska-Kowalczuk et al.2005). Twentyone and four individuals of this species were also found in samples from shallow depths in Adventfjorden in 2005 and 1998, respectively. This shows the huge range in environment where it can live. Kendall et al. (2003) found a decline in *Chaetozone setosa* with an increasing distance from the glacier in Kongsfjord.

It looks like organic effluents only affected station 13 in Adventfjorden, both in 1998 and 2005, but in much greater extent in 2005.The water currents are perhaps an important factor here. Station 13 is probably close (or closest) to what Pearson & Rosenberg (1978) called “peak of opportunists”, where the biomass of the fauna increase rapidly beyond the maximum pollution area, due to very high abundance of a few small opportunistic species that thrives in harsh environment. In polluted areas, K-strategists are often eliminated and r-strategist is prevailing (Warwick et al. 1987, Pearson & Rosenberg 1978). There have been a fluctuating abundance of *Capitella capitata* in Adventfjorden. Holte et al. (1996) found high abundance of this species in sampling in 1992, while Cochrane et al (2001) found much less in 1998. Causes of this may be several. The number of inhabitants and overnight stays may have stabilised before 1998 and caused that the amount of organic effluents have stabilised and that the fauna have adapted to the organic effluents. Pearson & Rosenberg (1978) stated that opportunistic species are short-lived and can have strong seasonal variations in abundance and that they can be reduced or disappear even if there occurs short-time changes in the environment.

Holte & Oug (1996) found distinct enriched zones characterized by a huge abundance of *Capitella capitata* near the city of Tromsø in northern Norway. It was suggested that these local effects were due to strong tidal currents that disperse the sewage matter over a large area (Holte et al.1987; Holte & Gulliksen 1987). Station 13 in Adventfjorden was not on exact same place in 1998 and 2005. This difference and also that currents may disperse the organic matter can be an important factor in the assessment of the two years. Holandsfjorden in northern Norway have two sills. The fjord has a relatively high inorganic sedimentation. The fauna in the fjord head have been reported to be dominated by the subsurface feeding detrivorous polychaetes *Scoloplos armiger* and the surface feeding detrivorous polychaetes, among others *Levinsenia gracilis* and *Chaetozone* spp. *Heteromastus filiformis* was abundant in Holandsfjorden, but only two individuals of this species were found in Svalbard fjords (Holte & Gulliksen 1997; Holte 1998). Larsen (1997) found that organic effluents had less influence on faunal diversity than the presence of a shallow sill. He found that sill fjords had generally lower diversities than open fjords or seaward side of the sills. It is reported from some north Norwegian fjords that among others *Maldane sarsi* and *Heteromastus filiformis* tended to increase with depth. It was suggested that this is probably due to change in physical factors and food supply. Waves and tidal currents may destabilize the sediments in shallow areas (Holte 2001; Holte et al.2004). Holte et al. (2005) found that organic effluent in three northern Norwegian sill fjords did not affect the fauna in a particularly way. This was probably due to strong water exchange, a more conspicuous feature in northern Norwegian fjords than in fjords further south.

Rygg (1985) investigated stations along the Norwegian coast and grouped the species in; (1) positive pollution indicators, which increase their dominance under pollution and (2) negative pollution indicators, which decrease and maybe disappear in polluted environment. He found that among others *Maldane sarsi was* a negative pollution indicator and that e.g *Chaetozone setosa, Cossura longocirrata, Capitella capitata* and *Heteromastus filiformis were* positive pollution indicators. *Maldane sarsi* was also suggested by Belan (2003) as a contaminant sensitive species and *Capitella capitata* as a contamint insensitive species in the Japan Sea. In a study from western Norway, it was found that *Capitella capitata* and *Heteromastus filiformis* showed high tolerance to organic pollution and that both *Capitella capitata* and *Heteromastus filiformis* were negatively correlated with increasing diversity (Airas & Rapp 2003).

It is documented from Mexico that *Capitella capitata* dominated in organic polluted areas (Mendez 2002). *Capitella capitata* is also known as a rapid coloniser after hypoxia (Rosenberg et al. 2002).

Bioturbators are known to destabilise sediment and increase oxygen level in the sediment and for that reason, increase the diversity in the fauna inhabiting the sediment. This species tend to be deposit-feeding, particle-sorting and show high degree of motility (Davis

1993; Cochrane et al.1998). Widdiscombe et al. (2004) found that bioturbators had a positive effect for the maintaining the biodiversity on soft-bottom fauna. It is a generally accepted view that bioturbation, or sedimentary reworking, is negative for suspension-feeders and tube-builders (Wilson 1991). In Adventfjorden, there were fewest suspension-feeders and tube-builders towards the fjord head, indicating a more perturbed area here. Wlodarska-Kowalczuk et al. (2005) stated that regardless of which type of disturbances (natural or anthropogenic), the pattern of response of the benthic community is the same, with a simplification of fauna structure and a decline in biomass, species richness and diversity.

Conclusions

The abundance of the opportunistic polychaete *Capitella capitata* was much higher on the station closest to main discharge point, both compared to the other stations and to the previous sampling that was carried out seven years earlier, even though one must have current conditions in mind. The opportunistic polychaete *Chaetozone* sp. was quite evenly distributed, both between station and between years. The benthic fauna in the inner part of Adventfjorden is different compared to other high-latitude fjords since it is dominated by *Capitella capitata*, which is not common in other arctic fjords. The fauna on the innermost station in Adventfjorden in 2005 displays a typical gradient of organic enrichment that is well known from literature (e.g Pearson & Rosenberg 1978) where reduced diversity occur as some species disappear and others bloom in enriched areas. This is often found in sites nearby discharge points. The species diversity and species richness was quite low on the innermost station, and there have been a decline in all of the species diversity indexes from 1998 to 2005 in the innermost part of Adventfjorden, even though lower indexes have been reported elsewhere in the Arctic (Wlodarska- Kowalczuk et al. 2004). The diversity increases towards the fjord mouth, followed by a disappearance of *Capitella capitata* and a gradual increase in contaminant sensitive species like *Maldane sarsi.*

All in all this indicates that there has been an increase in the organic effluents in Advenfjorden from 1998 to 2005. The increase in the discharge has in high extent influenced the benthic fauna, but the effect seems to be mostly connected to the inner part of the fjord.

Acknowledgements

I am grateful to Raul Primicerio and Rune Palerud for help with the statistical analyses, Bjørn Gulliksen, Anita Evenset, and Sten-Richard Birkely for guidance and comments to the manuscript, Frøydis Strand for helping me with the map, the crew of the ships of Nordsyssel and Polarsyssel and Akvaplan-niva for letting me participate in their project.

References

Airas S & Rapp HT (2003) Correlations between environmental gradients and the abundance of selected marine invertebrates. IFM rapport. 15 pp.

AMAP 2002. Arctic pollution (2002) Arctic Monitoring and Assessment Programme, Oslo, Norway, 112 pp

Belan T.A. (2003) Benthos abundance pattern and species composition in conditions of pollution in Amursky Bay (the Peter the Great Bay, the Sea of Japan). Mar Poll Bull. 1111-1116

Berge J, Johnsen G, Nilsen F, Gulliksen B, Slagstad D (2005) Ocean temperature oscillations enable reappearance of blue mussels *Mytilus edulis* in Svalbard after 1000 year absence. Mar. Ecol. Prog. Ser. 303 167-175

Burkow I.C & Kallenborn R (1998). Langtransport av miljøgifter til nordområdene. Ottar 219:24-28

Chareonpanich C, Tsutsumi H, Montani S (1994). Efficiency of the decomposition of organic matter , loaded on the sediment, as a result of the biological activity of *Capitella* sp. I Mar. Pollut. Bull. 28:314-318

Clarke KR & Warwick RM (1994) Change in marine communities: an approach to statistical analysis and interpretation. Natural Environment Research Council, UK. 144 pp.

Cochrane SJ, Næs K, Carrol J, Trannum HC, Johansen R, Dahle S (2001) Marin miljø-undersøkelse ved bosetningene Barentsburg, Longyearbyen og Pyramiden i Isfjorden, Svalbard. Akvaplan-niva. APN-report no.414.1466. 59 pp + appendix.

Cochrane, SJ., S. Dahle, Oug E, B. Gulliksen & S. Denisenko (1998) Benthic Fauna in the Northern Barents Sea. Akvaplan.niva. APN-report no. 414.97.1286. 35 pp + appendix

Davis,RD (1993) The role of bioturbation in sediment resuspensions and its interaction with physical shearing. J Exp mar Biol Ecol 171:187-200

Fieler R, Greenacre M J & Pearson T H (1994) Evaluation and development of statistical methods. Akvaplan-niva. APN-report no.92.347.01.03. 71 pp + appendix

Gabrielsen, GW; Henriksen, EO (2001) Persistent organic pollutants in Arctic animals in the Barents Sea area and at Svalbard: levels and effects. Memoirs of National Institute of Polar Research, 54, 349-364

Gorlich K, Weslawski JM, Zajackowski M (1987) Suspension settling effect on macrobenthos Biomass distribution in the Hornsund fjord, Spitsbergen. Polar Res 5:175-192

Gulliksen B, Holte B, Jakola K-J (1985) The soft bottom fauna in Van Mijenfjord and

Raudfjord, Svalbard. In: Gray JS, Christiansen ME (eds) Marine Biology of Polar Regions and Effects of Stress on Marine Organisms. Wiley, New York, pp 199-215

Holte B (2001) Possible ecological effects from maldanid (Annelida, polychaeta) "super-dominance" in a small North Norwegian sill system. Ophelia 55:69-75

Holte B, Oug E, Cochrane S (2004) Depth-related macrofaunal biodiversity patterns in three undisturbed north Norwegian fjords. Sarsia 89:91-101

Holte B, Oug E and Dahle S (2005) Soft-bottom fauna and oxygen fluctuasions in subarctic north Norwegian marine sill basins. Marine Biol Res. 85-96

Holte B, Gulliksen B (1998) Common macrofaunal dominant species in the sediments of some north Norwegian and Svalbard glacial fjords. Polar Biol 19:375-382

Holte, B., Dahle S, Gulliksen B & Næs K (1996) Some macrofaunal effects of local pollution and glacier-induced sedimentation, with indicative chemical analyses, in the sediments of two arctic fjords. Polar Biol 16:549:557

Holte, B & Oug E (1996) Soft-bottom macrofauna and responses to organic enrichment in the subarctic waters of Tromsø, northern Norway. Journal of Sea Research 36:227-237

Holte, B, Jakola K-J, Gulliksen B (1987) Benthic communities and their physical environment in relation to urban pollution from the City of Tromsø, Norway. 1. The physical environment hydrography, plant nutrients, organic enrichment, heavy metals, and redox conditions Sarsia 72:125-132

Holte, B & Gulliksen, B (1987) Benthic communities and their physical environment in relation to urban pollution from the City of Tromsø, Norway. 2. Soft-bottom communities Sarsia 72:133-141

Kendall MA, Widdiscombe S, Weslawski JM (2003) A multiscale study of biodiversity of the benthic infauna of the high-latitude Kongsfjord, Svalbard. Polar Biol 26:383-388

Larsen, L-H (1997) Soft-bottom macro invertebrate fauna of North Norwegian coastal waters with particular references to sill-basins. Part one: Bottom topography and species diversity. Hydrobiologia 355:101-113

Loeng H (1991) Features of the physical oceanographic conditions of the Barents Sea. Polar Research 10(1):5-18

Mendez N (2002) Annelid assemblages in soft bottoms subjected to human impact in the Urias estuary (Sinaloa, Mexico). Oceanologica Acta 25:139-147

Molvær J, Knutsen J, Magnusson J, Rygg B, Skei J, Sørensen J (1997) Klassifisering av miljøkvalitet i fjorder og kystfarvann. Kortversjon. SFT-veiledning 97:03.36pp

NS 9423 (1998) Norsk standard for vannundersøkelse. Retningslinjer for kvantitative undersøkelser av sublittoral bløtbunnsfauna i marint miljø.

Pearson TH & Rosenberg R (1978) Macrobenthic succecsion in relation to organic enrichment and pollution of the marine environment. Mar.Biol.Ann.Rev.16:229-311

Rosenberg R, Agrenius S, Hellman B, Nilsson H C, Norling K (2002) Recovery of marine benthic habitats and fauna in a Swedish fjord following improved oxygen conditions. Marine Ecology Progress Series 234:43-53

Rygg B (1985) Sammenheng mellom forurensningsgrad og forekomst av utvalgte arter av marin bløtbunnsfauna. Bruk av indikatorarter ved vurdering av forurensningtilstand. Niva-rapport 85121.36 pp.

Sejr MK, Jensen KT, Rysgaard S (2000) Macrozoobenthic community structure in a high-arctic East Greenland fjord. Polar Biol 23:792-801

Velvin R, Evenset A, Christensen G (2006) Akvaplan-niva (2006) APN report -412.3369. 36 pp

Warwick RM, Pearson TH and Ruswahyuni (1987) Detection of pollution effects on marine macrobenthos: further evaluation of the species abundance/biomass method. Marine Biology 95:193-200

Weslawski JM, Szymelfenig M, Zajaczkowski M and Keck A (1999) Influence of salinity and suspended matter on benthos of an Arctic tidal flat. ICES Journal of marine Science, 56 Supplement:194-202

Webber Dale F, Kelly Peter Wilson (2003) Characterization of Sources of Organic Pollution to Kingston Harbour, the Extent of Their influence and Some Rehabilitation Recommendations. Bulletin of Marine Science, vol.73, no.2, 257-271

Widdiscombe S, Austen MC, Kendall MA, Olsgard F, Schaanning MT, Dashfield SL, Needham HR (2004) Importance of bioturbators for biodiversity maintenance: indirect effects of fishing disturbance. Marine Ecology Progress Series Vol.275:1-10

Wilson WH (1991) Competition and predation in marine soft-sediment communities. Annu Rev Ecol Syst 21:221-241

Wlodarska-Kowalczuk M, Pearson TH, Kendall MA (2005) Benthic response to chronic natural physical disturbance by glacial sedimentation in an Arctic fjord. Marine Ecology Progress Series 303:31-41

Wlodarska-Kowalczuk M, Kendall MA, Weslawski JM, Klages M, Soltwedel T (2004) Depth Gradients of benthic standing stock and diversity on the continental margin at a high-latitude ice-free site (off Spitsbergen, 79 degrees N). Deep-Sea Research Part 1. Oceanographic Research papers, 51 (12):1903-1914

Wlodarska-Kowalczuk M, Pearson TH (2004) Soft-bottom macrobenthic faunal associations and factors affecting species distributions in an Arctic glacial fjord (Kongsfjord, Spitsbergen). Polar Biology 27 (3):155-167

Wlodarska-Kowalczuk M, Szymelfenig M & Kotwicki L (1999) Macro-and meiobenthic Fauna of the Yoldiabukta glacial bay (Isfjorden, Spitsbergen). Polish Polar Research. Vol.20.No.4:367-386

Zenkevich LA 1963 The Biology of the Seas of the USSR. Academy of Science of the USSR.

Moscow, Russia. 739 pp.

Legends to Figures, Tables and Appendix 1 and 2

Figure 1. Map of Adventfjorden, Longyearbyen, Longyearbreen, Adventdalen and the sampled stations in 1998 and 2005.

Figure 2. Dendrogram based on Bray-Curtis dissimilarity showing the results from the classification analysis of the fauna samples from 1998 and 2005 in Adventfjorden. L13198= Longyearbyen, station 13, sample 1, year 1998 etc.

Figure 3. 3-D nonmetric multidimensional scaling (NMDS) of the fauna samples from 1998 and 2005 in Adventfjorden, showing the samplings according to dispersion (faunal dissimilarity). L13198= Longyearbyen, station 13, sample 1, year 1998 etc.

Figure 4.Correspondence Analysis (CA) of the species from Adventfjorden in 1998 and 2005. The first CA axis accounted for 32.6 % of the variation and the second axis accounted for 21.6 %.

Figure 5. Canonical Correspondence Analysis (CCA) of the species from Adventfjorden in 1998 and 2005 together with the environmental variables depth, MUD (% < 0.063 mm) and total organic carbon (TOC). The open symbols shows the two years. The first CCA axis accounted for 29.2 % of the variation and the second axis accounted for 12.8 %.

Table 1.The positions (latitude, longitude) of the sampled stations, depth, total organic carbon (TOC) measured in wet weight and MUD.

Table 2. Number of individuals per m^2 (A) and taxa (S), Shannon-Wiener diversity index (H), Pielou index (P) and Hurlbert ES (100) index at the different stations.

Table 3. Listing of the top ten abundance taxa on the four stations in 1998 and 2005 per m^2. Phylum affiliation: A:Annelida, C: Crustacea, E: Echinodermata, M: Mollusca, N: Nemertini, Pr: Priapulida.

Appendix 1. Total number of individuals in three grab samples per station of the different species collected at the different stations in 1998 (1.2 $m^{2)}$. Abbreviations: ANNEL=

ANNELIDA, CNIDA= CNIDARIA, CRUST= CRUSTACEA, MOLLU= MOLLUSCA, NEMER =NEMERTINI, PRIAP= PRIAPULIDA, SIPUN= SIPUNCULIDA

Appendix 2. Total number of individuals in four grab samples per station of the different species collected at the different stations in 2005 (1.6 $m^{2)}$. Abbreviations: ANNEL= ANNELIDA, CNIDA= CNIDARIA, CRUST= CRUSTACEA, ECHIU= ECHIURIDA, MOLLU= MOLLUSCA, NEMAT= NEMATODA, NEMER= NEMERTINI, PLATY= PLATYHELMINTH, POGON= POGONOPHORA, PRIAP= PRIAPULIDA, TUNIC =TUNICATA

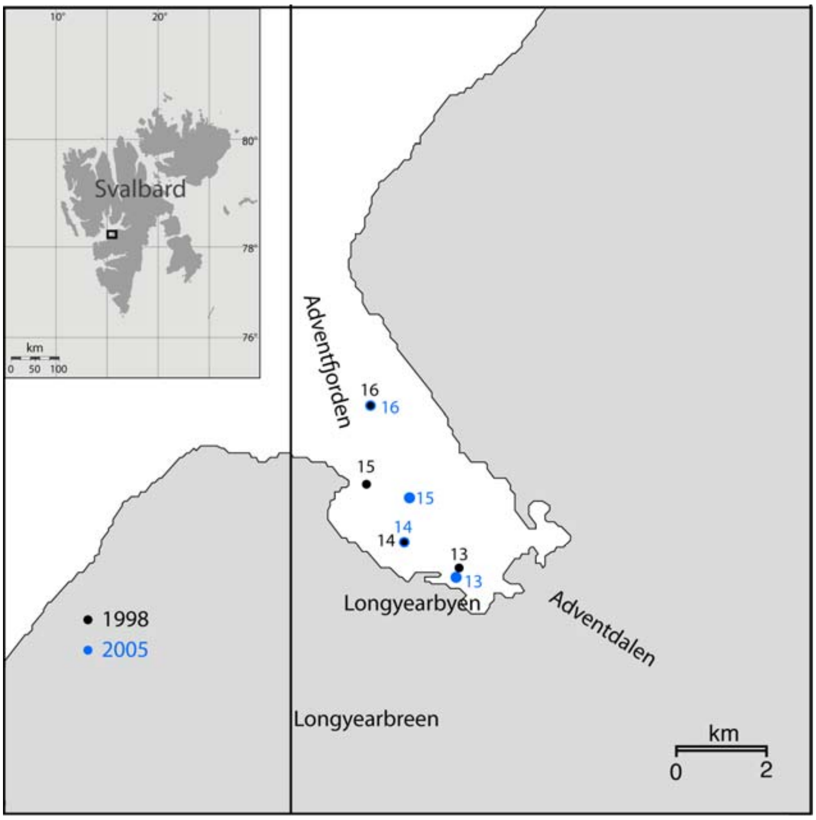
10°
20°
80°
Svalbard
78°
76°
km
0 50 100
Adventfjorden
16
16
15
15
14
14
13
13
Longyearbyen
Adventdalen
1998
2005
Longyearbreen
km
0
2

Fig.1

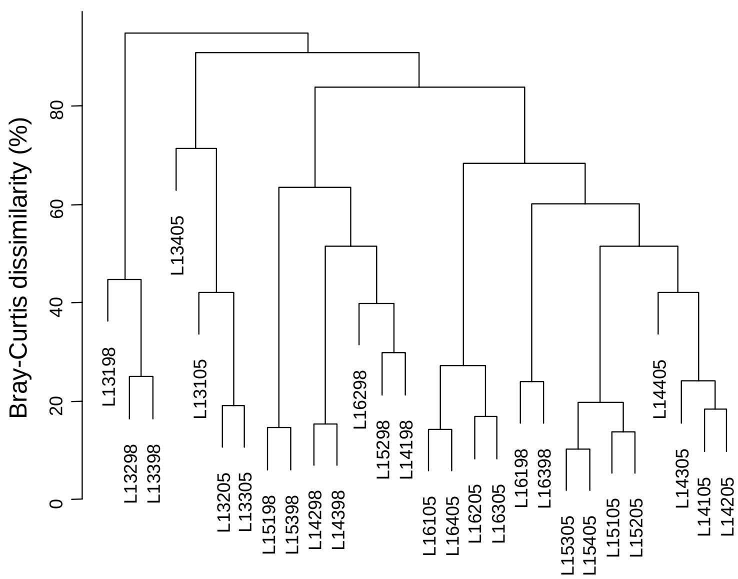
Bray-Curtis dissimilarity (%)
0
20
40
60
80
L13198
L13298
L13398
L13405
L13105
L13205
L13305
L15198
L15398
L14298
L14398
L16298
L15298
L14198
L16105
L16405
L16205
L16305
L16198
L16398
L15305
L15405
L15105
L15205
L14405
L14305
L14105
L14205

Fig.2

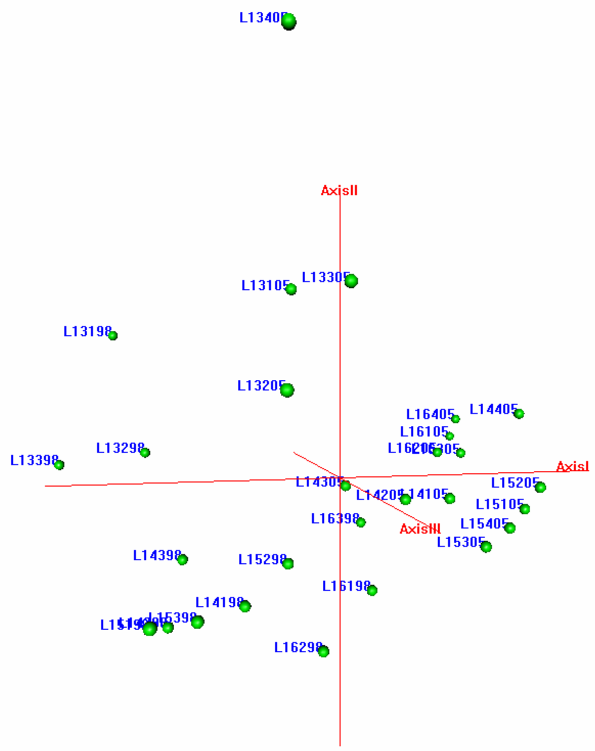
AxisII
AxisI
AxisIII
L13105
L13305
L13198
L13205
L16405
L14405
L16105
L13298
L13398
L14305
L15205
L14105
L15105
L16398
L15405
L15305
L14398
L15298
L16198
L14198
L16298

Fig.3

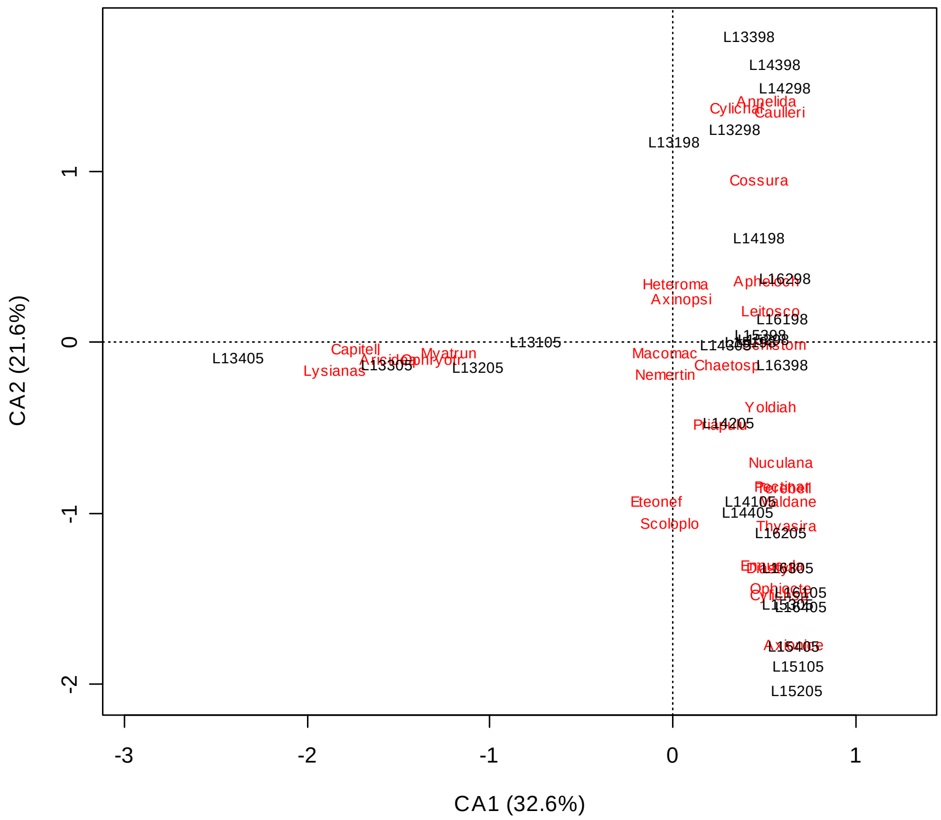

Fig.4

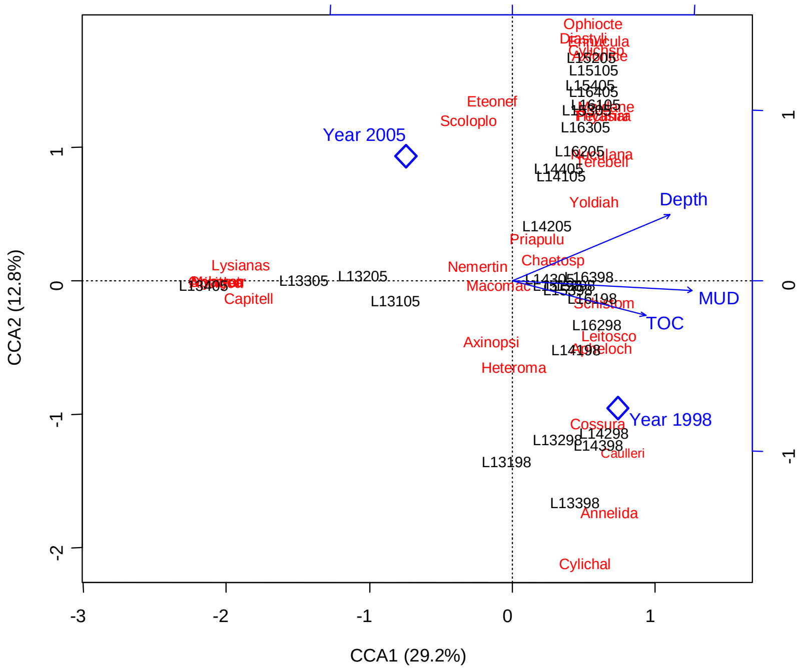

Fig.5

Formatert: Engelsk (Storbritannia)