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Benthic community distribution pattern in Sandnesfjorden

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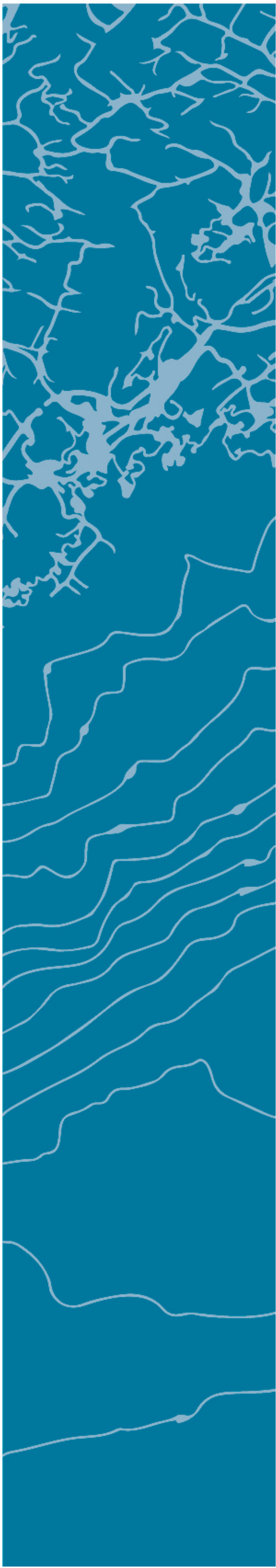

Abstract

In the marine environment, benthic macrofauna plays a crucial role in carbon and nutrient cycling, decomposition, and as prey items for higher-level consumers. The distribution and composition of macrofauna were studied in seven stations along the southern Norwegian Sandnesfjord. The sampling strategy employed four replications per station, limiting them to three inner replicates (A2 & A3). Similar to other studied Norwegian fjords, the polychaete and bivalvia were more abundant than gastropoda, echinoidea, crustacea, ophiuroidea, and "varia" in all stations. In this study, the diversity pattern was revealed by univariate analysis (Total and relative abundance, taxa richness, biomass, and various biodiversity indices) and multivariate analysis (Cluster analysis and nMDS). In total 3422 individuals and 100 species were recorded in the study. The individuals' numbers investigated in inner and outer stations range from 103 to 1172. Polycheates, such as *Pectinaria belgica, Pseudopolydora pulchra, Paramphinome jeffreysii, Scalibregma inflatum, Polycirrus plumosus, Jasmineira caudata,* and *Galathowenia oculata,* the bivalves *Thyasira flexuosa,* and *Corbula gibba,* and the gastropod *Turritella communis* were most important in terms of relative abundance and species composition, with different distributions along the gradient. The biomass of the groups ranged from (0.0284g to 49.19g) were polychaetes showed a considerably higher biomass than other groups. Clustering and ordination of the communities show the mid-inner communities share the highest similarity, followed by the inner stations. The outer stations, however, are less clustered together showing lowest similarity. The dominance of more tolerant polycheates and bivalves at the inner stations may be associated with the riverine inputs and associated nutrients, which is supported by the higher level of organic matter in the sediments. Further research on the impact of climate change and resampling in different seasons will better explain the observed results better.

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1 Introduction

The long Norwegian coastline extends from temperate regions in the South to an Arctic climate close to the Norwegian-Russian border in the North. The region is featured by various habitats providing a range of ecosystem goods and services: shelter, carbon sequestration, and climate regulation , with fjords playing an important role on those dynamics(Faust et al., 2017; Frigstad et al., 2020; Renaud et al., 2021) .Furthermore, coastal zones act as an ecological link between terrestrial and aquatic ecosystems, so their protection, restoration, and conservation are vital to maintaining biodiversity and ecological balance(Immanuel, 2018).

The fjord biogeochemical dynamics are complex and follow some patterns across environments. The three different modes of circulation drive the circulation of water in the fjord system: barotropic circulation forced by tides, estuarine circulation forced by freshwater supply, and intermediary circulation forced by wind (Stigebrandt, 2001). Most of the fjords exchange water with adjoining seas which is the basic features of the coastline. Fjords in Norway typically have significant rivers draining into the inner parts, and, particularly in summer, temperature and salinity gradients run through the upper water masses from the open coastal areas to the fjord's innermost parts (Asplin et al., 2020; T. S. Bianchi et al., 2020) . In addition to the dissimilarities in bottom topography, the variations in water depth at the sill (sill depth) result in very different water exchange conditions between fjords (Larsen, 1997).

There are primary forcing factors such as freshwater discharge, water depth, temperature, salinity, energy, disturbances, and landscape characteristics that shape the geomorphology of a system and second-order processes that impact nutrient levels, primary production, and food supplies (Tenore et al., 2006). Benthic communities in soft sediments play an important role in coastal ecosystems, but they are underexplored in some regions especially in the subtidal environments that typically make up the majority of benthic ecosystems in estuaries and coastal seas (Snelgrove, 1997; Tenore et al., 2006; Węsławski et al., 2011). Furthermore, biological, and anthropogenic activities, eutrophication, aquaculture, pollutants, and climate change alter sedimentation on the seafloor, are eventually influencing the benthic composition and threating to the ecosystem (Holte et al., 2004; Trannum et al., 2018). Nearly all of the major Norwegian rivers drain into the fjords, where short-term fluctuations in riverine inputs result in wide variations in salinity and concentration of land-derived substances (Frigstad et al., 2020).In fjords primarily influenced by rivers, the coastal zone of the fjord is anticipated to receive more terrestrial organic materials, thus altering the carbon cycle when compared to nonriverine-influenced fjord (McGovern et al., 2020).Thus, biodiversity in the fjords relies upon both natural and anthropogenic factors directly or indirectly interacting with the system

The benthic communities live at the bottom of the sea (i.e., benthic zone) and are divided into hard and soft bottom benthos (Gooday et al., 1992). The soft-bottom benthos inhabits within the sediment grains of mud and ores sand and are generally categorized by size: macrobenthos (retained by 1mm in size, e.g., polychaete worms, bivalves, mussels, corals, larger crustaceans), meiobenthos (l retained by 0.1 -1.0mm or greater than about 0.1 mm in size, e.g., nematodes, foraminifers, copepods) and microbenthos (less than 0.1mm in dimension e. bacteria, diatoms, ciliates (Richard Parsons & Lalli, 1997). Benthic fauna contributes to various functions in marine ecosystems, such as carbon and nutrient cycling, decomposition, and foraging for higher-level consumers (Gerlach, 1971; Renaud et al., 2021). Moreover, in coastal and estuarine ecosystems, energy, mass, and nutrients are exchanged dynamically from benthic to pelagic habitats via numerous pathways due to environmental variability, biogeochemical transformations, and biological interactions (Griffiths et al., 2017). Therefore, fjord ecosystems are characterized by a diversity of species and their interactions with environment that are also influenced by physical parameters.

Benthic infaunal communities are grouped structurally, numerically, and functionally according to gradients of organic enrichment (Graciela et al., 2012).Further, Benthic communities are dependent on the sedimentation of organic matter; both from land (e.g., runoff) and water column, but the relative importance and fate of terrestrial organic matter and nutrients is a substantial knowledge gap in our understanding of coastal systems (Kokarev et al., 2021; McGovern et al., 2020; Villnäs et al., 2019). In the sediment compartment, organic matter from primary production in the water column and contaminants associated with sinking particles are subject to physical, biological, and chemical processes at the sediment-water interface and within the sediment, determining the fate of organic matter (Duarte et al., 2008).

Benthic organism distribution is influenced by both abiotic factors, such as sedimentary and physicochemical characteristics, and biological factors, such as predation, competition, and bioturbation(Dauer, 1993; de Souza et al., 2013; Levinton, 1995; Snelgrove, 1998). The species' diversity and richness vary with e.g., the sediment composition (Gray & Elliott, 2009) and seasonal inflow of the organic matter from rivers (Holmes et al., 2012). Macrofauna is typically attached to the bottom, either crawl or swim and burrow tubes for foraging or protection from predators. The feeding behaviour of the soft bottom fauna is varied, and includes suspension feeding, surface and subsurface deposit feeder, filter, parasite, opportunist, scavenging, and predators (Degen & Faulwetter, 2019).Also the composition of feeding guilds the distribution pattern of the macrofaunal diversity is related with biological, and physical parameters of the fjord’s gradient.

Benthic communities are well suited for environmental monitoring as the constituent species are mainly sessile and relatively long-lived, and therefore integrate impacts of changes in environmental conditions over time (Ray’ et al., 1990). An analysis of changes in benthic communities resulting from environmental variation generally includes estimates of changes in species, abundance, and biomass patterns (Pearson Rosenberg, 1978). Thus, the periodic monitoring of the benthic species can support understanding the ecological and physical conditions in the marine ecosystem. Benthic community status is an integral part of Norwegian water authorities' monitoring of coastal water status following the EU Water Framework Directive (WFD), which also serves as a basis for fulfilling Norway's obligations under the Oslo-Paris Convention (OSPAR). The environmental goal is to achieve "good" ecological and chemical conditions in every natural body of water. Based on the ecological and chemical characteristics of all water bodies, the classification is taken under the five categories “Very Good”, "Good," "Moderate," "Bad," and "Very bad" (Direktoratsgruppa vanndirektivet, 2018).

Many western and northern Norwegian fjords have been studied, for instance, In Holandsfjord, Olderfjord, Byluft bay, Holte et al., (2004), observed species community distribution pattern related with the depth. Similarly, the Holte, (1998) studied the macrofauna in sill basin sediments (Holandsgfjord) and observed the organic carbon content and main macrofaunal interaction along the fjord gradient. Furthermore, in Kongsfjord Fetzer et al., (2002) observed juvenile benthic invertebrates with respect to their abiotic environment particularly reference to sill basins. Furthermore, Jordà Molina et al., (2019), studied environmental drivers of benthic community structure in Northern Tysfjord and Hellmofjord. Fauchald, (1972, 1974) observed the deep water polychaetes from Sognefjord, Hardangerfjord

There is a, however, a lack of studies on southern Norwegian unpolluted fjords (while polluted ones have been more studied). The survey in Songevann - Sandnesfjord (Kroglund, 2016) studied vegetation and benthic fauna along a salinity gradient from freshwater to fjord. Further, Oug, (2012) studied the biological traits analyses in the pollution gradient Oslo fjord and marine soft bottom assemblages in a fjord. Similarly, Trannum et al., (2018) observed the soft bottoms and response to climate variation and eutrophication in Skagerrak. Therefore, it is important to understand the dynamics of the climate change and the future of the macrofaunal response in unpolluted fjords. As a part of the further research the primary aim of the study is to understand the macrofaunal distribution along the fjord gradient. The specific purpose of the study includes:

1) Map the species composition along the fjord gradient in Sandnesfjord for the first time

2) Investigate the diversity pattern of the benthic community based on various biodiversity indices to obtain information on the ecological status of the fjord

2 Materials and Methods

The Sandnesfjord is located within the southern portion of Norway between Tvedestrand and Risør municipalities, Agder, Norway (Figure 1). The Storelva and the adjacent Steaelva rivers flow into Songevann, which ultimately flows into Nævestadfjorden and Sandnesfjorden. Additionally, 74% of the drainage area to Sandnesfjorden comes from Storelva, flowing into the western end of Songevann and stretches for 551 km (NIVA, 2016). Along its catchment area, Storelva and Steaelva rivers contribute terrestrial organic matter to Sandnesfjorden. The least depth of Sandnesfjorden is recorded as 19 meter and greatest depth is less than 70m. Storelva River flows are characterized by rapid response to precipitation events, with a relatively quick return to baseline levels after flood peaks. As a result, floods can occur throughout the year, regardless of seasonal patterns, including winter (NIVA,2020).

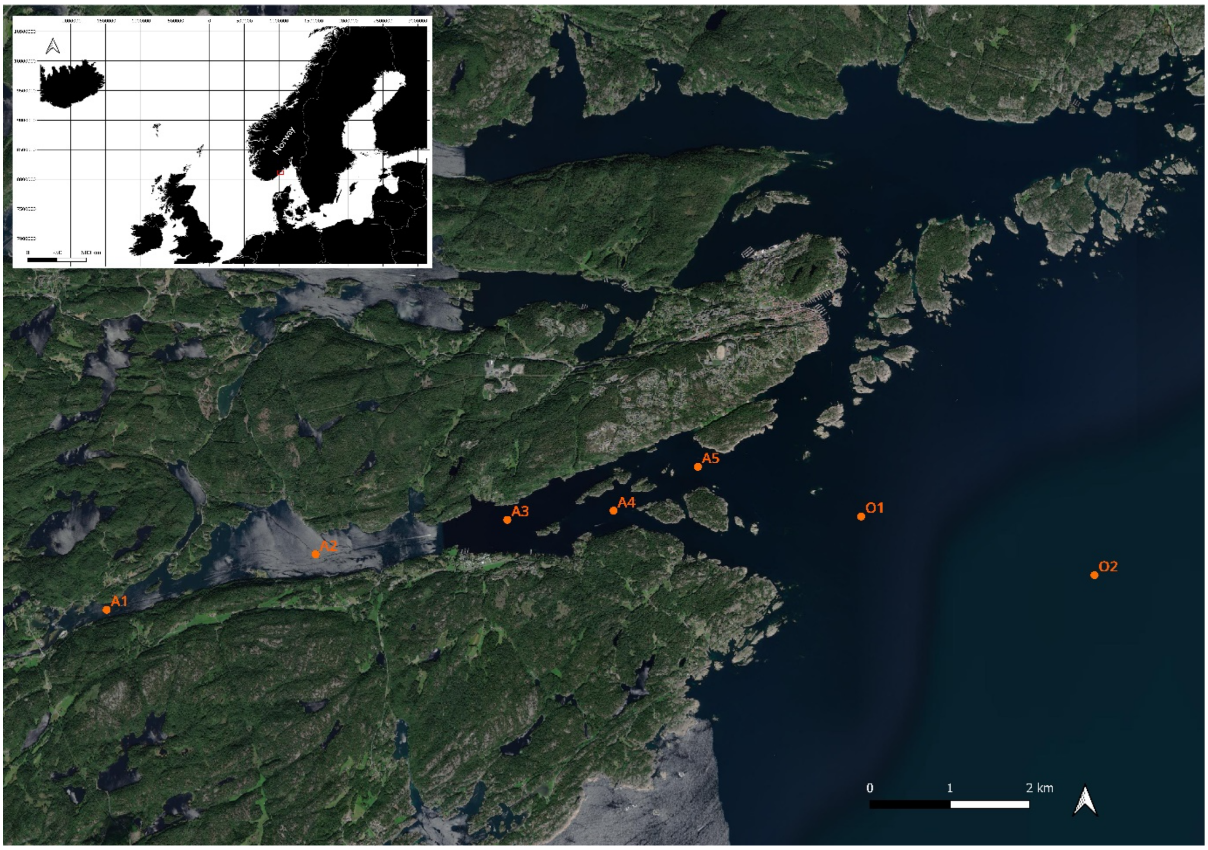

Figure 1: Map of the Sandnesfjord system highlighting the sampling location from inner (A1, A2, A3, A4 and A5)towards outer (01 and 02) stations.

2.1 Macrofauna sampling

The macrofaunal survey was conducted on October 07 & 23. 2020, using a boat from the Tvedestrand municipality. The fjord and coastal area were separated into inward and external parts, hereafter called inner stations (A1, A2, A3, A4, and A5) and outer stations (01 and 02) (Figure 1). The sampling stations were selected along the fjord to follow the gradient from the river outlet, potentially receiving different terrestrial material inputs and experience a range of salinity gradient. Coordinates, depths, and type of sampled material of each station are showed in Table 1.

Table 1: Details on the inner and outer sampling stations and its replication number with the geographic location and depth. Positions given in World Geodetic System 84 (WGS 84).

S. N	Station	Replication	Longitude	Latitude	Depth (m)	Collection
1	A1	1	58°41'11.4"N	9°05'04.8"E	19	Sediment
2	A1	3	58°41'11.4"N	9°05'04.8"E	19	Macrofauna
3	A2	1	58º41.565"N	9º07.783"E	67	Sediment
4	A2	3	58º41.565"N	9º07.783"E	67	Macrofauna
5	A3	1	58°41.799"N	9°10.265"E	60	Sediment
6	A3	4	58°41.799"N	9°10.265"E	60	Macrofauna
7	A4	1	58º41.862"N	9º11.642"E	44	Sediment
8	A4	4	58º41.862"N	9º11.642"E	44	Macrofauna
9	A5	2	58°42'09.5"N	9°12'43.3"E	60	Sediment
10	A5	4	58°42'09.5"N	9°12'43.3"E	60	Macrofauna
11	O1	2	58°41'48.9"N	9°14'51.9"E	60	Sediment
12	O1	4	58°41'48.9"N	9°14'51.9"E	60	Macrofauna
13	O2	2	58°41'17.23"N	9°17'19.78"E	60	Sediment
14	O2	4	58°41'17.23"N	9°17'19.78"E	60	Macrofauna

We have used a Van Veen grab of 0.1m^{2}and obtained four grab replications for macrofaunal investigation and two for sediment characterisation per station, except for the innermost stations A1 and A2 where sampling was limited to three replicated grabs for macrofauna.

Sediment material was sieved through the sieving table of 5mm and 0.1mm. Large macrofauna organisms (>5mm) from the sediments were collected during sieving with a tweezer, and the remaining materials were sieved and allocated in buckets for posterior analysis. The samples were fixed with 4% formaldehyde buffered with Borax, and Rose Bengal was added to facilitate the sorting process. A separate grab was deployed to collect the sediments for the Total Organic Carbon (TOC) and Total Nitrogen (TN) analysis. The sediment layer (0-2 cm) from each station was analysed for Total Organic Carbon and Total Nitrogen (TOC and TN).

The sampling was conducted according to ISO 16665:2014, as well as internal NIVA-procedures. Physicochemical parameters (temperature, salinity, density, and pressure) in the water column of most stations along the gradient were recorded using a CTD (Model SAIV SD-204 968) (Table 2).

2.2 Laboratory analysis

The sediment total organic carbon (TOC) and total nitrogen (TN) were estimated for each station using a CHN (Carbon, Hydrogen, and Nitrogen) analyser after acidification of the inorganic carbon content (Table 3 in appendix 3). Also grain size analysis was intended to be included, but due to Covid-restrictions, these laboratory analyses are not completed.

The fixed faunal samples were subsequently rinsed every two hours for one day with clean water prior to the lab investigation to remove excess formaldehyde. A stereomicroscope (LEICA 10450630) was used to sort samples, and the organisms were then transferred to 80% ethanol. Then, fauna was sorted into eight main groups: Polychaeta with and without tubes, Bivalvia, Gastropoda, Echinoidea, Crustacea, Ophiuroidea, and remaining groups e.g., Chaetognatha, Scaphopoda, Oligochaeta, Caudofoveata etc. were placed as Varia. The biomass of macrofauna from each group was measured using wet weight in a four-cases Scale Kern 770 scale. For the biomass weight the animals were placed in filter paper to get dried and quickly placed in the pre-weighted tray for measurement. The Polychaeta group was divided into tube and non-tube species, and the empty tubes were removed before weighing.

After the preservation of the samples, specimens were further identified to the lowest possible taxonomic level using the identification keys, following the description based on published and online resources (Table A2 in appendix B). Stereomicroscope pointed tweezer to open the polychaete with tubes, tweezer for picking and storing in separate vials, petri dishes, wash bottle etc was used for the identification purpose. Juan Pardo facilitated the sorting of the faunal group, and he helped identify the crustacean group. The families and species were verified by Rita Næss, a specialist at NIVA Grimstad. Finally, the family and species names were checked in the World Register of Marine Species (Worms). The laboratory procedures followed specifications in ISO 16665:2014.

2.3 Data analysis

Identified species were then compiled in a matrix; and the species list was used to calculate indices to reflect the community composition and structure, compare stations, and estimate the ecological condition. The following indices were applied:

2.3.1 Shannon-Wiener diversity index (H') (Shannon & Weaver, 1949)

Shannon-Wiener diversity is a commonly used diversity index to calculates the diversity of species (number of species and number of individuals per species) within a community. It is calculated by

$H' = - \sum i \ pi \log2 \ pi$

where pi = relative abundance (ni/N) of each species calculated as the proportion of individuals of a given species (ni) divided by the total number of all individuals of all species (N). PRIMER v7 is used to calculate the Shannon-Wiener diversity using log (2) as the base.

2.3.2 Pielou's Evenness Index (J') (Pielou, 1966)

Pielou's evenness index measures the distribution of the individuals among the various species. The index results within the of 0 to 1, where values close to 0 refer to unequal distribution of the individuals among the species, but 1 is an equal distribution among the species.It is calculated by:

$J' = H'/H'max$

Where H’ is the number obtained from Shannon diversity index, and H’max is the maximum value of each species of the different species.

2.3.3 Simpson's Diversity Index (D) (Simpson, 1949)

Simpson's Diversity Index is a measure of diversity, it accounts for the number of species present, as well as the abundance of each species. Simpson’s diversity index (SDI) measures community diversity, and the range is from 0 to 1, where high score close to the 1 indicates the high diversity while low diversity is shown by low scores closer to 0. Formula for the calculation of Simpson’s Diversity Index (D):

$$D = 1 - \frac{\sum n-(n-1)}{N(N-1)}$$

n = number of individuals of each species

N = total number of individuals of all species

2.3.4 Hurlbert’s diversity index (ESn) (Hurlbert, 1971)

Considering that species richness increases with N, it can be useful to reduce collections to a common size (n) before comparing species richness’s of various groups (Hurlbert, 1971).Hurlbert’s diversity index is used to calculate the expected number of species for the number of individuals(n). For this calculation, the total number of individuals(n) should not be less than 100(ES100). This index is used to know the distribution of the individual among the species. However, samples with the number of individuals in the sample less than 100 are excluded from the calculation

Hurlbert’s diversity index (ESn) formula as per (Hurlbert, 1971)

$$\mathrm{E}(S_n) = \sum_{i=1}^{s} \left[1 - \frac{\binom{N-N_i}{n}}{\binom{N}{n}} \right]$$

N represents the total number of individuals; Ni is the number of the individuals in the ith species and S is the total number of species. Higher number of the Hurlbert's diversity index (ESn) results in high diversity of species in the N.

2.3.5 Norwegian Quality Index (NQI1) (Rygg, 2006)

Rygg (2006) defined NQI1 as a composite index based on the sensitivity (AMBI) and diversity (SN) of the different species and values between 0 and 1. The total number of individuals is given by Additionally, AMBI draws its data from macroinvertebrate records from South Europe and lumps together species into five groups, decreasing the precision and relative sensitivity of the species (Rygg and Norling, 2013). It is calculated by:

$$NQI1 = \left[0,5 * \left(1 - \frac{AMBI}{7}\right) + 0,5 * \left(\frac{\left[\frac{ln(S)}{\ln(\ln(N))}\right]}{2,7}\right) * \left(\frac{N}{N + 5}\right)\right]$$

AMBI = sensitivity index, S is the number species and N represents number of individuals.

2.3.6 Norwegian Sensitivity Index (NSI_{2012}) (Rygg & Norling, 2013)

The Norwegian species-sensitivity-based index (NSI) assesses the ecological quality of the location. A sample's NSI index value is calculated by dividing the sum of its ES100 average values by the number of individuals in the sample, thereby calculating individual's average species sensitivity value.

$$\mathbf{NSI} = \sum_{i}^{S} \left[\frac{N_i * NSI_i}{N_{NSI}}\right]$$

Ni = Number of individuals of ith species, NSI_i = Species sensitive value and N_{NSI} = Individual with NSI_i assigned value.

2.3.7 Indicator Species Index (ISI_{2012}) (Rygg & Norling, 2013)

Similar to the Norwegian Sensitivity Index (NSI), the Indicator Species Index (ISI2012) is used to classifying the ecological condition of an area and sensitivity values is assigned to the species. It is calculated by:

$$\text{ISI} = \sum_{i}^{S} \left[\frac{ISI_i}{S_{ISI}}\right]$$

ISIi is *i*th species with sensitivity value and S_{ISI} is the assigned ISI values to the number of species.

Further, the values assigned for the five ecological category of the index is highlighted in (Table 3).

Table 3: The classification system for soft bottom fauna showing Norwegian Quality Index (NQI1), Indicator Species Index (ISI2012), Indicator Species Index (ISI2012), Hurlbert's diversity index (ESn), and Shannon-Wiener diversity (H') assigned values for ecological condition adapted from Veileder 02:2018.

Index	Very good	Good	Moderate	Bad	Very bad
NQI1	0.90 - 0.72	0.72 - 0.63	0.63 - 0.49	0.49 - 0.31	0.31 - 0.00
H'	5.7 - 3.8	3.8 - 3.0	3.0 - 1.9	1.9 - 0.9	0.9 - 0.00
ES100	50 – 25	25 - 17	17 -10	10 - 5	5 - 0
ISI2012	13.0 - 8.4	8.4 - 7.5	7.5 - 6.2	6.2 - 4.5	4.5 - 0.00
NSI	31 – 25	25 - 20	20 - 15	15 - 10	10 - 0

Diversity indices were calculated using the software PRIMER v7., while the indices based on species sensitivity; (Norwegian Quality Index (NQI1), Indicator Species Index (ISI2012), and Norwegian Sensitivity Index (NSI2012) were analysed by NIVA. It was necessary to have specific species information to calculate these latter indices; therefore, NIVA treated the data, based on their comprehensive database.

2.4 Multivariate analysis

2.4.1 Bray-Curtis dissimilarity index

In multivariate analyses of large datasets, Bray-Curtis dissimilarity index is helpful to determine how different two samples are from one another based on their species composition.

the Bray-Curtis dissimilarity index is a widely employed method for valid biological reasons and robustness (Clarke et al., 2006). It is employed to calculate the similarity of communities from different geographic locations or stations. The scale of the similarity is represented by a scale between 0 and 1, representing the dissimilarity of the species ratio and calculated between all pairs of samples (Quinn & Keough, 2002). The formula as described by Clarke et al (2006) is given by:

$$\delta_{jk} = 100 \frac{\sum_{i=1}^{p} \left| y_{ij} - y_{ik} \right|}{\sum_{i=1}^{p} (y_{ij} + y_{ik})}$$

Yij = abundance of the ith species in the jth samples, Yik = Number of the ith species in the kth samples and P = Total number of species

The Bray-Curtis dissimilarity index was calculated using the fourth root of data transformation to reduce the influence of the most abundant taxa. The calculation was performed in the PRIMER V7 software.

2.4.2 Cluster analysis

Based on the Bray-Curtis dissimilarity, the samples are then clustered and represented in a dendrogram. Hierarchical clustering of the different stations supports the identification of similarity among groups. Hierarchical agglomerative methods usually start with a similarity matrix and then fuse samples into groups and the groups into larger clusters, starting with the highest similarity level at which groups are formed and lowering it until all samples are in the same cluster (Clarke et al., 2006).

2.4.3 Non-metric multidimensional scaling (nMDS)

Non-metric MDS algorithms construct their multidimensional plots by iteratively relocating points (samples) accordingly to their similarities (Pacini et al., 2014) .Using the Bray-Curtis coefficient, the ordination based on distance/dissimilarity between each sample was identified and plotted. In addition, the coordinate system also calculates a stress value to indicate how well points fit together. The lower the stress level, the higher degree of fitness. A two-dimension plot was plotted using PRIMER V7.

3 Results

3.1 Environment characterization

CTD devices measured salinity, temperature, density, pressure (Table 2). The CTD data were collected on different dates, i.e., the outer station data was collected on October 7th, 2020, and the inner station was collected on October 9th, 2020. The CTD measurement on the different dates showed the high fluctuation on physical data, such as the salinity reading on the October 7th,2020, shows the low value than inner station, which is then not well suited to predict the actual difference between the inner and outer stations. Thus, CTD reading from the inner station conducted on the same date is presented to maintain the uniformity of the data.

The Inner station (A2) is recorded with the maximum value of salinity (32PSU), and the stations (A1 & A5) share a similar value of salinity slightly higher than 30PSU. There is a temperature difference of 1°C between the two inner stations (A2 & A5), but the temperature at the inner station (A1) is more than 14 °C. On the other hand, station A2 measured with a higher density of 24 kg/m3, while station A5 measured with a lower density of 22.81 kg/m3. Also, the pressure measured at stations (A2) is 44 decibars, significantly higher than the least value of 15 decibars at the mid station (A5).

Table 2: The physical parameters (Salinity, Temperature, Density, Pressure & Depth) of the Sandnesfjord inner stations measured in CTD device (mean ± standard deviation)

Station	Salinity (PSU)	Temperature(°C)	Density (kg/m3)	Pressure (decibar)	Depth(m)
A1	31.81±2.66	14.43±0.64	23.71±2.25	36.07±15.65	19
A2	32.16±2.91	12.20±3.15	24.47±2.52	44.61±14.08	67
A5	30.71±1.98	13.20±1.63	22.81±1.48	15.17±1.86	60

3.2 Sediment Characterization

In Sandnesfjord, the total organic carbon (%) and total nitrogen (%) content in the (0-2cm) surface layer of sediments from each station was analyzed (Table 3). The total organic carbon (TOC) at the innermost station was 4.68% while the outermost station had 0.27 %.

Similarly, total organic carbon at the inner and mid inner station (A2 &A3) contains more than 4%, while the mid inner stations and outer stations values range from 0.27 to 2.67.

The total nitrogen (%) at the inner and mid inner stations (A1, A2 & A3) shared similar ranges from 0.54 to 0.58. Accordingly, total nitrogen at the mid inner (A4 & A5) shows 0.17 and 0.34 and outer station (O1) with 0.23, but the outermost station has the lowest value of 0.03. It signifies that the organic matter content at the inner station is comparatively higher, slightly low at the mid inner station than the outer stations. At station 02, the C/N ratio is highest (10.31), while the inner station (A3) has the lowest value (7.06). Conversely, the midstation (A4) with a C/N ratio of 9.91 is relatively higher than the outer station(O1) with 8.21. Also, both inner (A1 & A2) and midstation (A5) have C/N ratios ranging from 8.71 to 7.79.

Table 3: Percentage of Total organic carbon, total nitrogen, and carbon nitrogen ratio content from surface layer(0-2cm) of each station

Stations	A1	A2	A3	A4	A5	O1	O2
TOC (%)	4.68	4.34	4.06	1.67	2.67	1.90	0.27
TN (%)	0.54	0.56	0.58	0.17	0.34	0.23	0.03
C/N	8.71	7.70	7.06	9.91	7.79	8.21	10.31

3.3 Macrofaunal Abundance

A total of 3422 individuals were identified that represented 100 taxa, with polychaetes having the highest number of 47 taxa and varia having the lowest taxa number of two. In addition, the group Bivalvia shared the second most taxa with 27 while Gastropoda (11), Crustacean (7), Ophiuroidea/Asteroidea (4), and Echinoidea(2) were also represented in the Sandnesfjord. The average number of species ranges from 7.67 to 34.50 per $0.1m^2$. The average number of individuals ranges from 34.33 to 293. The highest number of average individuals and species were at the stations (O2), 293 individuals and 34.50 species. The average individual at the station(A2) is 253, while the average species (15.67). In the mid-station (A3) and outer station (O1), the average species range from 12.75 to 14.25, and the individuals range from 93.25 to 173 (Figure 2). As for the mid inner station (A5), 44 average individuals and 16.50 species are present.

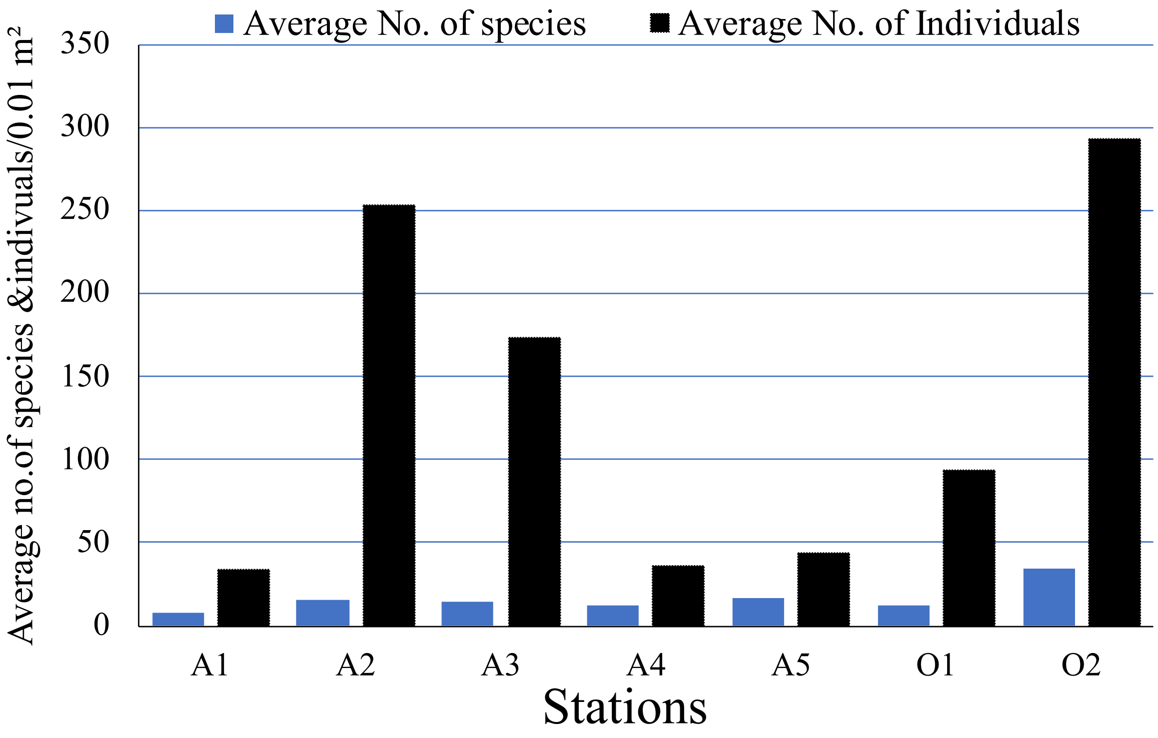

Figure 2: Average number of Species and individuals from the seven (inner and outer) sampled stations (0.1m^2± standard deviation)

Individuals appear to be most abundant on the station (A2) and outer station with fewer species. On the station (A3), the number of individuals is also increasing while the number of species decreases. The difference between species and individuals is less pronounced at the other stations (A1, A4, A5, and O1).

The relative abundance of the groups was analyzed in the study showed the group polychaeta as dominant group along the stations, reaching 90% of relative abundance in the inner station (A2) and representing more than 80% in the outer stations O1 & O2 (Fig 3). Bivalvia taxa are distributed among all stations and have their highest abundance in station A1 (46%), but low representation in the outer stations (4%). Gastropods are distributed between 30% and 20% at the inner station (A1) and midstation (A5), whereas station (A4) covers 18%. Compared with the inner stations, the outer stations have less than 10% gastropods, and station A3 has no gastropods. Comparatively, the relative abundance of ophiuroidea, and crustacean is less than 4% in all the station but cphiuroidea being found at 10% in station A3. The abundance of the group Echinoidea is slightly above 4% at the station (A4) but rarely found at the mid(A5) and outer stations.

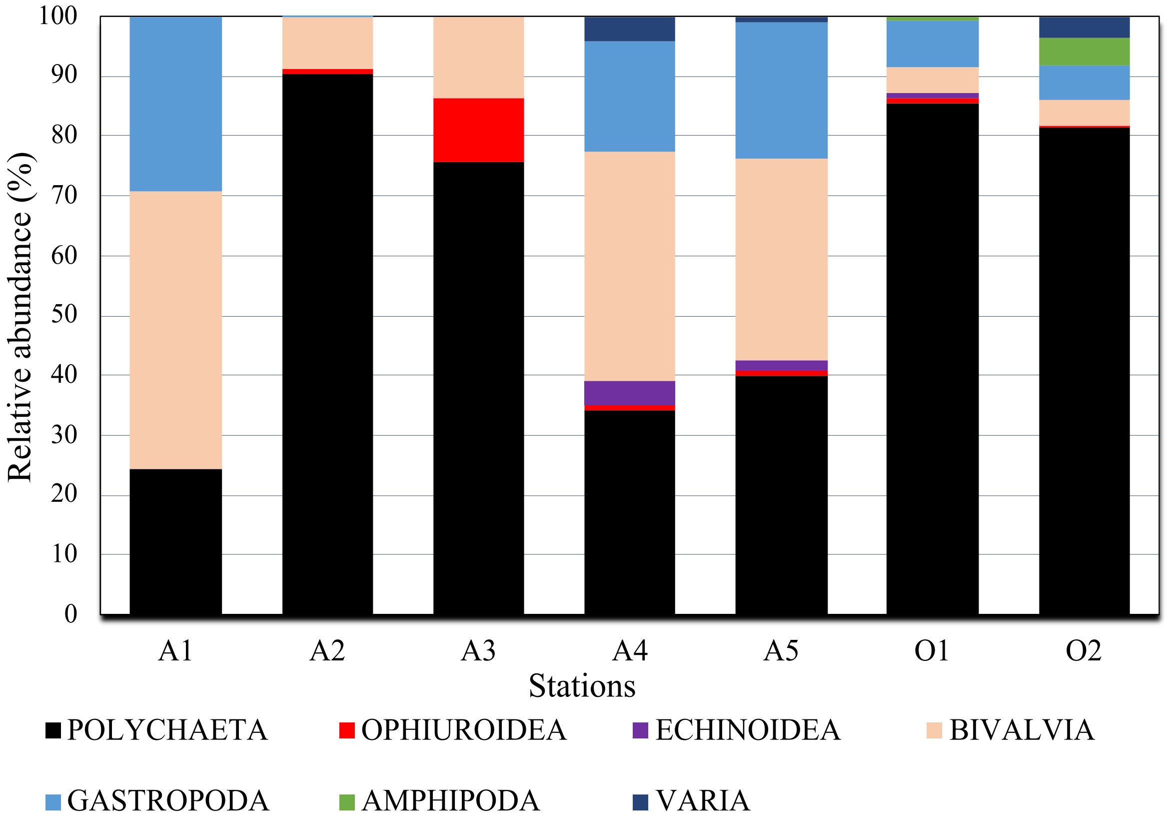

Figure 3: Relative abundance of the taxa (Polychaeta, Crustacea, Echinodidea Ophiuroidea, Bivalvia, Gastropoda and “Varia” among the stations (A1, A2, A3, A4, A5, O1 and O2) along the Sandnesfjord gradient ($0.1m^2$).

3.4 Community composition

To highlight the community composition, the percentages of ten macrofauna species most common in each station are listed in (Table 4); the complete list of species is included in the (Table A1 in appendix A). Among the top ten macrofauna, polychaetes and bivalvia seem to be more abundant, comprised 21 and 12 species, respectively, while gastropods, ophiuroidea, echinoidea, crustaceans, and “varia” were less abundant. The polychaete *Scalibregma inflatum* is a common species across the stations, except in the innermost (A1) and outer stations O1 and O2. Among the group bivalvia, *Corbula gibba* and *Thyasira flexuosa* are dominant within the inner stations, while *Turritella communis* is distributed at all the stations but with lower abundance. For example, the polychaete *Pseudopolydora pulchra* is most abundantly in the inner stations (A2 & A3), while *Jasmineira caudata* dominates the outer stations. However, the Polychaetes *Pectinaria belgica* is one of the most abundant species in the inner station (A1), representing 24% of the individuals.

Table 4: Overview of ten most abundant species, with abundances (N), mean values (per 0.1m^2) and percentage of total abundance (%) in inner and outer stations of Sandnesfjord. P = Polychaeta, B = Bivalvia, C = Crustacean, G = Gastropoda, O = Ophiuroidea, V = "Varia". Feeding guild: SDF: Surface deposit feeder, SSDF: Subsurface deposit feeder, D: Detritus. F: Filter, SF: Suspension feeder, P: Predator, O: Opportunist, S: Scavenger, PS : Parasite, SY: Symbiotic,C: Commensal, adapted from https://www.univie.ac.at/arctictraits/, www.marlin.ac.uk, www.sealifebase.ca and (Macdonald et al., 2010).

Station	Species	N	Composition %	Feeding guild
A1	*Pectinaria belgica* (P)	25	24.27	SDF
	Corbula gibba (B)	17	16.50	SF/D/SDF
	Thyasira biplicate (B)	13	12.62	F/SF
	Turritella communis (G)	10	9.71	F/SF
	Euspira montagui (G)	10	9.71	P
	Nucula sulcate (B)	6	5.83	SDF/F/SF
	Thyasira flexuosa (B)	6	5.83	SDF/F/SF
	Nassarius pygmaeus (G)	5	4.85	S
	Abra nitida (B)	3	2.91	SDF
	Bivalvia indet (B)	2	1.94	SDF/F/SF
A2	*Pseudopolydora pulchra* (P)	518	68.25	SDF/F/SF
	Paramphinome jeffreysii (P)	76	10.01	SDF/O/S/P
	Scalibregma inflatum (P)	34	4.48	SDF/SSDF/F/SF
	Thyasira flexuosa (B)	29	3.82	SDF/F/SF
	Corbula gibba (B)	15	1.98	SF/D/SDF
	Euchone sp (P)	12	1.58	SDF/F/SF
	Prionospio cirrifera (P)	10	1.32	SDF/F/SF
	Ennucula tenuis (B)	9	1.19	SDF/F/SF
	Nucula nitidosa (B)	7	0.92	SDF/F/SF
	Glycera alba (P)	6	0.79	SDF/P
A3	*Pseudopolydora pulchra* (P)	441	63.64	SDF/F/SF
	Amphiura chiajei (O)	40	5.77	SDF/F/SF
	Thyasira flexuosa (B)	39	5.63	SDF/F/SF
	Corbula gibba (B)	28	4.04	SF/D/SDF
	Paramphinome jeffreysii (P)	25	3.60	SDF/O/S/P
	Scalibregma inflatum (P)	21	3.03	SDF/SSDF/F/SF

	Amphiura filiformis (O)	20	2.88	SDF/F/SF
	Amphiura sp (O)	13	1.88	SDF/F/SF
	Ennucula tenuis (B)	11	1.59	SDF/F/SF
	Thyasira biplicate (B)	6	0.87	SDF/F/SF
A4	*Thyasira flexuosa* (B)	30	20.55	SDF/F/SF
	Turritella communis (G)	23	15.75	F/SF
	Scalibregma inflatum (P)	14	9.59	SDF/SSDF/F/SF
	Thyasira biplicate (B)	8	5.48	SDF/F/SF
	Nephtys sp (P)	7	4.79	SDF/P
	Notomastus latericeus (P)	6	4.11	SDF/SSDF
	Prionospio cirrifera (P)	6	4.11	SDF/F/SF
	Echinocardium cordatum (E)	6	4.11	SSDF
	Corbula gibba (B)	5	3.42	SF/D/SDF
	Bivalvia indet (B)	5	3.42	SDF/F/SF
A5	*Scalibregma inflatum* (P)	32	18.18	SDF/SSDF/F/SF
	Thyasira flexuosa (B)	19	10.80	SDF/F/SF
	Cylichna alba (B)	14	7.95	O/S/P
	Turritella communis	13	7.39	F/SF
	Myrtea spinifera (B)	8	4.55	SDF/PS/C/SY
	Pholoe baltica (P)	8	4.55	P
	Nephtys sp (P)	8	4.55	SDF/P
	Corbula gibba (B)	7	3.98	SF/D/SDF
	Nucula sulcate (B)	7	3.98	SDF/F/SF
	Tritia reticulata (G)	7	3.98	S
O1	*Scalibregma inflatum* (P)	225	60.32	SDF/SSDF/F/SF
	Polycirrus plumosus (P)	64	17.16	SDF/F/SF
	Turritella communis (P)	29	7.77	F/SF
	Abra nitida (B)	7	1.88	SDF
	Abyssoninoe hibernica (P)	6	1.61	SDF/SSDF/O/S
	Harmothoe sp (P)	4	1.07	O/S/P/PS/C/SY
	Pista cristata (P)	4	1.07	SDF/F/SF
	Brissopsis lyrifera (E)	3	0.80	SSDF
	Spiophanes kroeyeri (P)	3	0.80	SDF/F/SF
	Terebellides stroemii (P)	2	0.54	SDF/SSDF
O2	*Jasmineira caudata* (P)	547	46.67	SDF/F/SF
	Galathowenia oculata (P)	120	10.24	SDF/F/SF
	Ampharete lindstroemi (P)	100	8.53	SDF/F/SF
	Turritella communis (G)	54	4.61	F/SF
	Nematoda (V)	42	3.58	SDF/SSDF/F/SF/O/S/P/PS/C/SY
	Amphipoda indet (C)	38	3.24	SDF/SSDF/F/SF/O/S/P/PS/C/SY

	Amythasides macroglossus (P)	19	1.62	SDF/F/SF
	Lumbrineris aniara (P)	17	1.45	SDF/SSDF/O/S/P
	Abyssoninoe hibernica (P)	15	1.28	SDF/SSDF/O/S
	Euchone sp (P)	15	1.28	SDF/F/SF

3.5 Biomass composition

Biomass was measured from the seven stations and yielded in total 163.75g, with the polychaete tubes (49.19g) contributing the maximum mass and the echinodidea (0.0284) with lowest biomass (Fig 4). The higher biomass of polychaetes with tubes at outer stations (O2) indicates a higher composition of individuals than at inner stations (A2). In contrast, station A4 displayed the lowest biomass (4g) than other stations, whereas Crustacea and Echinoidea were absent from stations A1 & A5.

The gastropods weight in locations O1 and A1 was10g, and15g, respectively, but no gastropods were found in sites A2 andA3, while the low weight is less than 5g is calculated in A5 and A4. On the other hand, Bivalvia seems distributed along stations. Interestingly, the weight of Bivalvia is higher in the inner stations (A3 and A2) showing a decreasing trend following the gradient. In contrast, Echinodidea abundance is very low at all stations; the big sized were collected during sampling and weighted. Moreover, the weight of echinodidea collected from the outer stations was 19.90 g. The larger weight of the echinodidea might override the resolution of other groups. Therefore, the weight of the echinodidea was omitted from the presented (figure 4). Further, the wet weight of the Ophiuroidea is higher at the outer station(O2), followed by the station A2, A3, A1, A5 and O1.

Additionally, crustaceans from the outer station (O2) are comparatively more abundant than inner and mid stations. Furthermore, the biomass of "varia" (2g) at outer station is higher. Following the abundance data, the diversity of group polychaete with tubes seems higher at the outer stations (O2) followed by inner stations (A2 & A3). In contrast, other stations have fewer dominant groups, while the graphs of the inner station suggest less group composition.

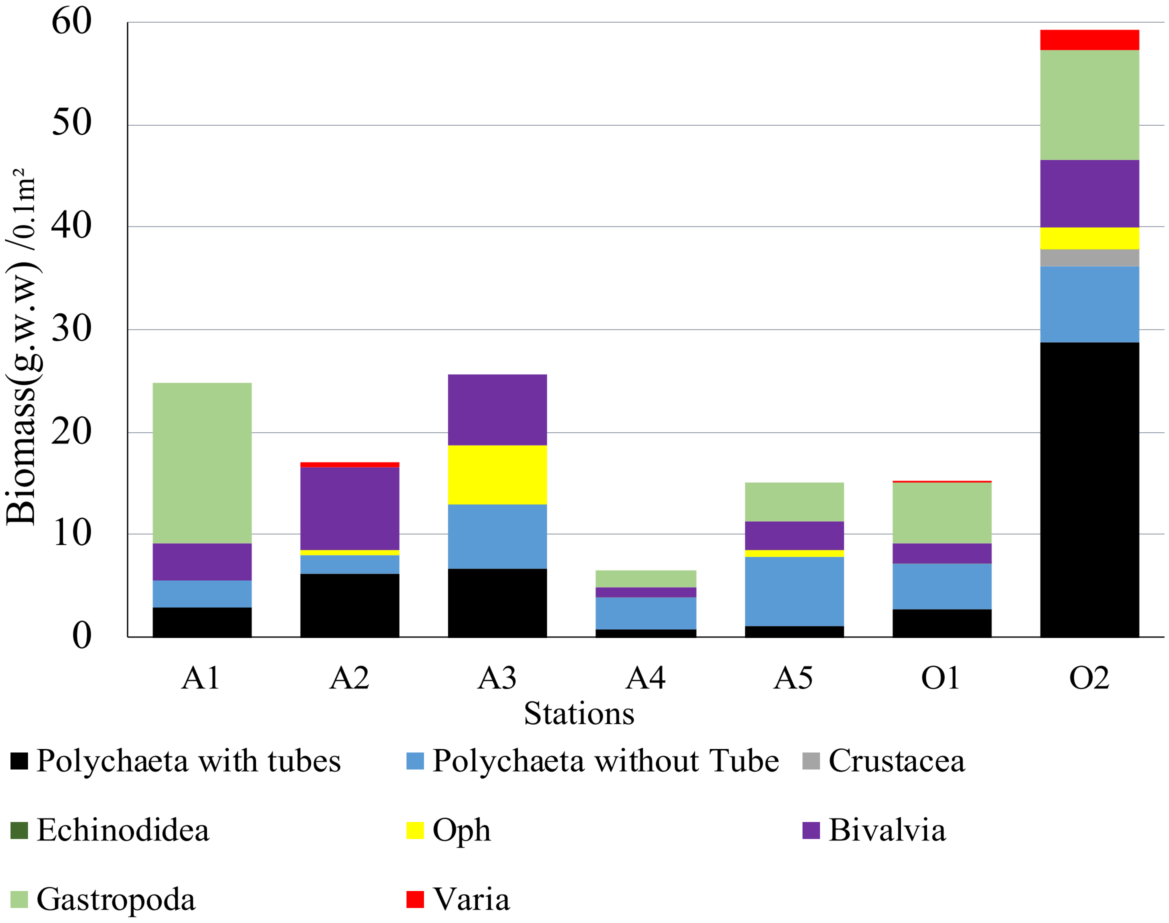

Figure 4: Wet weight (g.w.w)/0.1m^{2}of groups (polycheate with and without tubes, echinodidea, gastropoda, ophiuroidea, crustacea, bivalvia and varia) along the sampled inner and outer stations, omitting the big sized echinodidea from outer station (O2).

3.6 Diversity indices

Biodiversity indices have been calculated for each sample (Table 5 & 6). The Pielou's Evenness Index value at middle inner station A5 is approximately 1, suggesting a uniform distribution of individuals, followed by outer stations (O1 and O2) that have a small index value and suggest there are many individuals of the same species. Interpretation of the Shannon-Wiener diversity is satisfactory in most stations; the values exceed three along the transects of locations but station A2 shows value less than 2. The higher value from Hurlbert’s diversity index of the inner station A5 closer to the outer represents that the diversity is higher than that of the rest of the stations; exceptionally, inner station A1 has the lower value. Finally, the Simpson’s Diversity Index is close to 1 in most of the stations, indicating the complex diversity, except for the inner station A2, which seems to have most uniform species diversity (0.5).

Furthermore, the average of indices in each station was classified according to the Norwegian ecological classification system (Miljødirektoratet rapport, 2016). The blue, green, and yellow color was assigned for the very good, good, and moderate conditions. The Norwegian Sensitivity Index (NSI_{2012}) results were found "Good" in all the inner and outer stations but station (A2) with moderate conditions. Similarly, the Indicator Species Index (ISI_{2012}) values obtained from stations show very good ecological conditions. In contrast, the Norwegian Sensitivity index (NQI1) results from mixed characteristics like the outer station (O2) shows very good condition, mid inner station (A4 & A5) has good condition, and station (A2 & A3) results in moderate condition.

Table 5: Average value of the Indices at Sandnesfjorden, H = Shannon-Weiner diversity index, ES_{100} = Hurlbert's diversity index, NQI1 = Norwegian quality index, ISI_{2012} = Indicator species index, NSI_{2012} = Norwegian Sensitivity Index. blue = "very good", green = "good" and yellow = "moderate".

Stations	H	ES100	NQI1	ISI_{2012}	NSI_{2012}
A1	2.56 ±0.21	-	0.64	9.68	23.79
A2	1.91 ±1.10	12.84	0.53	7.49	16.38
A3	2.68 ±0.94	9.72	0.61	7.46	20.55
A4	3.14 ± 0.38	-	0.65	8.73	24.41
A5	3.55 ±0.28	-	0.71	8.86	24.05
O1	2.12 ±0.79	6.98	0.59	9.31	23.66
O2	3.20 ±0.44	20.97	0.76	9.64	24.69

Table 6: Mean ± standard deviation of the community indices per station (S = Total species. N = Total individual, d = Species richness, J' = Pielou's Evenness Index, D = Simpson's Diversity Index)

Station	**S**	**N**	**d**	**J'**	**D**
A1	7.67 ±1.15	34.33 ±16.26	1.96 ±0.35	0.87 ±0.02	0.83 ±0.03
A2	15.67 ±6.03	253 ±199	2.81 ±1.38	0.48 ±0.21	0.50 ±0.27
A3	14.25 ±3.09	173.25 ±248	3.07 ±0.71	0.71 ±0.26	0,73 ±0.26
A4	12.50 ±3.20	36.50 ±9.34	3.18 ±0.67	0.87 ± 0.03	0.88 ±0.03
A5	16.50 ±1.29	44 ±9.05	4.12 ±0.29	0.88 ±0.07	0.90 ±0.05
O1	12.75 ± 3.59	93.25 ±32.57	2.66 ±0.91	0.57 ±0.16	0,62 ±0.21
O2	34.50 ±9.25	293 ±132.5	5.95 ±1.21	0.63 ±0.11	0.77 ±0.09

3.7 Multivariate analysis

3.7.1 Cluster Analysis

A cluster analysis was conducted to analyse how the stations clustered together after community data transformation to the fourth root (Fig 5 & 6). The midstation (A4 & A5) shared a similarity of more than 40% with inner station A1, and the inner station (A2 & A3) shared a similarity of 35% with the stations (A1, A4 & A5). Consequently, the outer (O1 & O2) shows a low similarity of 30% with the mid inner and inner station. The hierarchical clustering among the group shows that the midand innermost stations are close to 50% similar, but the outermost stations share 35% of group similarity.

A non-metric Multidimensional scaling (nMDS) ordination was performed for station and replicates of each station. For the good representation of the distance 2D plot is preferred (Fig 6) using Bray-Curtis disimilarity index. As a result, the inner station A1 and outer station (O2) shows high dissimilarity between the samples. In addition, the level of similarity between outer stations O1 and O2 seems very low. Meanwhile, the inner station (A2 & A3) and mid inner station (A4 & A5) had almost equal distances, showing a high degree of similarity. Furthermore, the stress value obtained from nMDS 0.04 indicated a low level of stress. Thus, it is reasonable to assume that the species composition within the outer stations differ from the inner and midstations. The x-axis seems to represent the fjord gradient from the inner to the outer station, while the y-axis represents another kind of variation probably related to depth and physical parameters.

Similarly, hierarchical cluster analysis and nMDS 2D plots of each grab were performed to analyze the clustering structure of the community and the distance between each replicate (Fig 8). In brief, the highest similarity within the replicates was observed at outer station (O1), showing more than 50% of the similarity than the lowest observation of less than 50 % within the replicates at inner stations. Interestingly, some of the grab replicates of the inner station and mid inner stations show high similarities. For instance, the grab replicate of inner station (A2 & A3) and mid inner stations (A4 &A5) shared a higher degree of similarities. Similarly, the nMDS plot of the grab at inner stations (A1) reflects the maximum distance between the grab replicates than the outer stations (O1 & O2) show the minimum level of dissimilarities. Meanwhile, the stress value of replicates (0.2) represents the poor goodness-of-fit whereas, stress value of stations (0.04) indicates the goodness of fit is perfect.

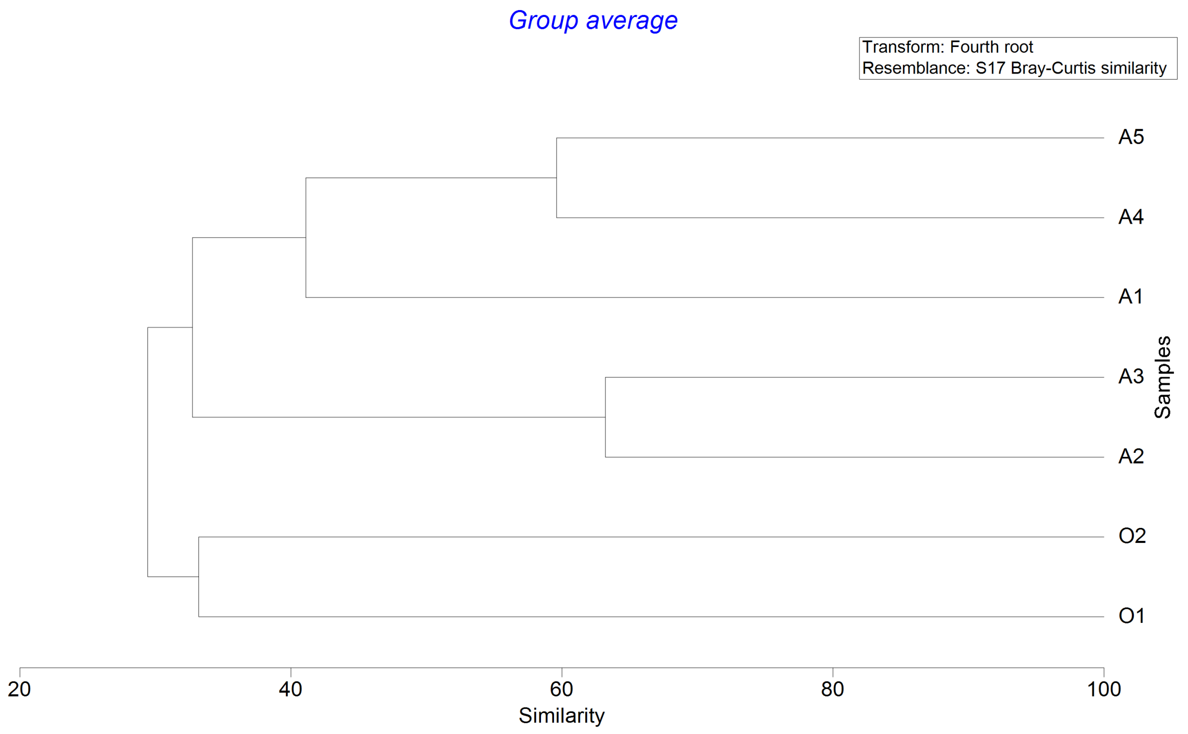

Figure 5: Hierarchical cluster analysis of the average group composition of the stations, using the fourth root of data transformation. Bray-Curtis dissimilarity.

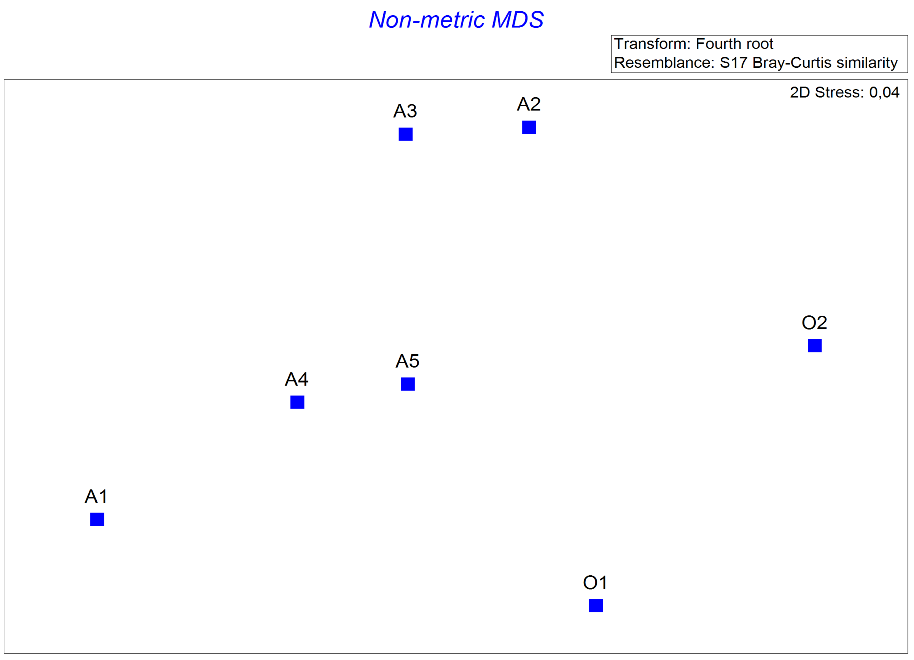

Figure 6: nMDS plot of the average data of the group, data transformed to fourth root, stress level of 0.04. Bray-Curtis dissimilarity.

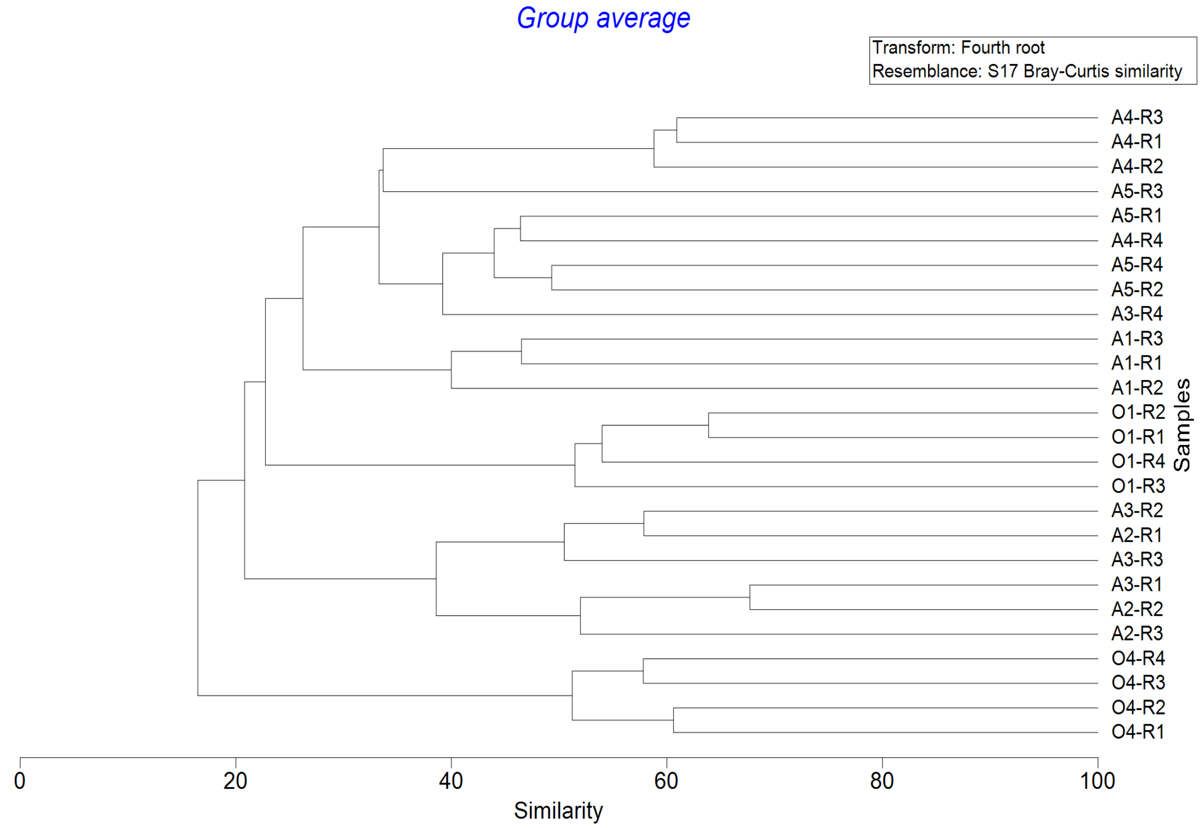

Figure 7: Hierarchical cluster analysis of the average group composition of the replicates, using the double root of data transformation. Bray-Curtis dissimilarity.

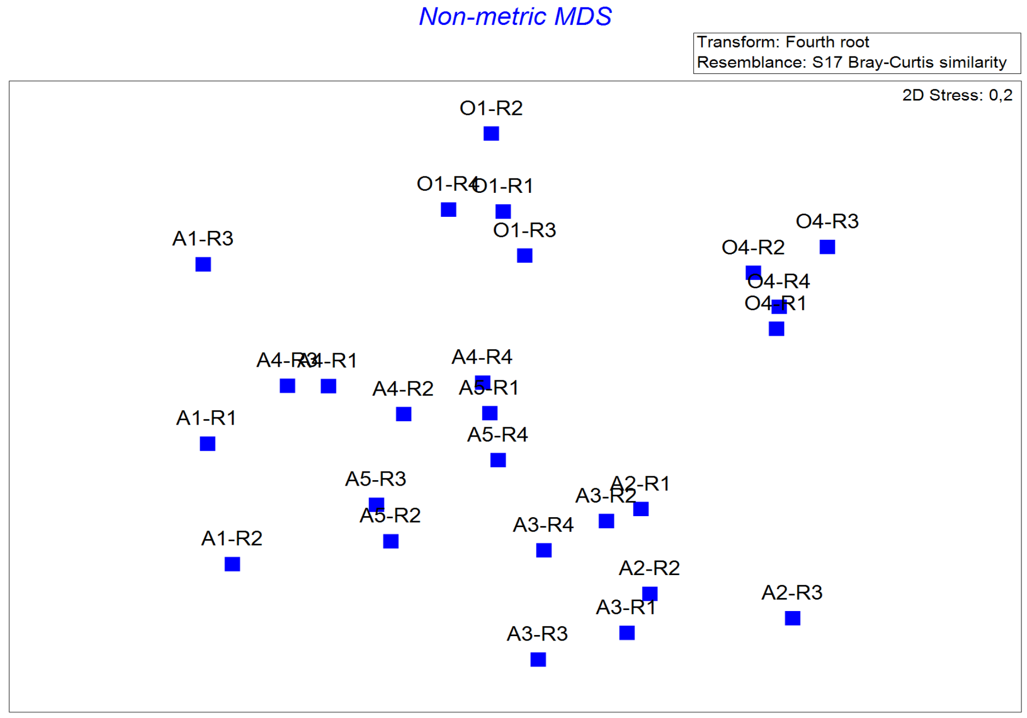

Figure 8: nMDS plot of the data of the replicates, data transformed to double root, stress level of 0.2. Bray-Curtis dissimilarity.

4 Discussion

Benthic community' distribution among estuarine gradients is usually marked by some structuring and diversity composition. The bottom topography of fjords is a dominant factor influencing water exchange and sedimentation conditions, and along with other environmental characteristics (e.g., organic matter content, tides), support the diversity of macrofauna species (Larsen, 1997). Macrobenthic invertebrates play a fundamental role in sediment processes, predator-prey interactions, and act as bioengineers, and are usually well adapted to natural environmental changes, particularly those that affect sediment chemistry and quality (Quintino et al., 2006). The result from the physical parameters in the Sandnesfjord shows a gradient variation among the stations supporting the composition variation of the macrofauna community. When evaluating the communities, diversity indices in the outer stations showed a tendency of higher biodiversity than of inner stations. The group polychaete, for instance, dominates the fjord gradient, followed by the relatively strong presence of bivalves and gastropods. When evaluating the communities, diversity indices in the outer stations showed a tendency of higher biodiversity than of inner stations. The macrofaunal composition, relative abundance, and biomass from the study also clearly reflects the overall "Good" benthic conditions. Furthermore, environmental quality indices, such as AMBI, ISI, and NQI values of the stations, mirrored the fjord system's ecological status is structurally "Good".

Environmental characterization showed higher percentage of organic carbon (TOC) and nitrogen (TN) in the inner stations from the upper sediment layer (0-2cm) in the inner stations were higher than in the outermost stations. Therefore, the composition of the TOC and TN might influence the habit and taxa abundance. The ratio between TOC and TN is an indication of either terrestrial or marine predominance influence in the benthic compartment (Aksnes et al., 2009; Frigstad et al., 2013; McGovern et al., 2020) .Usually, a high C/N ratio, often associated with more terrestrial derived material can prolong the composting process, while a low C/N ratio can promote nitrogen loss (Akratos et al., 2017). All values are considered relatively low (<11), and mainly reflects sedimentation of marine material (Inge Synsfjell, 2016). Surprisingly, the C/N ratio observed from the stations shows the ratio is similar at the outer station and lower at the inner station. In contrast, the C/N ratio of the Sandnesfjord survey in August 2014 (Kroglund, 2016) shows the inverse trend of increasing the C/N ratio i.e., higher towards the inner station (10) and low at outer stations (8.5). A potential explanation is the high input of algae in the outer station which have been showing in other studies with values ranging from 10 (Rosenfeld, 1981) up to 17 in more deeper layers (Blackburn & Henriksen, 1983). Also, it may indicate that the inner station had high marine and high rate of nitrification (Ferguson et al., 2003). By looking at the previous report in the area, the relative amount of total organic carbon in inner stations (<4%) from this study indicates an increase in terrestrial materials and high runoff supplies, but seasonal events can also contribute to these differences. However, further investigation with the use of stable isotopes and resampling in different periods will give a better explanation of the obtained results.

Diversity of species is widely used to monitor ecological changes and is often expressed via several environmental indexes (Spellerberg, 2008). Pearson and Rosenberg's paradigm (Pearson & Rosenberg, 1976; Pearson & Rosenberg, 1978; Quintino et al., 2006) that depicts community responses to an organic pollution gradient of disturbance is an ecological foundation of many benthic indicators used today. However, indices differ in the way they are calculated, bringing complementary information about the system. The value derived from Shannon Diversity index (H'Log2), for instance, indicates that faunal assemblages in the Sandnesfjord are higher at the outer station (O 1 &O2) and lower at the inner station (A1). The observed gradient follows the trend of other fjord estuarine systems, gradually changing the biodiversity as moving from inner towards the outer, like described for the Northern fjords, e.g Holandsfjord and Tysfjord (Holte, 1998; Jordà Molina et al., 2019b; Włodarska-Kowalczuk et al., 2012). As the number of species increases, the H' index will also increase, as individuals are more evenly distributed among species (Gray & Elliot, 2009). Also following an expected trend, the uneven distribution of the individuals among the species list observed by Pilou's evenness index reported lower at the shallow inner station (A2) (>0.48), whereas the mid inner stations (A4 & A5) share similar values (<0.8). Interestingly, Simpson's diversity index(D) value at the mid inner station (A4) seems closer to 1, indicating a very high diverse taxonomic composition. According to the intermediate disturbance theory, regions with intermediate ecological disturbance tend to have higher biodiversity since they allow early and late-successional species to coexist more successfully (Roxburgh et al., 2004). Differently from the outer and innermost stations, the A4 intermediate station has a high number of species with more balance number of individuals per species. For example, the Hurlbert's diversity index (ES 100) at the outer station (O2) and inner stations (A2 & A3) indicates the presence of more species.

The Sandnesfjord system seems to follow a benthic structure like other Norwegian non-heavily impacted fjord systems, concerning macrofaunal distribution patterns. For example, the study on Northern Norwegian fjord systems (Olderfjord, & Lafjord) reported by (Holte et al., 2004) found macrofauna at all spatial scales with dominance of polychaetes, mollusca, and crustaceans and higher species richness following the gradient (inner to outer stations). The study examined differences in the macrofaunal community composition within the stations and documented the large differences in distribution pattern of species and individuals across the fjord gradient. Like, the average number of individuals at the inner station (A2) and mid station (A4) varies from 44 - 253. Interestingly, the average species shared among these stations range 15.67 to 16.50. For instance, as followed by the mentioned diversity indices, the occurrence of more individuals from the same species at the station (A2) might be characterized by the sediment, nutrient, physical parameters, and depth of the stations, favoring their settlement and structuring (Holte et al., 2004; Teal et al., 2010). Further, highest proportion of individuals and species at the outer station (O2) shows the distribution pattern is related with the depth and common feeding behaviour (Holte et al., 2004).

The fauna of the Sandnesfjord includes almost 100 taxa with 47 taxa belonging to the polychaeta's group. The relative abundance of the group polychaetas represents frequent occurrence across the station, whereas the outer stations and inner stations (A2 and A3) were densely populated by polychaetes. In low-flow locations, flow regulates the food supply of benthic species and muddy sediments (Snelgrove, 1994). Thus, we may expect different quality and quantity of organic material from the inner to the outer stations, which may be reflected in the macrofauna community. For example, Bivalvia was very abundance (~30%) at the innermost (A1) and mid station (A4 & A5). Their abundance may indicate the high accumulation of organic matter, also reflected in the species that are resilient to high organic matter content e.g bivalvia *Corbula gibba*, polychaete *Pectinaria belgica.* Moreover, bivalvia *C. gibba* is often considered a sign of environmental instability resulting from pollution, low oxygen levels, or turbidity and this species was dominant at the inner station (Hrs-Brenko, 2006).

The biomass of the macrofaunal community usually follow a decrease trend from inner to outer stations mainly due to the varied species diversity and food input (Holte, 1998). In the inner stations, the presence of rooted plants and coarse woody debris affects the diversity as also as biomass of the benthic invertebrate community (Warfe & Barmuta, 2004). In the

Sandnesfjord, polychaetes with tubes comprised a high proportion of the outer station(O2) biomass. This dominance may be linked to the finer sediments and nutrient availability (Pearson Rosenberg, (1978). Also, the high biomass of gastropods at the inner (A1), and bivalvia in the station (A2 and A3) indicates the organic enrichment and favored settlement in less turbulent areas for these mollusk groups (Graniero et al., 2016) at inner station. The high biomass of suspension and detritivore feeder group at the inner stations and filter feeder at the outer station indicated the organic flow decreased as the depth changes (Flach et al., 1998). It was noted that the biomass for the groups Echinodidea, Varia, Crustacea, and Ophiuroidea was low.

The common species from the inner and outer station shows polychaete *Pseudopolydora pulchra, Scalibregma inflatum,* Bivalvia *Corbula gibba* and Gastropod (*Turritella communis*), as the most common species. In the Northern Norwegian fjords Holandsfjord, Olderfjord, Spitsbergen fjords, it was demonstrated a maximum taxa diversity and richness in the outer part of the fjord and a gradual decline in the inner part (Holte, 1998; Renaud et al., 2007; Włodarska-Kowalczuk et al., 2012). The work from (Grall & Glemarec, (1997) classified groups-based on sensitivity of the macrofauna towards the organic matter, which may support the explanation of some of the widely distributed species across stations. To highlight, polycheates *Ampharete lindstroemi, Galathowenia oculata,* Echinodidea *Echinocardium cordatum,* Ophiuroidea *Amphiura filiformis,* Gastropods *Turritella communis* are species usually linked with unpolluted conditions and are most sensitive to organic enrichments; in the order side, some tolerant species to high organic matter content were also found, *e.g* polychaete *Nephtys sp and Glycera alba.* The high abundance of omnivorous polychaete *Paramphinome jeffreysii* at stations (A2 & A3) may reflect the ecological opportunism and increase in organic matter in inner stations (Bannister et al., (2014; Gunton et al., (2015). In contrast, the high abundance of filter feeder polychaete species (*Jasmineira caudata*) at the outer stations is an indication of higher availability of high-quality nutrients (e.g., phytoplankton) in the water column.

The relationship between annelids and molluscs has been described as "trophic group amensalism" where tube building annelids interfere in the growth and survival of bivalves due to competition, physical harm, and sedimentation (Rhoads & Young, 1970). For instance, the polychaeta family Spionida have been shown particularly negative impact on the Bivalvia community structure (Trannum et al., 2004) .Food availability in deep depositional sites is generally more degraded compared to shallow coastal sites, which has a noticeable effect on macrofaunal composition (Dauwe et al., 1998)(The fauna from inner and outer stations numerically dominated by subsurface feeder polychaetes (*Scalibregma inflatum, Pectinaria belgica, Heteromastus filiformis, Ophelina acuminta, Praxillella affinis* etc.), followed by the surface feeder polychaetes (*Terebellides stroemi, Melinna cristata, Spiophanes kroeyeri)* (Macdonald et al., 2010). As a result of competition for food, space, light, and other resources, competitive interactions in the benthic environment can become intense when these resources are limited (Coutinho et al., 2018). In the Balsfjord (Northern Norway), Oug, (2000), observed that nutrient dynamics could explain species numbers and density caused by the significant plankton exchanges in and out of the system. More intensively in river-dominated fjords, such as the Sandnesfjord, environmental changes along the gradient can reduce the complexity of the community structure and the degree to which the sediment is re-worked by the fauna (Pearson & Rosenberg 1978). When more refractory terrestrial material is delivered to the deeper stations during bigger run-off events, these communities may be able to bury the terrestrial organic matter more effectively than the chronically afflicted communities near the river mouth (McGovern et al., 2020). For instance, Gastropods *Nassarius pygmaeus* is associated with the riverine inputs (Lorenti et al., (2011) and the "ecosystem engineer" gastropods *Turritella communis* can survive in variety of depth, temperature, and salinity Allmon, (2011) are common in the inner stations.

Our study showed that the benthic composition of Sandnesfjord reflects a diverse system when compared to other Norwegian fjords, (Fauchald, (1972, 1974). The cluster analysis shows the mid stations (A4 & A5) and (A2 & A3) inner stations have high similarity, which was not the case for the outer stations (O1 & O2). Therefore, it seems the clustering of the mid stations and inner stations is influenced by the sediment composition and sharing the similar habitat. Moreover, variances in inorganic sedimentation levels have been attributed to differences in macrofauna diversity in identical habitats (Kendall & Aschan, 1993; Włodarska-Kowalczuk et al., 1998). The nMDS analysis shows the macrofaunal communities changed across the depth, salinity, and sediment gradient. For instance, the outer and inner stations show the highest dissimilarity matrix than inner and mid stations. The clustering of the mid station and inner represents the sharing of the similar physical parameters (Salinity, depth, temperature) whereas, the difference between the outer station might be influenced by nutrient flow, grain size and water currents.

Sandnesfjord seems to be a less human-influenced unpolluted fjord among the southern part of Norway with a clear and transparent benthic gradient. Nevertheless, the different habits and motility of diverse communities ultimately contribute to the ecological balance, biogeochemical cycle and indicates the conditions of the fjords. Ecosystems have been altered in many ways due to the overexploitation of biological resources, direct habitat modification of sea and coastal areas, introduction of exotic species, pollution, and climate change (C. N. Bianchi & Morri, 2000). The classification of environmental condition and ecological condition of the Sandnesfjord is based on the (Direktoratsgruppa vanndirektivet, 2018) and the indices value shows most of the ecological condition of the stations seems to be “Good”. The inner part was characterized as anoxic (Kroglund, 2016); but the part of the fjord sampled here, from an ecological perspective and the gradient's taxonomic composition and biodiversity indices suggested that oxygen supply is adequate.

This study is the first in-deep benthic community estimation in the Sandnesfjord, and a contribution to the sparse information of benthic structuring along fjord-coast gradient of uncontaminated fjords in south Norway. Climate change is increasing freshwater runoff, and sediment deposition because of this increased runoff is posing a threat to shallow estuarine and coastal benthic populations around the world (Edgar & Barrett, 2000; Norkko et al., 2002). The changing climate and reduction of nutrients or increase in some regions in the water mass affect the composition of the community, which may gradually shift towards small, sensitive molluscs and tube-building annelids (Trannum et al., 2018).Additional research from our perspective would be trait-based analysis, climate change response of the community, benthic-pelagic coupling, and food web dynamics of the system.

5 Conclusion

A benthic macrofauna distribution pattern was examined along the gradient of Sandnesfjord, a southern Norwegian fjord. The difference in density, pressure, depth, and salinity provides clues for the taxa distribution. Moreover, both total organic carbon and total nitrogen are higher at the inner station. Furthermore, variation in the number of taxa, abundance, biomass, and biodiversity indices indicates the biodiversity change from inner(shallow) towards the outer stations. The indices values from each station suggested the ecological status of the fjord is considered “Good”. The polychaete group was highly abundant, followed by the Bivalvia and gastropod. The primary ten species contribution and their relative abundance were calculated for each station. Furthermore, the multivariate analyses revealed that mid stations possessed the highest similarities, whereas the outer stations showed minimum similarities. These analyses also reflected the faunal gradient from the inner to the outer part of the fjord. Differences in community composition along the fjord gradient were probably due to the differences in nutrients, sediment composition, depth, and varying degree of disturbances.

In this study, the distribution of benthic communities in the unpolluted fjord of southern Norway is described in detail. In order to ensure the sustainability of the fjord ecosystem, more study is needed on climatic change, sediments and carbon isotopes, and benthic-pelagic coupling.

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Appendix

Appendix A: List of Group, Family and species present the Sandnesfjord

Table A1 1 of 3

GRUPPENAVN	FAMILIENAVN	GYLDIG_SYNONYM_WoRMS_sp	A1G1	A1G2	A1G3	A2G1	A2G2	A2G3	A3G1	A3G2	A3G3	A3G4	A4G1	A4G2	A4G3	A4G4	A5G1	A5G2	A5G3	A5G4	O1G1	O1G2	O1G3	O1G4	O2G1	O2G2	O2G3	O2G4
POLYCHAETA	Amphinomidae	Paramphinome jeffreysii				46	26	4	17	3	5																	
POLYCHAETA	Polynoidae	Gattyana cirrhosa								1													2				2	
POLYCHAETA	Polynoidae	Harmothoe sp.																			1	2		1	1			
POLYCHAETA	Phyllodocidae	Phyllodoce groenlandica							2																		1	
POLYCHAETA	Pholoidae	Pholoe baltica				3				2		1					3	1	2	2	1				1	1		2
POLYCHAETA	Syllidae	Syllis cornuta								1	1																	
POLYCHAETA	Nereididae	Nereis sp.																							1			
POLYCHAETA	Nephtyidae	Nephtys incisa											1	1	1	1		2					2			1		
POLYCHAETA	Nephtyidae	Nephtys paradoxa																						3				
POLYCHAETA	Nephtyidae	Nephtys sp.													2	5		4	4									
POLYCHAETA	Glyceridae	Glycera alba				1	3	2	2	3		2		1		3	2	2							3	4	2	2
POLYCHAETA	Goniadidae	Goniada maculata				3		2												1					1	1	1	
POLYCHAETA	Lumbrineridae	Abyssoninoe hibernica								1						1	1				1	2	1	2	2	8	4	1
POLYCHAETA	Lumbrineridae	Lumbrineris aniara														1									12	2		3
POLYCHAETA	Orbiniidae	Phylo norvegicus																1		1					1		2	
POLYCHAETA	Paraonidae	Levinsenia gracilis				1													1	1				1			1	
POLYCHAETA	Poecilochaetidae	Poecilochaetus serpens									1														1		4	3
POLYCHAETA	Spionidae	Laonice sarsi																							2			
POLYCHAETA	Spionidae	Prionospio cirrifera				10										6									1	1		
POLYCHAETA	Spionidae	Prionospio dubia																							1	1		
POLYCHAETA	Spionidae	Prionospio fallax					3																					
POLYCHAETA	Spionidae	Pseudopolydora pulchra					393	125	439			2							1						8			
POLYCHAETA	Spionidae	Spiophanes kroyeri																			3				2	1		
POLYCHAETA	Chaetopteridae	Chaetopteridae indet												1														
POLYCHAETA	Cirratulidae	Chaetozone sp.				2			1	1										1								
POLYCHAETA	Flabelligeridae	Diplocirrus glaucus																						1				
POLYCHAETA	Scalibregmidae	Scalibregma inflatum				21	6	7	7	8		6	6	7		1	5	7		20	40	114	21	50				
POLYCHAETA	Opheliidae	Ophelina cylindricaudata																							3	1	8	
POLYCHAETA	Capitellidae	Heteromastus filiformis																							1			

Table 2 of 2

GRUPPENAVN	FAMILIENAVN	GYLDIG_SYNONYM_WoRMS_sp	A1G1	A1G2	A1G3	A2G1	A2G2	A2G3	A3G1	A3G2	A3G3	A3G4	A4G1	A4G2	A4G3	A4G4	A5G1	A5G2	A5G3	A5G4	O1G1	O1G2	O1G3	O1G4	O2G1	O2G2	O2G3	O2G4
POLYCHAETA	Capitellidae	Notomastus latericeus											3		3										5			1
POLYCHAETA	Maldanidae	Praxillella affinis					2													1			1		6		7	1
POLYCHAETA	Oweniidae	Galathowenia oculata																							35	26	4	55
POLYCHAETA	Pectinariidae	Pectinaria belgica	9	16								1	1			3		1		1								
POLYCHAETA	Ampharetidae	Ampharete lindstroemi					1	2																	14	59	13	14
POLYCHAETA	Ampharetidae	Amphicteis gunneri				1																			2	2		2
POLYCHAETA	Ampharetidae	Amythasides macroglossus				1																			11	5	1	2
POLYCHAETA	Ampharetidae	Anobothrus gracilis																							3	2	3	
POLYCHAETA	Ampharetidae	Lysippe fragilis																							1			
POLYCHAETA	Ampharetidae	Melinna cristata				1	2	3	5	1	1																2	1
POLYCHAETA	Ampharetidae	Melinna elisabethae																							1			
POLYCHAETA	Ampharetidae	Sosane sulcata																							1	1		
POLYCHAETA	Terebellidae	Pista cristata					1		1		1					1					1		3			2	1	
POLYCHAETA	Terebellidae	Polycirrus plumosus				1				1	1	3		1				2	1		18	15	16	15	1			
POLYCHAETA	Trichobranchidae	Terebellides stroemii																		2		1	1		5	1	4	
POLYCHAETA	Sabellidae	Euchone sp.					4	8				2													8	2		5
POLYCHAETA	Sabellidae	Jasmineira caudata				1			2																255	162	41	89
CUMACEA		Cumacea indet																				1					1	
CUMACEA	Diastylidae	Diastylis sp.																							2			
TANAIDACEA	Parathanidae	Tanaidacea indet																								1		
AMPHIPODA		Amphipoda indet																						1	7	12	7	12
AMPHIPODA	Gammaridea	Gammaridea indet																							3			
AMPHIPODA	Caprellidae	Caprellidae indet																							2			
MYSIDA		Mysida indet																					1			1	4	1
ASTEROIDEA	Asteriidae	Asterias rubens																						1				
OPHIUROIDEA	Amphiuridae	Amphiura chiajei				2		2	16		24										1							
OPHIUROIDEA	Amphiuridae	Amphiura filiformis				2				11	5	4				1	1			1			1		1			
OPHIUROIDEA	Amphiuridae	Amphiura sp.							10	3																		
ECHINOIDEA	Brissidae	Brissopsis lyrifera																			1		1	1		1		1
ECHINOIDEA	Loveniidae	Echinocardium cordatum							1				1	5				3										
PROSOBRANCHIA		Gastropoda indet			1			1																				1
PROSOBRANCHIA	Pyramidellidae	Spiralinella spiralis															1										1	
PROSOBRANCHIA	Lacunidae	Lacuna vincta															1											
PROSOBRANCHIA	Turritellidae	Turritellinella tricarinata	8		2								3	7	8	5	5		4	4	9	3	7	10	22	13	2	17

Table 3 of 3

GRUPPENAVN	FAMILIENAVN	GYLDIG_SYNONYM_WoRMS_sp	A1G1	A1G2	A1G3	A2G1	A2G2	A2G3	A3G1	A3G2	A3G3	A3G4	A4G1	A4G2	A4G3	A4G4	A5G1	A5G2	A5G3	A5G4	O1G1	O1G2	O1G3	O1G4	O2G1	O2G2	O2G3	O2G4
PROSOBRANCHIA	Naticidae	Euspira montagui	4		6									1					2						1	1	1	4
PROSOBRANCHIA	Naticidae	Euspira nitida															1		1									
PROSOBRANCHIA	Nassariidae	Tritia reticulata	2											1			1	3	3						2			
PROSOBRANCHIA	Nassariidae	Tritia varicosa		4	1																							
PROSOBRANCHIA	Turridae	Bela powisiana																										1
OPISTOBRANCHIA	Scaphandridae	Cylichna alba											2						14									
BIVALVIA		Bivalvia indet		2										1	2	2		1										
BIVALVIA	Nuculidae	Ennucula tenuis				3	6		6	5									2						2	3		
BIVALVIA	Nuculidae	Nucula nitidosa				3	4				3	1								1								
BIVALVIA	Nuculidae	Nucula sulcata	4	1	1												2	4		1				1				
BIVALVIA	Nuculidae	Nucula tumidula				1																						
BIVALVIA	Nuculanidae	Nuculana minuta				2				1	1																	
BIVALVIA	Nuculanidae	Yoldiella nana																			1	1						
BIVALVIA	Nuculanidae	Yoldiella philippiana	1							1	3						1	3		1						4		
BIVALVIA	Mytilidae	Modiolus modiolus																2	1	1								
BIVALVIA	Limidae	Limatula bisecta																							1			
BIVALVIA	Pectinidae	Similipecten similis																							2			
BIVALVIA	Lucinidae	Lucinoma borealis																								1		
BIVALVIA	Lucinidae	Myrtea spinifera														4	1	3		4								
BIVALVIA	Thyasiridae	Adontorhina similis																						1				
BIVALVIA	Thyasiridae	Axinulus croulinensis																									1	
BIVALVIA	Thyasiridae	Mendicula ferruginosa																									1	1
BIVALVIA	Thyasiridae	Thyasira biplicata	1	12			1		4		2		4	3	1		3											3
BIVALVIA	Thyasiridae	Thyasira flexuosa		6		11	18		6	8	22	3	9	13	5	3	2	5	5	7				2	2			
BIVALVIA	Montacutidae	Tellimya ferruginosa																1	1									
BIVALVIA	Astartidae	Astarte elliptica																							1		1	1
BIVALVIA	Astartidae	Astarte montagui																							2			
BIVALVIA	Cardiidae	Acanthocardia echinata																										1
BIVALVIA	Cardiidae	Papillicardium minimum																					1	1	6	5		
BIVALVIA	Scrobiculariidae	Abra nitida			3	2							1	1	1						1		5	1				
BIVALVIA	Veneridae	Timoclea ovata																							3		1	4
BIVALVIA	Corbulidae	Varicorbula gibba	9	6	2	3	12		25	1	2			3	1	1			3	4			1		3	2		1

Appendix B: Benthic Identification literature

List of identification literature: Table A2

Group	Family	Literature for Benthic identification
POLYCHAETA	Lumbrineridae	Oug, E. (2012). *Guide to identification of Lumbrineridae (Polychaeta) in north east Atlantic waters*.
POLYCHAETA	Poeciliochaetidae	Mackie, A. S. Y. (1990). *The Poecilochaetidae and Trochochaetidae (Annelida: Polychaeta) of Hong Kong View project*. https://www.researchgate.net/publication/230602718
POLYCHAETA	Ampharetidae	Jirkov, I. (2009). *Revision of Ampharetidae (Polychaeta) with modified thoracic notopodia Fauna Iberica View project Fauna Iberica View project*. https://www.researchgate.net/publication/259865868
POLYCHAETA	Terebellidae	Garraffoni, A. R. S. (2008). *Phylogenetic relationships within the Terebellidae (Polychaeta : Terebellida) based on morphological characters*. https://doi.org/10.1071/IS070061445-5226/08/060605 Carrerette, O., Hutchings, P., & Miguel De Matos Nogueira, J. (1846). *Polychaetes from Southern Brazil View project Revision of Hydroides (Serpulidae) View project Pat Hutchings Australian Museum Handbook of Zoology Online Terebellidae s.* Fitzhugh & Hutchings. https://www.researchgate.net/publication/316228627
POLYCHAETA	Oweniidae	Koh, B. S., Bhaud, M. R., & Jirkov, I. A. (2003). Two new species of Owenia (Annelida: Polychaeta) in the northern part of the North Atlantic Ocean and remarks on previously erected species from the same area. *Sarsia*, *88*(3). Parapar, J. (2003). Oweniidae (Annelida, Polychaeta) from Icelandic waters, collected by the BIOICE project, with a description of Myrioglobula islandica n. sp. *Sarsia*, *88*(4), 274–290. https://doi.org/10.1080/00364820310002506

POLYCHAETA	Sabeliidae	Cochrane, S. J. (2000). *TAXONOMY AND SYSTEMATICS OF SELECTED MARINE SOFT-BOTTOM FAN-WORMS (POLYCHAETA : SABELLIDAE : SABELLINAE)*. http://research-repository.st-andrews.ac.uk/ TAXONóMICA, Actuali., & Ana Tovar-Hernández, M. (2010). Miguel Alemán 616-4B, Col. In *Anales Instituto Patagonia (Chile)* (Vol. 38, Issue 2).
POLYCHAETA	Scalibregmatidae	Parapar, J., Gambi, M. C., & Rouse, G. W. (2011). A revision of the deep-sea genus Axiokebuita Pocklington and Fournier, 1987 (Annelida: Scalibregmatidae). *Italian Journal of Zoology*, *78*(SUPPL. 1), 148–162. https://doi.org/10.1080/11250003.2011.598350 Worsfold, T. *Identification guides for the NMBAQC Scheme: 1. Scalibregmatidae (Polychaeta) from shallow seas around the British Isles*.
POLYCHAETA	Nephtyidae	Fauchald, K. (1963). Nephtyidae (polychaeta) from norwegian waters. *Sarsia*, *13*(1). https://doi.org/10.1080/00364827.1963.10409514
POLYCHAETA	Orbiniidae	Blake, J. A. (2021). New species and records of Orbiniidae (Annelida, Polychaeta) from continental shelf and slope depths of the Western North Atlantic Ocean. In *Zootaxa* (Vol. 4930, Issue 1, pp. 1–123). Magnolia Press. https://doi.org/10.11646/zootaxa.4930.1.1
POLYCHAETA	Goniadidae	Böggemann, M. (2005). Revision of the Goniadidae (Annelida, Polychaeta). In *Naturwissenschaftlichen Vereins in Hamburg*. NF.
POLYCHAETA	Paraonidae	López, E., & Sikorski, A. (2017). The Paraonidae (Annelida: Sedentaria) from Norway and adjacent seas, with two new species, four new records, and a redescription of Paraonides Nordica Strelzov, 1968 based on type material. *Zootaxa*, *4320*(1), 41–67. https://doi.org/10.11646/zootaxa.4320.1.3

POLYCHAETA	Sigalionidae	Pettibone, M. ^. (1992). TWO NEW GENERA AND FOUR NEW COMBINATIONS OF SIGALIONIDAE (POLYCHAETA). In *PROC. BIOL. SOC. WASH* (Vol. 105, Issue 3).
POLYCHAETA	Trichobranchidae	Parapar, J., & Hutchings, P. A. (2015). Redescription of Terebellides stroemii (Polychaeta, Trichobranchidae) and designation of a neotype. *Journal of the Marine Biological Association of the United Kingdom*, *95*(2), 323–337. https://doi.org/10.1017/S0025315414000903 Solis-Weiss, V., Fauchald, K., & Blankensteyn, A. (1991). TRICHOBRANCHIDAE (POLYCHAETA) FROM SHALLOW WARM WATER AREAS IN THE WESTERN ATLANTIC OCEAN. In *PROC. BIOL. SOC. WASH* (Vol. 104, Issue 1).
POLYCHAETA	Spionidae	Blake, J. A. (1971). Revision of the genus Polydora from the east coast of North America (Polychaeta: Spionidae). *Smithsonian Contributions to Zoology*, *75*. https://doi.org/10.5479/si.00810282.75 Mackie, A. S. Y. (1984). On the identity and zoogeography of Prionospio cirrifera Wiren, 1883 and Prionospio multibranchiata Berkeley, 1927 (Polychaeta; Spionidae). *Proc. 1st International Polychaete Conference, Sydney, 1983*. Ramberg, J. P., & Schram, T. A. (1983). A systematic review of the oslofjord species of polydora bosc and pseudopolydora czerniavsky, with some new biological and ecological data (polychaeta: Spionidae). *Sarsia*, *68*(4). https://doi.org/10.1080/00364827.1983.10420577
BIVALVIA		Caspers, H. (1968). NORMAN TEBBLE : British Bivalve Seashells. A Handbook for Identification. With 110 fig., 12 pl. London: Trustees of the British Museum (Natural History) 1966. 212 pp. 14 s. *Internationale Revue Der Gesamten Hydrobiologie Und Hydrographie*, *53*(4). https://doi.org/10.1002/iroh.19680530411
BIVALVIA		Warén, A. (1989). Taxonomic comments on some protobranch bivalves from the northeastern atlantic. *Sarsia*, *74*(4). https://doi.org/10.1080/00364827.1989.10413432

BIVALVIA	Thyasiridae	Keuning, R., Schander, C., Kongsrud, J. A., & Willassen, E. (2011). Ecology of twelve species of Thyasiridae (Mollusca: Bivalvia). *Marine Pollution Bulletin*, *62*(4), 786–791. https://doi.org/10.1016/J.MARPOLBUL.2011.01.004
BIVALVIA	Thyasiridae	Payne, C. M., & Allen, J. A. (1991). The morphology of deep-sea Thyasiridae (Mollusca: Bivalvia) from the Atlantic Ocean. *Philosophical Transactions - Royal Society of London, B*, *334*(1272). https://doi.org/10.1098/rstb.1991.0128
ECHINODERMATA		Høisæter, T. (1990). An annotated check-list of the echinoderms of the norwegian coast and adjacent waters. *Sarsia*, *75*(2). https://doi.org/10.1080/00364827.1990.10413443
GASTROPODA		Graham, A. (1988). Molluscs: Prosobranchs and Pyramidellid Gastropods: Keys and Notes for the Identification of the Species. *Synopsis of the British Fauna (New Series)*, *2*.
GASTROPODA		Brattegard, T., & Holthe, T. (1997). Distribution of marine, benthic macro-organisms in Norway. In *Research Report for DN. Directorate of Nature Management*.
CRUSTACEAN		Hayward J.Peter, & Ryland S. John. (2017). Handbook of the Marine Fauna of North-West Europe. In *Handbook of the Marine Fauna of North-West Europe*. https://doi.org/10.1093/acprof:oso/9780199549443.001.0001

Appendix C: Total organic carbon (TOC) and totalt nitrogen (TN) at each replicate of the Sandnesfjord stations.

Table A2

LOKALITET	STAS	TOC	TN
Sandnesfjorden	A1	3,58	0,36
Sandnesfjorden	A1	3,58	0,36
Sandnesfjorden	A1	3,58	0,36
Sandnesfjorden	A2	4,39	0,56
Sandnesfjorden	A2	4,39	0,56
Sandnesfjorden	A2	4,39	0,56
Sandnesfjorden	A3	4,30	0,56
Sandnesfjorden	A3	4,30	0,56
Sandnesfjorden	A3	4,30	0,56
Sandnesfjorden	A3	4,30	0,56
Sandnesfjorden	A4	1,58	0,18
Sandnesfjorden	A4	1,58	0,18
Sandnesfjorden	A4	1,58	0,18
Sandnesfjorden	A4	1,58	0,18
Sandnesfjorden	A5	2,81	0,33
Sandnesfjorden	A5	2,81	0,33
Sandnesfjorden	A5	2,81	0,33
Sandnesfjorden	A5	2,81	0,33
Sandnesfjorden (out)	O1	1,96	0,25
Sandnesfjorden (out)	O1	1,96	0,25
Sandnesfjorden (out)	O1	1,96	0,25
Sandnesfjorden (out)	O1	1,96	0,25
Sandnesfjorden (out)	O2	0,27	0,03
Sandnesfjorden (out)	O2	0,27	0,03
Sandnesfjorden (out)	O2	0,27	0,03
Sandnesfjorden (out)	O2	0,27	0,03

Appendix D: Images collected from the samples of Sandnesfjorden (Polychaete)

Fig 1; *Sosane Sulcata*.

Fig 2: *Lysippe fragilis*

Fig 3: *Amythasides macroglossus*

Fig 4: *Ampharete lindstroemi*

Fig 5: *Amphicteis gunneri*

Fig 6: *Anobothrus gracilis*

Images (Polychaete)

Fig 7; *Abyssoninoe hibernica*

Fig 8: *Lumbrineris aniara*

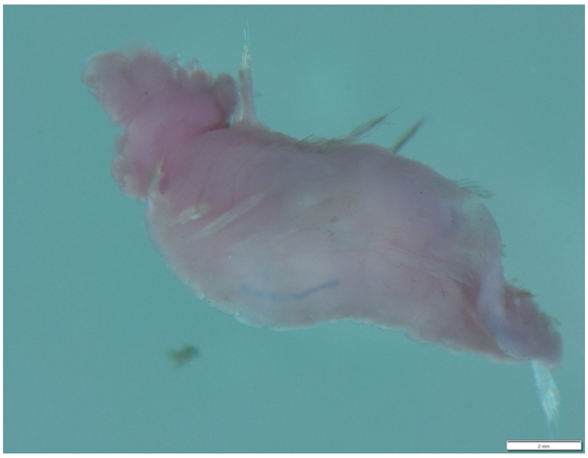

Fig 9: *Polycirrus plumosus*

Fig 10: *Laonice sarsi*

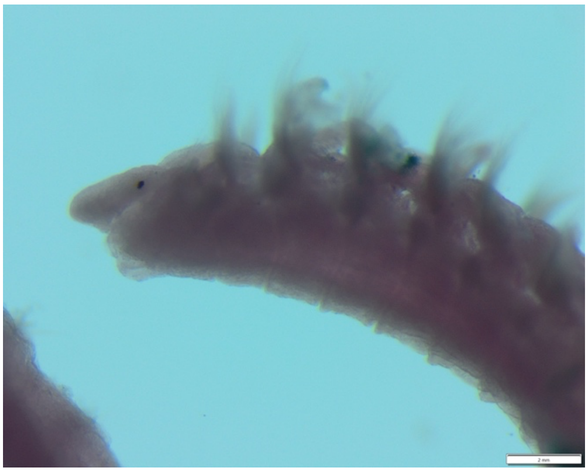

Fig 11: *Prionospio cirrifera*

Fig 12: *Prionospio dubia*

Images (Polychaete)

Fig 13; *Spiophanes kroeyeri*

Fig 14: *Goniada maculata*

Fig 15: *Tomopteris helgolandica*

Fig 16: *Ophelina cylindricaudata*

Fig 17: *Scalibregma inflatum*

Fig 18: *Diplocirrus glaucus*