UNIVERSITY OF BERGEN

Soft-Bottom Ecological Status and Distribution of *Leptosynapta* sp. in Kviturspollen

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Abstract

This thesis aims to give an overview of the current ecological status of Kviturspollen by using CTD data and soft-bottom samples to evaluate the conditions, and results from past surveys to evaluate any improvement or deterioration. Kviturspollen is a land-locked fjord located approximately 14 km south of Bergen, and has been a part of the local recipient surveys in 1990, 2013 and 2014. Due to a shallow sill between Raunefjorden and Kviturspollen, as well as a canal which changed the main current from the neighboring land-locked fjord away from Kviturspollen, the oxygen levels through time have been very low and periodically absent. Kviturspollen is a land-locked fjord with two eelgrass meadows, and therefore has a unique and important ecosystem to preserve.

In this survey, eight stations were chosen in Kviturspollen and one was chosen in Raunefjorden for reference. CTD-measurements were taken in three main areas: the innermost and the outer part of Kviturspollen, as well as in Raunefjorden. All samples were collected between May 2021, and February 2022. At some of the stations, additional samples were taken to more accurately map the distribution and density of the holothurian *Leptosynapta* sp.

Comparing results from past surveys with the results from this, shows that Kviturspollen has undergone slight improvements in relations to diversity and sensitivity of the species. The salinity levels in the land-locked fjord were good, and the oxygen levels were high throughout all out measurements, although the sediment in some of the stations contained H_2S. The bottom fauna samples presented great variations in diversity and sensitivity between the stations, and nearby stations often showed low similarity. In Kviturspollen, the diversity and sensitivity were highest at station 3 and 6, probably because of low amounts of sedimentation and high exposure to the current. Station 1 and 2 were completely lifeless, with sediment smelling of H_2S. This is likely because the previous surveys have shown that the bottom water in the deepest basins frequently have been anoxic in the past. The stations are also located outside the current in an area with high sedimentation. The density of *L.* sp. was highest in the areas with high sedimentation and no H_2S.

The ecological status of Kviturspollen appears to have improved slightly, with a higher number of individuals found per m^2, higher NQI1 values, and no anoxic bottom water measured.

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1. Introduction

1.1 Kviturspollen

Kviturspollen in Bergen is one of many small land-locked fjords (in Norwegian called a "poll") on the Norwegian west coast. Because it has shallow sills and receives great amounts of runoff (Kvalø et al., 2014), a land-locked fjord can have an ecosystem very different from the more open seas. The bottom water in a land-locked fjord is often very still (Dybern, 1967) and with either low or no oxygen, meaning it is regularly anoxic. In such cases, it is common for H_2S to develop, and it is unlikely that any live animals will be present (Hestetun et al., 2012). Past surveys of Kviturspollen have indicated that the environmental and ecological conditions are poorer than the areas outside (Kvalø et al., 2014, 2015), and that it has periodic presence of H_2S (Wassmann & Aadnesen, 1984). Eutrophication, the occurrence of a redundant amount of nutrients, can cause intense primary production and result in reduced oxygen levels (Hestetun et al., 2012). Kviturspollen has historically received sewage, which has caused poor oxygen levels and large amounts of organic nutrients (Kvalø et al., 2017). Because Kviturspollen has a unique fauna and two eelgrass meadows (Lundberg, 2015), it is an important and interesting area for further studies.

From an aerial view, Kviturspollen has a shape resembling an "S" (Figure 1). It consists of several basins, the deepest being 15 m. The basins in the outer part of the land-locked fjord are generally deeper, in average around 10 m deep, than the inner ones, which are generally no more than 6 m deep (Dybern, 1967). Land areas around Kviturspollen contain many houses, roads, and large forested areas near the water. This is part of why the bottom sediment in several areas contain high amounts of organic matter and mud (Kvalø et al., 2017). The bottom of the land-locked fjord is divided into rocky and muddy areas in what is described by Dybern (1967, p.21) as a "mosaic-like pattern". Due to the sills, it is common for a land-locked fjord to have poor water circulation, but in Kviturspollen the poor circulation was aggravated when a canal was opened which changed the main current from Vågsbøpollen (Nygaard & Golmen, 1996).

On November 11. in 1996, a canal was opened between Vågsbøpollen and Vestrepollen to ensure a higher rate of water exchange in Vågsbøpollen and to make it more accessible for small boats (see the red circle in Figure 1) (Nygaard & Golmen, 1996). This has resulted in a change of the main water current from Vågsbøpollen, and most likely a new pattern of water

flow in Kviturspollen (Kryvi et al., 2010). Prior to the opening, the Bergen Sailing Association (Bergens Seilforening), which is based in Kviturspollen, filed a formal complaint to Bergen municipality concerning a potentially increased amount of ice in Kviturspollen (Nygaard & Golmen, 1996). Because the current from Vågsbøpollen to Kviturspollen would be affected, the fear was that reduced water movements in Kviturspollen would lead to more ice. Prior to the building of the canal, the Norwegian Institute for Water Research (NIVA) made models of the water current and water levels to estimate the potential consequences of the canal. The models found that the tidal current in Kviturspollen would likely decrease by 20%, and potentially lower the salinity in the water due to higher levels of inflow from Vågsbøpollen (Nygaard & Golmen, 1996). The main conclusion of the report was, however, that these changes would not have a significant impact on ice formation in Kviturspollen. The conditions in Kviturspollen today are unstable, and major parts of the bottom are lifeless up to a shallow depth (Johannessen et al., 2010). Despite this, the overall perception is that the canal has more advantages for the ecosystem in Vågsbøpollen, than disadvantages to the ecosystem in Kviturspollen (Golmen & Nygaard, 1997; Kryvi et al., 2010).

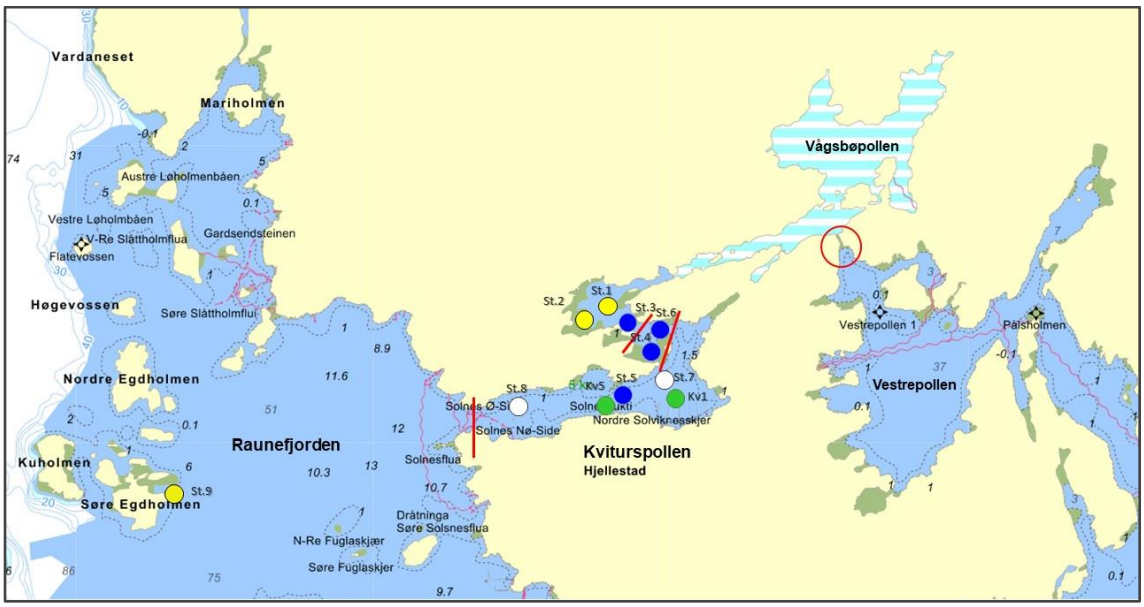

Figure 1. An overview of Kviturspollen and the surrounding areas with all stations from this survey, and stations Kv1 and Kv5 from the recipient surveys of fjords in Bergen (Kvalø et al., 2017). The color of the circle indicates the number and type of grab samples that were taken: yellow indicates that two grab samples were taken for faunistic examinations, white indicates that two grab samples were taken for collecting *Leptosynapta* sp. specifically, blue indicates both two grab samples for faunistic examinations and two grab samples for *L.* sp. were taken, while Kv1 and Kv5 are marked with green. The shallowest sills are marked with red lines and the canal is marked with a red circle.

There are two registered eelgrass meadows in Kviturspollen: one in the inner part with a size of 3,700 m^2 and one smaller in the middle part of 300 m^2 (Lundberg, 2015). One of the stations chosen in this thesis is located in the largest of the meadows (St. 2). Seagrass meadows are of great ecological interest because they are important habitats to many species, function as nursery and breeding grounds, and they are photosynthetic (Kaiser, 2020). They are also great carbon binders, and seagrass helps make the water clearer by trapping fine-grained particulate material (Agawin & Duarte, 2002), as well as protecting the coast from erosion (Lundberg, 2015). Seagrasses are marine angiosperms, flowering vascular plants, which in Norway are represented by only three species, the most common being eelgrass (*Zostera marina*). Eelgrass meadows are declining on a global scale, and similar patterns are also evident in Bergen, without any obvious cause other than their habitat being in coastal areas which are impacted by humans (Lundberg, 2015). The two meadows in Kviturspollen are therefore important to monitor and preserve.

1.2 Recipient Surveys

There are several legislations and regulations on how water ecosystems should be used in a sustainable way and protected (Vannportalen, 2022). In 2000, the EU settled on a common framework for water policy, the Water Framework Directive (2000/60/EC), which applies to Norway through the EEA agreement. It has an overall goal for all waters to maintain a "Good" condition after a set of criteria. A part of achieving this requires knowledge based on mapping, monitoring, and careful evaluations of risk and conditions of water environments (Vannportalen, 2022)**.** In Norway, the Norwegian Environment Agency has been given the task of keeping "Vann-Nett" updated on information on water in the country and keep this information available to the public (Vann-Nett, 2022)**. "**Vann-Nett" keeps information on the status of the environments, the goals and the measures taken to achieve these. A well-practiced method for monitoring water ecosystems for this, is with recipient surveys.

Recipient surveys is a survey of the recipients of some factor, in this case the water ecosystem would be the recipient of waste and sewage from land. The aim of a recipient survey can be simply to monitor ecosystems over long periods of time so that changes can be easily discovered, and the impact of measures to improve the conditions can be evaluated (Kvalø et al., 2017). Monitoring recipient surveys may include a survey of the intertidal zone when relevant, measurements of nutrients and chlorophyll, measurements of salinity, temperature,

and oxygen (hydrography), bacteria, chemical pollutants, and the soft-bottom fauna. When the surface water cools down during the fall and winter, the water layers mix, and nutrients from the bottom water reaches the surface (Kaiser, 2020). Followed by this is often an algal bloom in the spring when the surface water heats up and the water becomes stratified again. It is therefore recommended to measure the oxygen levels between September and April in land-locked fjords, as that is when the saturation is expected to be the lowest (Direktoratsgruppen vanndirektivet, 2018b). In Bergen Municipality and the surrounding municipalities with fjords, a comprehensive recipient survey has been executed since 1973 in the periods 1973–74, 1979–84, 1990–94, 2000–04, and 2011–2020.

1.2.1 Soft-Bottom Biodiversity

Part of recipient surveys involves mapping and monitoring the soft-bottom biodiversity. The soft-bottom fauna is well suited for biodiversity monitoring due to it being relatively stable and perennial, and the species and number of specimens present therefore reflects the environmental conditions of that habitat (Kvalø et al., 2014). Biodiversity is a measure of how many species are present in each area, and how specimens are distributed between the species (Kryvi et al., 2010). The Shannon index (H'; Shannon & Weaver, 1949), which uses both the evenness of specimens between the species and the number of species as a measure of the alpha diversity in a community, is a good way of measuring the biodiversity in one area. However, to say something about the environmental condition of a community, it can be useful to also use sensitivity indices, such as the AMBI (Azti Marine Biotic Index), the NSI (Norwegian Sensitivity Index) or the ISI (Indicator Species Index).

Soft-bottom species vary in what levels of nutrients, oxygen and water exchange they require or can tolerate (Kryvi et al., 2010). Sensitivity indices use the sensitivity of the species towards such environmental stressors as indicators. Sensitive species are found in great abundances in clean waters with satisfying levels of oxygen, while tolerant species are common in waters with limited oxygen (Direktoratsgruppen vanndirektivet, 2018b). Areas with low levels of environmental toxins will generally have a high number of species and high evenness without a few number of species dominating in abundance. In a more impacted environment, there will be lower evenness and typically fewer species (Kvalø et al., 2014). It is common for more tolerant species to dominate areas that are highly impacted by humans (Direktoratsgruppen vanndirektivet, 2018b). The ecological condition is reduced when sensitive species decrease in abundance (Direktoratsgruppen vanndirektivet, 2018b). By using biological variables to

control the quality of a marine environment, it is easier to monitor ongoing restorations of ecosystems and it can be used to measure the biota directly (Borja et al., 2000). Commonly used in Norway is the Shannon diversity index, ISI and NSI sensitivity indices, and AMBI is only used as a parameter of the combined index NQI1 (Norwegian Quality Index 1).

The AMBI is a sensitivity index where experts have sorted species into ecological groups (EGs) based on how sensitive the species are to eutrophication (Direktoratsgruppen vanndirektivet, 2018a). EG I contains species that are only present in unpolluted and not overly enriched areas, while EG V contains highly opportunistic species which can thrive in eutrophic environments (Borja et al., 2000). AMBI is calculated based on the number of specimens in each EG (Direktoratsgruppen vanndirektivet, 2018a). The NSI is an index made based on the same logic as the AMBI, but it is adapted to the Norwegian coastal fauna (Rygg & Norling, 2013). The NSI value is the average sensitivity-value of all specimens from every species in the sample (Direktoratsgruppen vanndirektivet, 2018a). AMBI and NSI are quantitative because they use the number of specimens in each species in the calculation.

The ISI_{2012} is also a sensitivity index, but unlike the AMBI and NSI, it is a qualitative index. The ISI_{2012} index only takes into consideration which species are present, and not the number of specimens in each species or ecological group (Rygg & Norling, 2013). The ISI value therefore presents the average sensitivity of all present species. Both NSI and ISI are pure sensitivity indices, while NQI1 is a combined index which, in addition to sensitivity (AMBI), also takes the diversity into consideration (Rygg, 2006). The index gives a value between 0 and 1**,** and is intercaliberated between all countries in the Northeast Atlantic Geographical Intercalibration Group (NEAGIG) (Pedersen et al., 2016).

1.2.2 Past Recipient Surveys of Kviturspollen: *Byfjordsundersøkelsene*

Bergen Municipality has, since 1973, surveyed the fjords in Bergen with the monitoring programme named “Byfjordsundersøkelsen”. As part of this recipient survey, Kviturspollen has been surveyed three times: in 1990, 2013 and 2014. Originally, the aim of the surveys was to guide the municipality in rearranging the sewage outlets from vulnerable ecosystems to more stable ecosystems (Johannessen et al., 1991). In recent years the aim has been to keep general documentations on the environmental conditions of the fjords, as well as mapping polluted areas and evaluate whether the measures from the municipality on reduction of harmful sewage discharge are useful (Hestetun et al., 2012). The recipient surveys of the fjords around Bergen

have been of great importance in monitoring the rearrangements of the sewage systems in the area (Johannessen et al., 2010). From 2011, the recipient survey was expanded to be a cooperation between several municipalities surrounding the fjords in addition to Bergen: Askøy, Fjell, Lindås, Meland, Os and Sund (Hestetun et al., 2012). The recipient surveys around Bergen have used two stations named Kv1 and Kv5 (Figure 2). Kv1 was located by the Bergen Sailing Association in the deepest part of Kviturspollen, at 14 m depth. Kv5 was located further west towards Raunefjorden, at 10 m depth.

At station Kv1 there have been surveys of hydrography, nutrients, chlorophyll-a and sediment composition in 2013 and 2014, and at Kv5 there have been faunistic surveys of the soft-bottom sediment the same years (Kvalø et al., 2014, 2015). Measures of nitrogen and phosphate were taken from water samples, chlorophyll-a was measured by a fluorescence sensor attached to a CTD probe, oxygen measurements were taken by an oxygen sensor attached to the CTD probe as well as from water samples, and the sediment samples were collected by a van Veen grab with a surface area of 0.1 m^2. Anthozoa, Annelida, Sipuncula, Echinodermata and Mollusca were detected in the analyses. In 1990, Priapulida, the crustaceans *Calocaris macandreae* and *Eriopisa elongata*, and Ascidiacea were detected as well, while in 2013 and 2014, the crustaceans *Verruca stroemia*, *Balanus* sp., *Eriopisa elongata*, *Calocaris macandreae* and *Calocarides coronatu*s, the phoronid *Phoronis* sp., Enteropneusta, Brachiopoda and Ascidiacea were detected (Johannessen et al., 1991; Kvalø et al., 2014, 2015).

The main results from these surveys found that the oxygen levels of the bottom water were very poor, with H_2S found in most of the measurements from 1990- 2014. The levels of heavy metals were slightly higher in 2013 than in 1990, probably due to the increased number of boats in the area, and the benthic fauna had a slightly higher diversity and number of specimens. In 1990 the fauna was dominated by one single species of annelid, *Oxydromus flexuosus*, and the conclusion was that the land-locked fjord had poor oxygen levels and the area was almost completely lifeless up to 10 m depth. Kviturspollen (station Kv5) had a very low diversity in 1990 with Shannon H' = 0.55 (Johannessen et al., 1991). The bottom conditions have improved after 1990, and in 2013 the Shannon index was at 2.65 in average, and at 3.61 average in 2014. In 2013 there were 414 specimens of 24 species found. The three most abundant species were the annelids *Scalibregma inflatum* (46%), *Capitella capitata* (13%) and the brittle star *Ophiocten affinis* (8%) (Kvalø et al., 2014). In 2014 there were 879 specimens of 32 different species. The most abundant species that year were the annelids *Pholoe inornata* (20 %), genus

Chaetozone (13 %) and *O. affinis* (10%) (Kvalø et al. 2015). On the NQI1 index of diversity and sensitivity, the station was at a moderate level (III) in both 2013 and 2014.

1.3 *Leptosynapta inhaerens* and *Leptosynapta bergensis*

Leptosynapta inhaerens and *L. bergensis* are two species of holothurians that live buried in soft-bottom sediments, usually more muddy than sandy (Hayward & Ryland, 2017). The bottom sediment in Kviturspollen is known to be both muddy and sandy (Dybern, 1967), substrates potentially suitable for the species. Both species are slender, pale red to brown in color, they lack tube feet and have approximately 12 tentacles at the anterior part of the body (Hayward & Ryland, 2017). A few characteristics separate *L. inhaerens* from *L. bergensis*: the length of the intestinal tract, the body surface and the number of paired side branches of their tentacles (Hansson et al., 2013). *L. bergensis* has a straight intestinal tract visible through the body surface, while *L. inhaerens* has a longer and looped tract. The number of paired side branches of the tentacles is often 8-9 with *L. bergensis* and only 5-7 with *L. inhaerens*. *L. inhaerens* also has a sticky, Velcro-like surface, whereas *L. bergensis* does not (Hansson et al., 2013). These traits, however, vary greatly between specimens and only a look at the intestinal tract or DNA-sequencing can be used to separate the two.

Many observations of *L. inhaerens* and *L. bergensis* are registered along the Norwegian coast. *L. inhaerens* is far more commonly observed than *L. bergensis* with 1778 observations on the Norwegian continental shelf (Artsdatabanken, 2022b). It is mostly found along the edge of the continental shelf outside Vestland and Rogaland, and along the coast between Rogaland and Trøndelag. There are only 160 registered observations of *L. bergensis* on the Norwegian continental shelf, spread along most of the coastline, but it has been registered the most times in Møre and Trøndelag (Artsdatabanken, 2022a). Both species are found in relatively shallow waters from 5-50 meters depth (Hansson et al., 2013). Outside the northern coast of Britain, *L. bergensis* has been found to live in relation to the annelid *Arenicola marina* (Hansson et al., 2013), however, in Norway this observation has never been reported.

The bivalve *Devonia perrieri* has been documented to be an ecto-symbiont of *L. inhaerens* and possibly *L. bergensis* (Bristow et al., 2010). It has on several previous occasions been found in close proximity to both species (Johannessen & Stensvold, 1986), but *D. perrieri* has only once been recorded attached to *L. inhaerens* in Norway (Bristow et al., 2010).

1.4 Research Aims

The main aim of this thesis is to map out the biodiversity of the soft-bottom fauna in Kviturspollen and to give a description of the current ecological status by answering the following questions: How are the oxygen levels in the land-locked fjord compared to the sediment samples? What is the distribution of diversity? How sensitive are the species we found? What has been the development in Kviturspollen the last few years?

The questions will be discussed by looking at the oxygen levels at different stations in the main areas of the land-locked fjord, and how these results match the sediment samples we collect, as well as past surveys of the area. The distribution of the species in the land-locked fjord is interesting because it gives information on the local conditions of communities in Kviturspollen, and shows whether there is an even distribution of species in the area or not. From the soft-bottom fauna, the biodiversity status will be evaluated based on the Shannon diversity index and the Bray-Curtis similarity analysis, as well as the NSI and ISI sensitivity indices, and the NQI1 combined index. A brief discussion on the distribution of *L*. sp. in the area and whether a symbiosis with *D. perrieri* was observed will be included.

We want to find out what species live in the different areas of the land-locked fjord, and if the diversity has changed since the last surveys. We also want to find out whether the species in the area are sensitive or tolerant, and if the indices are useful and adequate to evaluate the ecosystem. The changes seen in the land-locked fjord since the last surveys, in 2013 and 2014, to this survey will be discussed, and a brief description on the degree of impact the canal has had on the ecosystem will be applied finally.

2. Material and methods

2.1 Study Area

Kviturspollen is located approximately 14 km south of Bergen City center, between Vågsbøpollen and Raunefjorden (Golmen & Nygaard, 1997). The land-locked fjord is separated from both Raunefjorden and Vågsbøpollen by shallow sills. The inlet to Kviturspollen from Raunefjorden, Synningasundet, is shallow and only 80 m wide (Hestetun et al., 2012). The deepest part of Kviturspollen, near the Bergen Sailing Association, is approximately 15 m deep (Kvalø et al., 2015). Between Kviturspollen and Vågsbøpollen, there is a more than 600 m long natural canal of around 5 m width, and with a sill of just 0.5 m depth, called Ådlandsstraumen (Kvalø et al., 2015; Nygaard & Golmen, 1996). At the shallowest point where the sill is located, there is also a small island which limits water flow further (Nygaard & Golmen, 1996). Inside Kviturspollen there are two additional sills (Figure 2). One sill is separating the innermost part with stations 1-3 from the middle part where stations 4 and 6 are located. The middle part of Kviturspollen is separated with another sill from the outer part where stations 5, 7 and 8 are located.

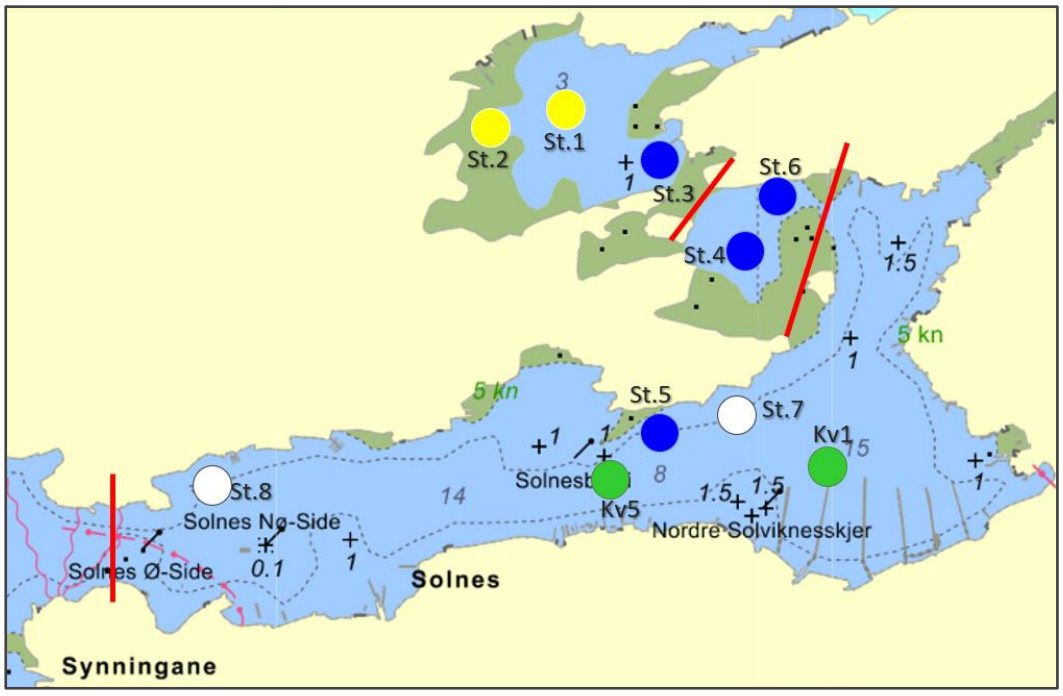

Figure 2. A closer view of Kviturspollen with all the stations from this survey and the recipient survey of the fjords in Bergen (Kvalø et al., 2017), Kv1 and Kv5, marked by green-colored circles. The yellow-colored circles indicate that two grab samples were taken for faunistic examinations, white indicates that two grab samples were taken for *Leptosynapta* sp. collecting specifically, and blue indicates both two grab samples for

faunistic examinations and two grab samples for *L.* sp. were taken. The shallowest sills are marked with red lines.

For the surveys in this thesis, sampling was done at nine separate stations. Eight of the stations are in Kviturspollen in a gradient from the innermost and most still parts, to the outer part. The stations had varying degrees of sedimentation at the bottom, and different exposure to the current. Station 9 is located outside the land-locked fjord by the island Søre Egdholmen (Figure 1). This station is to function as a reference station. In the innermost part of Kviturspollen, station 1 is in the deepest part at 7.9 m depth, station 2 (depth was not registered during field work) is in a shallower location with eelgrass, and station 3 is in the main current at approximately 4 m depth with more rocky bottom. In the middle part, station 4 is located outside the main current at 4.2 m depth in a muddy area, while station 6 is at 4.9 m depth in the main current with some larger rocks. Stations 7 and 8 are both at approximately 5 m depth near land with woods, and station 5 is located close to Kv5 from the recipient surveys in Bergen, at 4.2 m depth. Our reference station, station 9, is at 6.3 m by the island Søre Egdholmen in Raunefjorden. Exact coordinates of the stations are shown in Table 1.

Table 1. An overview of the stations with exact coordinates and depth, date and number of grab samples collected, and a brief description of the sample.

Station Date	Location Coordinates	Depth	No. of grab samples	Description
St.1 15.12.2021	Innermost part 60°15’59.8’’N, 005°14’46.8’’E	7.9 m	2	Distinct H_2S smell. Black color of sediment. Mud. Both grab samples for bottom fauna.
St.2 15.12.2021	Eelgrass in the innermost part 60°15’59.8’’N, 5°14’41.6’’E	-	2	Slight smell of H_2S. Dark mud with eelgrass. Both grab samples for bottom fauna.
St.3 15.12.2021	Main current of innermost part 60°15’58.7’’N, 5°14’52.7’’E	3.8 m	2	Sand, mud and some small rocks. Both grab samples for bottom fauna.
St.4 1- 2: 21.01.2022 3- 4: 03.02.2022	Middle part 60°15’55.5’’N, 5°15’00.3’’E	4.2 m	4	Dark mud. Smell of H_2S. Grab 1 and 2 for bottom fauna. Grab 3 and 4 for *Leptosynapta* sp.

St.5 1- 2: 21.01.2022 3- 4: 03.02.2022	Outer part 60°15’49.4’’N, 5°14’52.5’’E	4.2 m	4	Mud and organic material from nearby woods. Grab 1 and 2 for bottom fauna. Grab 3 and 4 for *Leptosynapta* sp.
St.6 1- 2: 21.01.2022 3- 4: 03.02.2022	Current of middle part 60°15’57.6’’N, 5°15’00.3’’E	4.9 m	4	Sand and mud with some larger rocks. Light color. Grab 1 and 2 for bottom fauna. Grab 3 and 4 for *Leptosynapta* sp.
St.7 03.02.2022	Outer part 60°15’50.0’’N, 5°14’58.3’’E	5.0 m	2	Mud with small rocks. Brown and gray color. Both grab samples for *Leptosynapta* sp.
St.8 03.02.2022	Outer part 60°15’47.8’’N, 5°14’20.8’’E	5.0 m	2	Mud and sand with small rocks. Dark brown color. Both grab samples for *Leptosynapta* sp.
St.9 03.02.2022	Søndre Egdholmen outside Kviturspollen 60°15’35.5’’N, 5°12’52.4’’E	6.3 m	2	Sand and shell fractions. Both grab samples for bottom fauna.

2.2 CTD Measurements

Using a CTD instrument, the percentage of dissolved oxygen and the salinity in the water columns were measured in three main areas, from the water surface to the sea bottom. The area “Mynteviken” is in Raunefjorden just outside Kviturspollen, “Outer part” is the outer area of Kviturspollen by the sailing association, and “Inner part” is the innermost area of Kviturspollen. The instrument was carefully released from the side of the boat and started measuring when the instrument hit the water surface. It made measurements every second until it was pulled back up above the water surface after being brought down to the sea floor. The measurements taken in December 2021, January and February 2022 were taken by Thomas Sørlie at the same time as the bottom samples were collected, while the measurements taken earlier than that were taken by Sørlie on previous surveys. Using Guide 02:2018 from the Norwegian Environment Agency to classify water (Table 2) (Direktoratsgruppen vanndirektivet, 2018b), the stations were put into condition classes from I-V where I is “Excellent”, and V is “Very poor”.

Table 2. The Norwegian Environment Agency's classification of conditions for oxygen in deep waters. Given a salinity above 18 from table 9.26 in Guide 02:2018. table 9.26 (Direktoratsgruppen vanndirektivet, 2018b).

Parameter		Condition classes				
		I	II	III	IV	V
		Excellent	Good	Moderate	Poor	Very poor
Deep water	Oxygen (ml O_2/l)	> 4.5	4.5 - 3.5	3.5 - 2.5	2.5 - 1.5	< 1.5
	Oxygen saturation (%)	> 65	65 - 50	50 - 35	35 - 20	< 20

2.3 Collecting Bottom Samples

A van Veen grab with a surface area of 0.1 m^2 was used to collect sediment samples from all stations. Some stations were used to determine the general biodiversity of the land-locked fjord, while others were used mainly to examine for *Leptosynapta* sp. specifically. The sampling was done on December 15, 2021, January 21, and February 3, 2022, with a small boat, driven by lead research technician Tomas Sørlie. On board the boat collecting samples were also Henrik Glenner, Jon Thomassen Hestetun, and students Torill Synnøve Fjørtoft Johansen and Jonette Larsen Eckholdt. The samples were sieved and rinsed at the marine biological station Espegrend, where Thorolf Magnesen helped provide all necessary equipment.

2.3.1 Bottom Fauna

Two grab samples were collected at each station 1, 2, 3, 4, 5, 6 and 9. Once returned to Espegrend, the samples were carefully sieved, first through a sieve with holes of 5 mm diameter, then another sieve with 1 mm diameter holes. This was done by scooping a hand bailer of sediment into the sieve, and rinsing with water from a water hose connected to a sea water pump. The sediment was carefully stirred with our hands if necessary. The sieved samples were fixed in ethanol directly after sieving, with a change of ethanol a few hours later. The samples from the different grabs were marked with the number of the station and a letter representing the individual grab sample.

In a laboratory, the organisms from one and one sample were sorted out from the sediment under a stereomicroscope by Eckholdt and Johansen. Looking at one teaspoon of sediment at a time, all specimens were picked out and sorted into phyla Mollusca, Annelida, Crustacea, Echinodermata, Nematoda, Nemertea and varia. When all sediment samples were sorted, all the specimens that were sorted to phyla, were then sorted to species and counted (Figure 3). For species determination, Jon Thomassen Hestetun helped with identifying the molluscs,

Henrik Glenner and David John Rees helped with the crustaceans and Tom Alvestad was of great guidance and help with determining the annelids.

Because no animals were observed in the samples from station 1 and 2 during sieving, only a subsample was examined. When no specimens were found in the subsamples, the samples were not examined further.

Figure 3. The sorting and identification of species demanded great amounts of glasses and a good system for counting. This picture shows some of the glasses used only for polychaeta.

2.3.2 *Leptosynapta* sp.

To get a more accurate picture of the density and distribution of *Leptosynapta* sp. through Kviturspollen, additional samples were collected by a van Veen grab of 0.1 m^2. Due to the size of the specimens from this species, it was only considered necessary to sieve the samples though a 5 mm holed sieve. This was done onboard the boat (Figure 4). Sediment samples for this purpose were taken from stations 4, 5, 6, 7 and 8.

Figure 4. The pictures show Jonette sieving the additional samples collected to decide the density of *Leptosynapta* sp. They were sieved through a 5 mm holed sieve onboard the boat. The pictures are taken by Torill Synnøve Fjørtoft Johansen.

The specimens were fixed in ethanol in situ and changed when returned to the lab. These, along with the *L.* sp. found in the other 12 grab samples already collected from stations 1- 6, were counted. Due to the ethanol preservation, the *L.* sp. shrank as a result of dehydration and were virtually impossible to identify by morphological features (Figure 5 and 6). We were therefore unable to determine what species of genus *Leptosynapta* that was present in Kviturspollen.

Figure 5. The pictures show a *Leptosynapta* sp. on the boat before it was preserved in ethanol.

Figure 6. A picture of *Leptosynapta* sp. taken in the laboratory after it had been preserved in ethanol.

The density of *L.* sp was calculated by adding together the number of specimens from every station and dividing it by the total area of surface sediment taken. For example, at station 4, a total of 19 *Leptosynapta* sp. were found, and four grab samples were taken, each of 0.1 m^2. A total of 0.1x4 = 0.4 m^2 was examined, and the density of *L* sp. at station 4 was therefore: 19/0.4 m^2 = 47.5 per m^2.

2.4 Analyses

In order to gain a broader insight to the ecological status of Kviturspollen, the biodiversity was calculated as alpha- and beta-diversity, and ISI_{2012} and NSI were applied to gain information on the sensitivity of the communities. The combined NQI1 index was used to get a measure that uses both the diversity and the sensitivity of the individual grab samples, and for easier comparisons with the previous surveys. Alpha diversity is a measure of how the species composition is within a grab sample, while beta diversity says something about the differences or similarities in species composition between the samples (Kaiser, 2020).

2.4.1 Alpha Diversity

The number of different species within a locality is called the alpha diversity (Kaiser, 2020). In this thesis the alpha diversity was calculated using indices for diversity (Shannon), sensitivity (ISI and NSI) and a combination of both (NQI1). In this survey, the index is used on each

individual sample. The values retrieved from the calculations were then used as indications of the current ecological status in Kviturspollen, based on the class limits from Guide 02:2018 (Direktoratsgruppen vanndirektivet, 2018b), presented in Table 3. Kviturspollen is in category N3 because of its location in the southern part of the North Sea (N) and its salinity > 30‰ (3).

Table 3. The class limits for soft-bottom fauna in water type N3-5. The table is from the Norwegian Environment Agency (Direktoratsgruppen vanndirektivet, 2018b)**.**

INDEX	CLASS LIMITS				
	Excellent	**Good**	**Moderate**	**Poor**	**Very poor**
H'	5.9 - 3.9	3.9 - 3.1	3.1 - 2	2 - 0.9	0.9 - 0
NSI	29 - 24	24 - 19	19 - 14	14 - 10	10 - 0
ISI_{2012}	13.1 - 8.5	8.5 - 7.6	7.6 - 6.3	6.3 - 4.5	4.5 - 3
NQI1	0.9 - 0.72	0.72 - 0.63	0.63 - 0.49	0.49 - 0.31	0.31 - 0

Shannon Index

The Shannon index (H') (Shannon & Weaver, 1949) uses the number of species in a community (richness) and how evenly distributed the specimens are between the species (evenness) as a measure of the alpha diversity. The index will be low if either a low number of species are present in the community or if a few species dominate in abundance (Direktoratsgruppen vanndirektivet, 2018a). The Shannon index was calculated for each grab by the following formula:

$$H' = \sum_{i=1}^{S} \left[\left(\frac{N_i}{N} \right) \cdot log_2 \left(\frac{N_i}{N} \right) \right],$$

where N_i is the number of specimens in species *i*, *N* is the total of specimens in the grab and *S* is the number of species in the grab (Hestetun et al., 2012). In this thesis, the Shannon index was calculated for each 1 mm grab sample, using the Caswell- analysis in Primer v7. The calculations were done with $\log_2$ for easier comparisons with the recipient surveys from Bergen. The framework of how the water directive should be completed in Norway (Guide 02:2018) also uses $\log_2$ (Direktoratsgruppen vanndirektivet, 2018a)**.**

The Shannon index gives information on the biodiversity only, but to get information on the ecological quality of the community, sensitivity indices also need to be applied. NSI, ISI_{2012} and NQI1 indices were therefore applied to each grab sample.

Norwegian Sensitivity Index

In the NSI, all species have been categorized by experts into a sensitivity group based on their tolerance to eutrophication (Direktoratsgruppen vanndirektivet, 2018a). The calculations of the NSI are based on the amount of specimens in each species to weight the different sensitivities (Rygg & Norling, 2013), making it a quantitative index. The NSI value for each grab sample was calculated in R using the BBI package (Cordier & Pawlowski, 2018). The formula that was used to calculate the NSI was:

$$NSI = \sum_i^S \left[\frac{N_i \cdot NSI_i}{N_{NSI}}\right] ,$$

where N_i is the number of specimens in species i, NSI_i is the NSI-value for species i, and N_{NSI} is the number of specimens with that NSI value.

Indicator Species Index

The ISI uses sensitivity values that each species has been assigned to, to give an average sensitivity of the species in the community (Direktoratsgruppen vanndirektivet, 2018a). In this thesis, the ISI was calculated using the BBI package in R (Cordier & Pawlowski, 2018). Because the number of specimens of each sensitivity does not matter, only the number and category of the species, the ISI is a qualitative index. It is calculated as:

$$ISI = \sum_i^S \left(\frac{ISI_i}{S_{ISI}}\right) ,$$

where ISI_i is the given value for species i, and S_{ISI} the number of species with that assigned value.

NQI1

A combined index, NQI1, was used to compare the sensitivity and diversity of the samples to the past results from the recipient surveys in Bergen. The NQI1 uses the AMBI to account for sensitivity, in light of the diversity (Rygg, 2006). In this thesis the NQI1 was calculated in R the BBI package (Cordier & Pawlowski, 2018). The following formula was used:

$$NQI1 = \left[0.5 \cdot \left(1 - \frac{AMBI}{7}\right) + 0.5 \cdot \left(\frac{\left[\frac{ln(S)}{ln(ln(N))}\right]}{2.7}\right) \cdot \left(\frac{N}{N+5}\right)\right] ,$$

where N is the number of specimens, and S is the number of species.

The NQI1 gives a value between 0 and 1, where 0 is the lowest and 1 is the highest. Values above 0.63 are classified as “Good” or “Excellent”.

2.4.2 Beta diversity

Although the alpha diversity gives useful information on the diversity within a community (Kaiser, 2020), a calculation of the beta diversity is necessary to get information on how community compositions are in relation to each other. Because we also want to look at the similarities and differences between the samples and stations in Kviturspollen, we used a Bray-Curtis analysis in addition to the alpha diversity calculations.

Bray-Curtis Pairwise Similarity

The Bray-Curtis similarity index (Bray & Curtis, 1957) is used to compare how different the species composition in the different grab samples are. In this thesis it will be used for non-metric multidimensional scaling (NMDS) and group average cluster analysis with the software Primer v7. To make the difference between the most species-abundant and the least abundant stations smaller, a fourth root transformation was executed on every species number in the species list. The transformation keeps the relative difference in abundance the same, but it makes sure that large numbers of species at one station will not have greater influence in the analyses than it does in reality (Jensen, 2018). A fourth root transformation is also what is used in the recipient surveys from Bergen. The species (a) from grab samples j and k was compared using the following formula:

$$D_{jk} = \frac{\sum_{i=1}^{a} |Y_{ij} - Y_{ik}|}{\sum_{i=1}^{a} (Y_{ij} + Y_{ik})},$$

where Y_{ij} is the number of species at station j, and Y_{ik} is the number of species at station k.

Non-Metric Multidimensional Scaling

Using Primer v7, Non-metric Multi-dimensional Scaling was applied to the Bray-Curtis matrix retrieved from the species list. The algorithms use a scaling system where the differences between the grab samples are ranged in relation to each other, and not as their exact difference value (Agarwal et al., 2007). The goal of a multi-dimensional analysis is to get an overview of which samples have the most species in common. The results are presented as a scatter plot where the distance between the points represent the difference in their community structures (Jensen, 2018). The closer two samples are on the plot, the more species they have in common.

Average Linkage Cluster Analysis

An Average Linkage Cluster Analysis was chosen to present the similarity between the grab samples as a dendrogram. This was done using Primer v7 on the Bray-Curtis matrix of the species list. A dendrogram is a graphic representation in the form of a tree showing the hierarchical relationships of similarities (Saraçli et al., 2013). This is made by algorithms placing each grab in its own cluster, then merging the clusters most similar to each other until all clusters are linked (Charikar et al., 2019). Every possible pair is tried at every step, to ensure the highest average similarity within each cluster (Bridges, 1966).

3. Results

3.1 CTD Measurements

Salinity

The salinity levels from Mynteviken, the outer and inner part of Kviturspollen measured from the sea surface to the seafloor, showed overall salinity levels increasing with depth. In Mynteviken, the measurements of the bottom water were between 34-35‰, measured on December 15, 2021, and May 5, 2021, respectively (Figure 7A). The outer part of Kviturspollen had the lowest salinity in the bottom water of 33‰, measured on both October 7, 2021, and January 21, 2022, and the highest bottom water salinity was 34‰ on September 22, 2021 (Figure 7B). The measurements from the inner part of Kviturspollen showed salinity values between 30-33‰ in the bottom water (Figure 7C).

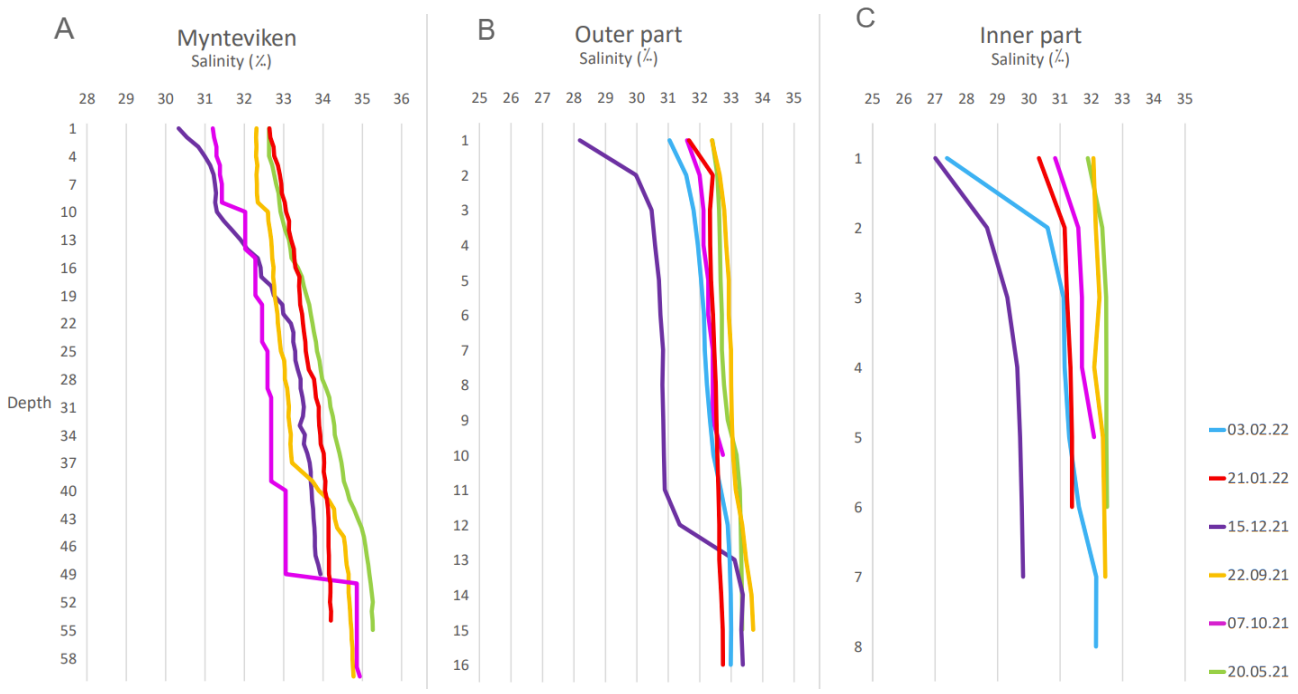

Figure 7. CTD measurements of salinity presented as vertical profiles from the sea surface to the floor in 3 different areas. A) Measurements from Mynteviken in Raunefjorden as a reference. B) Measurements taken in the deepest basin in the outer part of Kviturspollen, close to the Bergen Sailing Association. C) Measurements taken in the deepest parts of the innermost part of Kviturspollen.

Oxygen

The CTD measurements of oxygen showed a general pattern of a slight decrease in saturation just above the seafloor in all areas. In each area, the measurements are taken at slightly different locations in the area, and the depth therefore varies between the measurements.

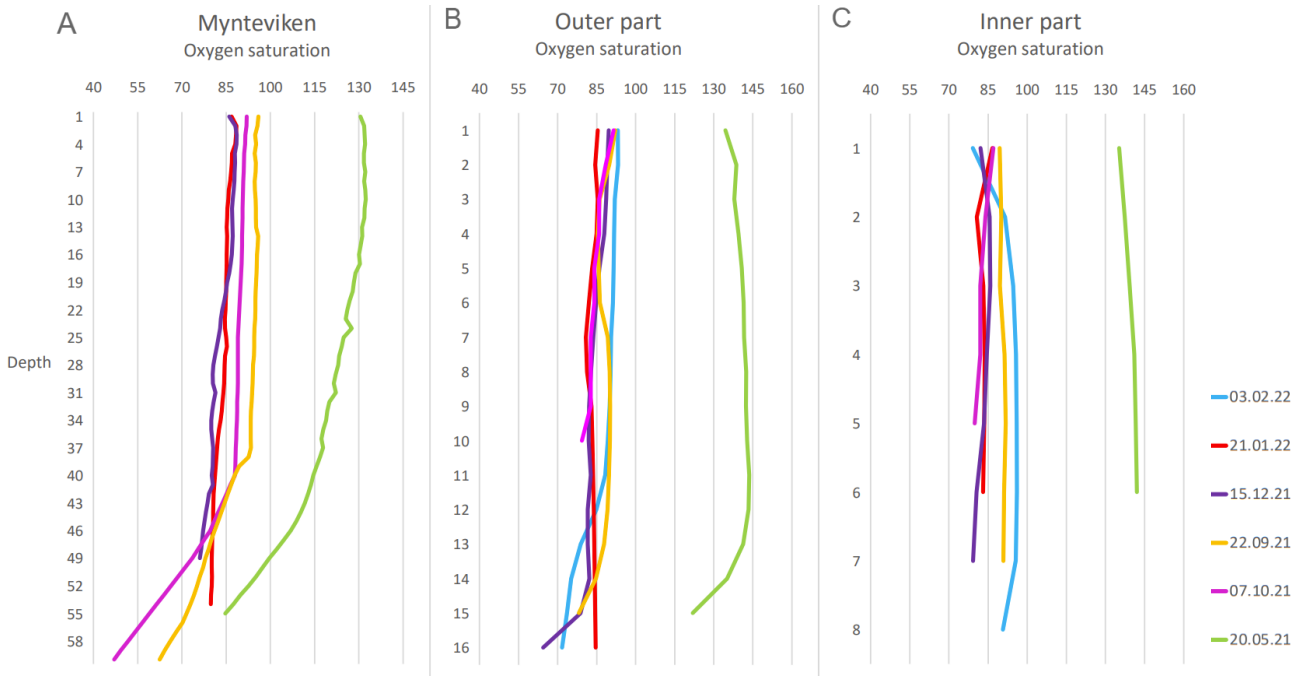

Figure 8. Vertical profiles of CTD measurements of oxygen in 3 different areas. A) Measurements from Mynteviken in Raunefjorden as a reference. B) Measurements taken in the deepest basin in the outer part of Kviturspollen, close to the Bergen Sailing Association. C) Measurements taken in the deepest parts of the innermost part of Kviturspollen.

3.1.1 Mynteviken

In Mynteviken, the measured oxygen saturations of bottom water were above 75% on May 20, 2021, January 1, 2022, and December 15, 2021 (Figure 8A). On September 22, in 2021, the lowest saturation measured was at 63%, while the lowest saturation levels measured on October 7, in 2021 was 47%.

3.1.2 Outer Part of Kviturspollen

Outside the Bergen Sailing Association, the oxygen saturation levels of the stations generally decreased just above the seafloor (Figure 8B). The lowest measured oxygen saturation was above 64% on all stations. The highest saturation of 144% was measured on May 20, 2021, and the lowest saturation of 65% was measured on December 15, 2021.

3.1.3 Inner Part of Kviturspollen

The measurements of oxygen saturation from the stations in the innermost part of Kviturspollen, fluctuated between 79% and 150% (Figure 8C). Just above the sea floor, the lowest measured oxygen saturation was 79%.

3.2 Sample Observations

When collecting the sediment samples, there were both visible and odorous differences between the stations. At station 1 there was an intense smell of H_2S, and the sediment was extremely fine-grained and almost black colored mud. Station 2 also smelled of H_2S, but not as intensely as at station 1. The sediment was very dark and muddy, and we observed eelgrass from the boat and in our samples. The eelgrass did not look very healthy, but brown and almost dead. At station 3, the sediment contained more sand and some gravel in addition to mud, and there was no smell of H_2S at this station. The sample was dominated by sea urchin spines. Station 4 had dark and compact mud, and the smell of H_2S was distinct. The sediment from station 5 had a lot more organic material from land and was mud-dominated. There was also a subtle smell of H_2S. Station 6 had a much lighter-colored sediment than station 5, with sand, some larger rocks, and some mud. Station 7 looked pretty similar to station 6, but with fewer rocks. There was no H_2S smell at either station. Station 8 had a darker brown color than 6 and 7, more mud and no bad smell. In the samples were also a few rocks and a great amount of green algae. Station 9 was outside Kviturspollen and was dominated by shell fractions and small gravel. The color was light beige and there was no smell of H_2S. In the samples, particularly sample 9B, were great amounts of green and red algae.

3.3 Bottom Fauna

At stations 1 and 2 there were no live animals found. At station 3 a total of 648 specimens of 44 species were found, and 22 of the species were found in both grab samples. At station 4, 415 specimens of 22 species were found, with 8 species present in both grab samples. Station 5 had 96 specimens from 14 species, where 3 of the species were found in both samples. At station 6, 1321 specimens were found. These were of 54 species and 25 species were found in both of the samples. At station 9 there were 292 specimens of 47 species found, with 12 of the species present in both samples. The three most abundant species at station 3 were *Kurtiella bidentata* (32%), *Pholoe* sp. (10%), and *Orbiniidae* sp. (8%). At station 4, the most abundant species were *K. bidentata* (69%), *Platynereis* sp. (5%), and *Crisilla semistriata* (4%). The most

abundant species at station 5 were *K. bidentata* (64%), *Microdeutopus anomalus* (8%), and *Platynereis* sp. (8%). At station 6, *Protodorvillea kefersteini* (59%), *Platynereis* sp. (6%), and *Cirriformia tentaculata* (6%) were the most abundant species, and at station 9 the most abundant species were *P. kefersteini* (11%), *Platynereis* sp., *Capitellidae* sp., and *Amphipholis squamata* (9%). The complete species list of the bottom fauna surveys is presented in Appendix I. No specimens of *Devonia perrieri* were found in the samples.

3.3.1 Alpha Diversity

Shannon Index

The Shannon index of the different stations put 3A and 9A in the "Excellent" class, 3B and 9B in the "Good" class, 4B, 6A and 6B in the "Moderate" class, 5A and 5B in the "Poor" class, while 4A was in the "Very poor" class.

	N	S	H' (log_2)
1A	0	0	N/A
1B	0	0	N/A
2A	0	0	N/A
2B	0	0	N/A
3A	278	33	4.19
3B	370	33	3.11
4A	227	10	0.89
4B	188	19	2.89
5A	20	7	1.82
5B	76	10	1.93
6A	764	38	2.84
6B	557	41	2.52
9A	213	40	4.40
9B	79	19	3.52

Table 4. The number of specimens (N), species (S), and Shannon index (H') from samples 3A-3B, and 9A-B. The color shows the condition class based on class limits from Guide 02:2018 (Table 3).

Sensitivity Indices

The ISI index was highest in sample 3A (Table 5). The second highest was 9A, while the lowest was sample 9B. Only three samples, 4A, 5B and 9B, were classified as a "Moderate" ISI value according to Guide 02:2018 (Direktoratsgruppen vanndirektivet, 2018b). The remaining stations were all in the "Good" class.

Sample 9A had the highest NSI value, sample 3A had the second highest, and 9B had the third highest. These three samples were in the "Good" class, and the remaining samples were "Moderate". The lowest NSI values were in sample 4A, 5B and 4B.

The combined index, NQI1, had the highest value in sample 9A, while 3A and 6B scored the same value. These three samples were in the "Excellent" class. The lowest values were in sample 4A, 5A and 5B, which qualified to the "Moderate" class. The remaining samples were "Good".

Table 5. The ISI_{2012}, NSI and NQI1 values for each sample. The color represents the condition class it qualifies to according to the Norwegian Environment Agency Guide 02:2018 (Direktoratsgruppen vanndirektivet, 2018b) (Table 3).

	ISI_{2012}	NSI	NQI1
3A	8.20	20.41	0.73
3B	7.68	16.99	0.68
4A	7.52	14.92	0.54
4B	8.01	16.46	0.68
5A	7.62	17.34	0.59
5B	7.08	15.38	0.59
6A	8.02	17.74	0.69
6B	7.74	17.22	0.73
9A	8.04	21.66	0.74
9B	6.50	19.23	0.69

3.3.2 Beta Diversity

The beta diversity is presented as a Non-Metric Multidimensional Scaling (NMDS) plot (Figure 9) and an Average Grouped Cluster analysis (Figure 10) from the Bray-Curtis pairwise similarity (Table 6).

Table 6. The Bray-Curtis similarity of stations 3A-6B, 9A-B. The number presents the similarity between the samples as a percentage.

Similarity (0 to 100)										
	Samples									
Samples		3A	3B	4A	4B	5A	5B	6A	6B	9A	9B
	3A										
	3B	64.61									
	4A	35.55	40.02								
	4B	57.76	54.46	54.93							
	5A	17.54	14.69	35.53	28.12						
	5B	39.28	37.56	68.70	55.82	37.37					
	6A	56.19	50.41	25.13	41.52	14.97	27.20				
	6B	59.68	51.24	29.87	40.71	15.60	29.78	63.50			
	9A	41.98	41.81	22.65	32.00	12.68	22.65	32.37	43.78		
	9B	29.20	32.25	30.81	32.05	21.25	29.95	27.43	29.28	38.74	

The most similar grab samples are 4A and 5B with 69%, 3A and 3B with 65% and 6A and 6B with 64% similarity. The least similar grab samples are 5A and 9A with 13%, 5A and 6A with 15%, and 5A and 6B with 16% similarity (Figure 9 and 10).

Non-Metric MDS

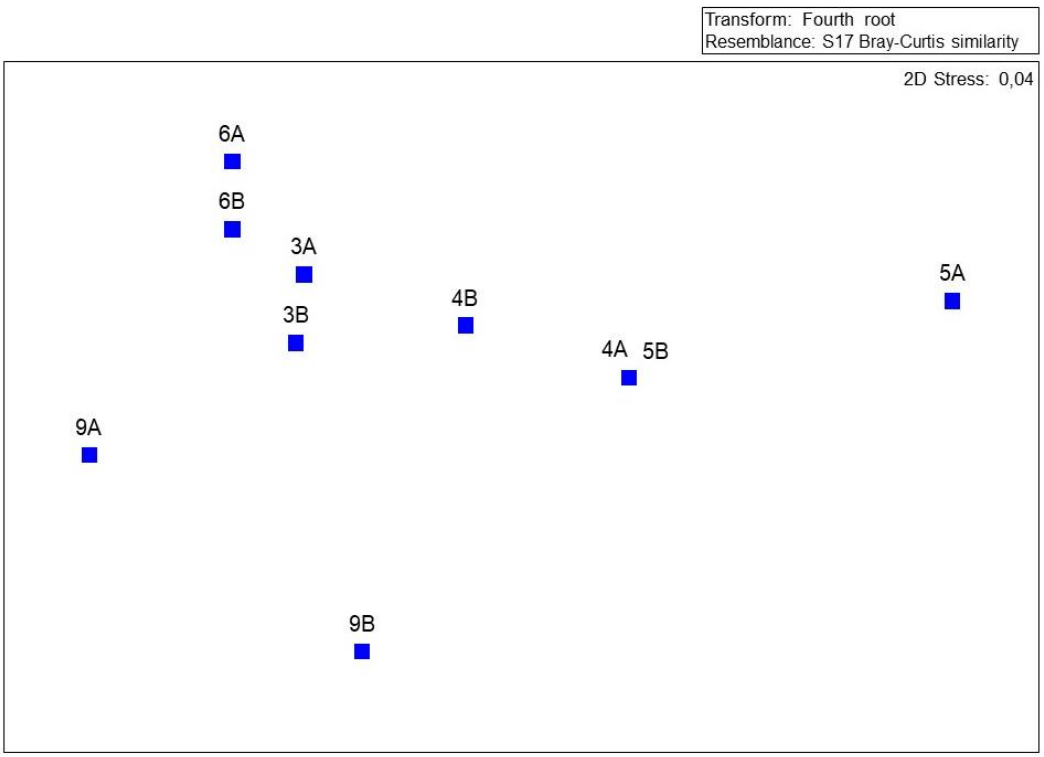

Figure 9. An NMDS plot showing the similarity of the stations. The grab samples are sorted into colors and shaped based on their similarity.

Group Average Cluster Analysis

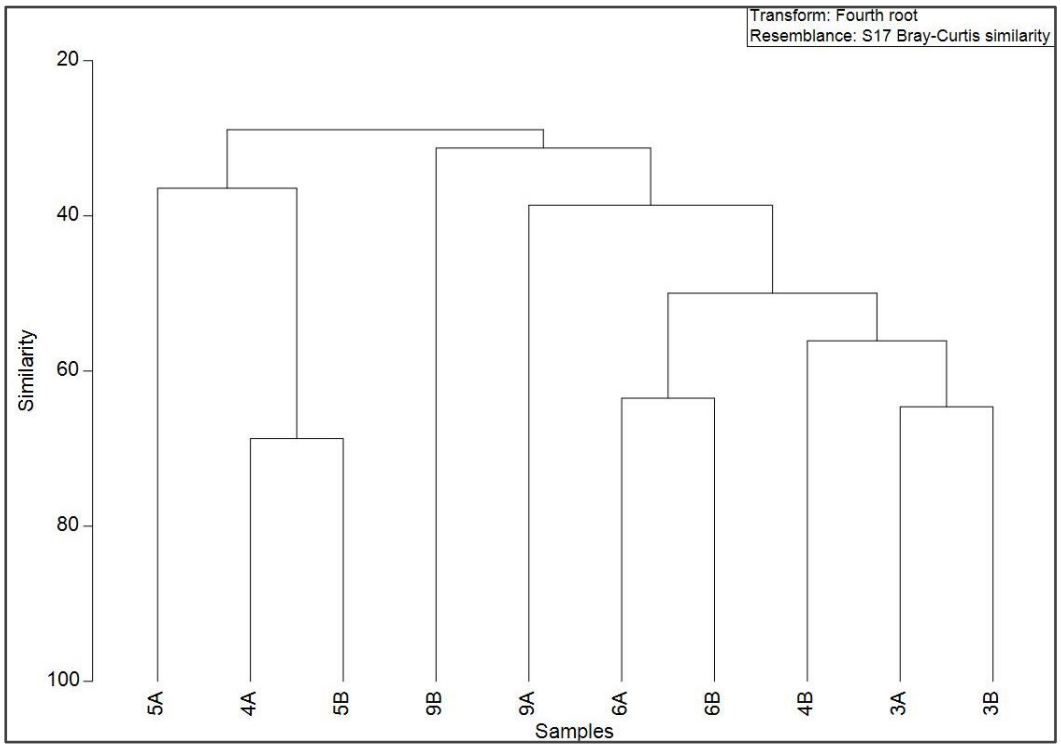

Figure 10. The Bray-Curtis pairwise similarity presented as an average linkage cluster analysis.

3.4 Density of *Leptosynapta* sp.

Specimens of *Leptosynapta* sp. were found in five of the eight stations in Kviturspollen. Table 7 shows the number of specimens found in each grab sample. Samples A and B were taken for the faunistic surveys, while samples C and D were taken for mapping the diversity of *L.* sp.

Table 7. The number of *L.* sp found in each sample in Kviturspollen.

Sample	3A	3B	4A	4B	4C	4D	5A	5B	5C	5D	6A	6B	6C	6D	7C	7D	8C	8D
Specimens	7	1	3	8	4	4	2	1	2	1	-	-	2	2	3	3	-	-

The density of *L.* sp. was highest at station 4 with 47.5 specimens per m^2, followed by station 3 with 40 per m^2, and station 7 with 30 per m^2 (Figure 11). Station 5 had 15 specimens per m^2 and station 6 had 10 per m^2, while there were no *L.* sp. found at station 8 or at the reference station (St. 9).

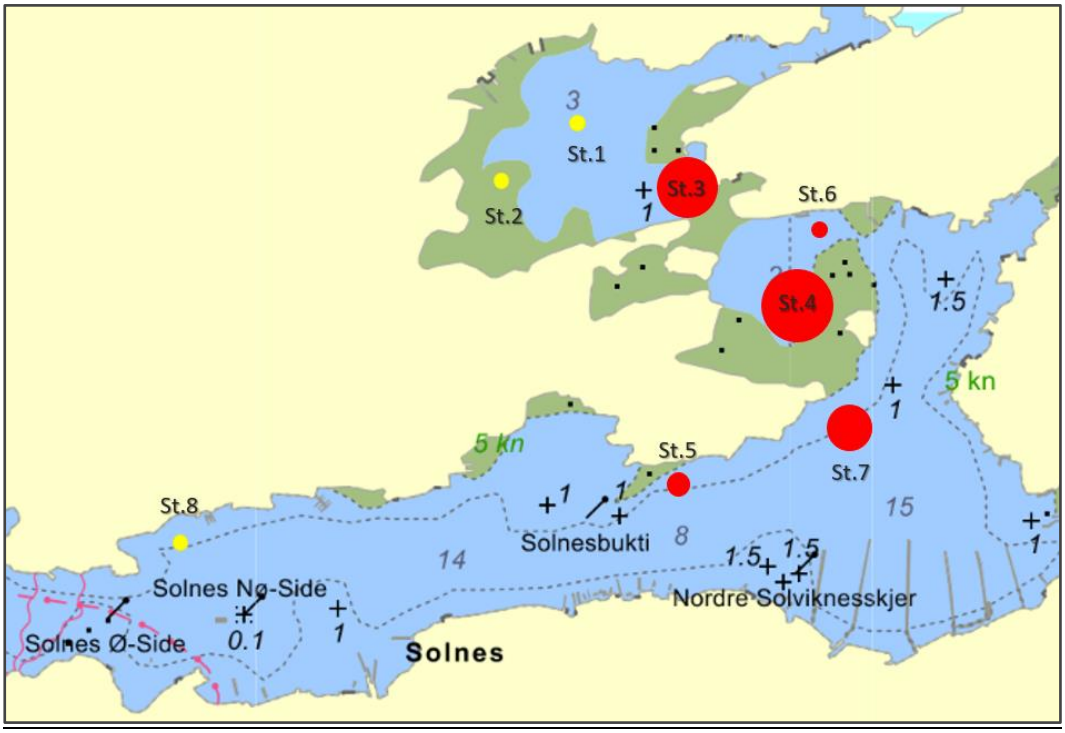

Figure 11. An overview of the *Leptosynapta* sp. density at each station in Kviturspollen. The yellow circles indicate a density of zero, while the size of the red circles represent the density: larger circle means higher density.

4. Discussion

To conclude on the ecological status of Kviturspollen, we need to look at the oxygen results, diversity, distribution, and sensitivity considering the past results and the possible changes caused by the opening of the canal in 1996.

4.1 High Oxygen Levels and Lifeless Bottom

Kviturspollen is a land-locked fjord, which is characterized by a shallow sill and poor bottom water exchange, and the oxygen levels in the bottom waters were therefore expected to be low (Kvalø et al., 2014). In addition to the sill, the canal that opened between Vågsbøpollen and Vestrepollen in 1996 changed the main current from Vågsbøpollen that previously had gone through Kviturspollen (Golmen & Nygaard, 1997). Kviturspollen also receives a great amount of runoff (Wassmann & Aadnesen, 1984), which could cause low salinity. The results from the past surveys of Kviturspollen have found very poor oxygen levels in the bottom waters, and frequent H_2S recordings. In this survey, however, high values of salinity and oxygen were found in all waters above the sea floor, yet some of the sediment samples had a characteristic smell of H_2S, indicating anoxic conditions. The inner part of Kviturspollen has the overall highest oxygen levels of the three areas, where all the measurements were in condition class I according to Guide 02:2018 (presented in Table 2), yet in the two stations with the most distinct H_2S smell (St. 1 and 2), no organisms were found in the sediment. This could perhaps be explained by looking at the previous CTD results from the area.

The past surveys of the oxygen levels in Kviturspollen have shown periodic and frequent periods with anoxic bottom water (Kvalø et al., 2014, 2015; Wassmann & Aadnesen, 1984). When there is a complete absence of oxygen for a longer period, the soft bottom infauna will not be able to survive. The periods when the water is oxygenated will have to be long for the community to reestablish. Because the anoxic periods in the past have been recorded frequently in the deeper parts of Kviturspollen, the communities in these areas might not have had enough time since the last anoxic period to reestablish in the areas, even though it had oxygen when our measurements were taken. This could explain why there were no organisms found in station 1 or 2, despite that the oxygen levels in the water were high. At station 2 there was eelgrass, but the sediment was, most likely, completely anoxic. Because of all the organic debris from the surrounding woods, and the low exposure to the current, the bottom in this area is very

muddy. In the inner part of Kviturspollen, many organisms were found in the more current exposed station 3.

Station 3 is located in the main current in the inner part, which provides a higher circulation rate and more oxygen. It is also shallow (3.8 m) and therefore is probably never anoxic. It is in an area with a very mosaic-like bottom, with small areas of soft-bottom sediment and other small areas with large rocks. It is only the deepest and most still parts, outside the main current, that are without life in the sediment and frequently undergo anoxic water conditions. The recipient survey in Bergen added station Kv5 (10 m) in the land-locked fjord to their monitoring studies in 2013 because the existing station, Kv1 (14 m), was too deep for there to be found life due to anoxic conditions in the deepest bottom waters (Kvalø et al., 2014**).** It is therefore not very surprising that we did not find organisms in the deepest area of the innermost part of the land-locked fjord.

All our oxygen measurements from the outer part of Kviturspollen, except for December 15, 2021, were in condition class I. The results from December 15, 2021, qualified to class II. The smell of H_2S was present also in the sediment samples from station 4, but because some animals were found here, it is assumed that the sediment is anoxic further down than it is at station 1 and 2, and that some organisms therefore can live in the upper centimeters of the sediment. Station 4 is probably not as frequently anoxic as stations 1 and 2, or the anoxic periods probably last for shorter periods of time.

4.2 Distribution of Diversity

There were great variations in the diversity between the stations in Kviturspollen. Station 3 had the highest Shannon value of 3.65 on average (Good), followed by station 6 with 2.68 on average (Moderate). Station 6 is located on a slope, which could explain less sedimentation and higher diversity at the station. The lowest diversities were found in station 4 and 5 (both "Poor"). Station 5 had the lowest Shannon value of all the stations inside Kviturspollen, except from station 1 and 2 with zero diversity. Station 3 and 6 are more exposed to the current than station 4 and 5, and station 1 and 2 are located completely on the outside of the current. The topography of the bottom in Kviturspollen is known from past studies to be locally either muddy or more rocky (Dybern, 1967). This could explain the large variation between nearby stations, such as station 6 and station 4.

Some nearby stations also showed high dissimilarity based on the Bray-Curtis analysis. For example, based on location, it would be expected that station 6 and 4 had higher similarity than station 6 and 3, but the Bray-Curtis analysis shows that the opposite occurred. Station 3 and 6 have more similar sediment and local environment than station 6 and 4 have. Station 4 and 5 showed high similarity although they are located relatively far from each other, but these stations both have a high amount of sedimentation and a medium exposure to the current. This shows that in Kviturspollen, the bottom topography and amount of sedimentation is very local and has a large impact on the diversity.

The samples varied from "Very poor" to "Excellent" Shannon values. At some of the stations, the two samples showed low similarity. At station 4, only 8 species were found in both samples, meaning that sample 4B contained 11 species that were not present in sample 4A at all (Table 4). The two samples from station 5 had only three present species in common, so it is likely that there are more species in these stations than we found in this survey. The average Shannon value in Kviturspollen was only moderately high, but the land-locked fjord has some species that are unique to ecosystems like Kviturspollen.

The density of *Leptosynapta* sp. was highest at stations 4, 3 and 7, showing no clear gradient from inner to outer parts of Kviturspollen. There was no *L.* sp. found at station 9, which is not surprising as the environment in station 9 is quite different from what the holothurian normally prefers. The sediment at station 9 was sandy with high amounts of shell fragments, while *L.* sp. is mostly found in sediments dominated by mud and organic matter. Inside the land-locked fjord, the species was found in station 3, 4, 5, 6 and 7, with the highest density at station 4. Most of these stations were very muddy. No *L.* sp. were found in station 8, which is surprising, as the sediment is muddy, and the samples were taken at the same depth as the samples from station 7. We also know that the station was habitable because other organisms were found there, although these were not counted and used in the biodiversity calculations. The density was the highest in the middle part of Kviturspollen, in the areas with mud and small gravel.

Leptosynapta sp. seems to prefer muddy, but not H_2S affected areas. It is assigned to the NSI EG II (Direktoratsgruppen vanndirektivet, 2018b), meaning it is a rather sensitive species and does not like affected areas. It could perhaps function as an indicator species of oxygenated sediment with moderate to high content of organic matter. The bottom fauna surveys gave no observations of *Devonia perrieri*, and this thesis can therefore not support the bivalve and *L.* sp. having a symbiotic relationship.

4.3 Sensitivity of the Species

In Kviturspollen (station 9 excluded), the average ISI and NQI1 were "Good", and the average NSI was "Moderate" in our results. The ISI values were generally higher than the NSI values, which indicates that there was a domination of specimens from the species with higher tolerance than the average species in the samples. Station 3 and 6 had the highest diversity and sensitivity of the stations in the land-locked fjord.

The samples from station 3 had "Good" and "Excellent" Shannon values and "Good" and "Moderate" NSI values, meaning the Shannon classes were one level higher than the NSI classes in both samples. This tells us that although the diversity in the samples were high, the species found were more tolerant than sensitive, indicating that the area is probably more affected than the Shannon class implies. The most abundant species in the samples from station 3 were *Kurtiella bidentata*, *Pholoe* sp., and *Orbiniidae* sp. *K. bidentata* is in NSI EG IV, and *Pholoe* sp. is in EG II while *Orbiniidae* sp. is not assigned to a group. The dominating number of *K. bidentata* (32%) in NSI EG IV can explain part of why the NSI class is lower than the Shannon class.

The samples from station 4 and 5 showed the opposite pattern of station 3. In these stations the Shannon class was lower than the NSI class. The Shannon values were "Moderate", "Poor" and "Very Poor", while all the NSI values were "Moderate". *K. bidentata* dominated the specimen abundance in station 4 with 69%. *Crisilla semistriata* is not assigned to an NSI EG, and *Platynereis* sp. is in NSI EG III (Rygg & Norling, 2013). Sample 4A had a "Very poor" Shannon value, but the sensitivity indices indicate that although there are very few species present, these are not very tolerant. The most abundant species in station 5 were *K. bidentata* (64%), *Platynereis* sp. (8%), and *Microdeutopus anomalus* (8%). *M. anomalus* is assigned to NSI EG I, meaning it is a very sensitive species. Because there is a high abundance of sensitive species, the NSI is moderate despite the Shannon being moderate to low.

At Station 6 the Shannon and the NSI classes were the same (Moderate). There was a vast dominance of specimens from the species *Protodorvillea kefersteini* (59%), which is in NSI EG IV (Rygg & Norling, 2013). The second and third most abundant species were *Cirriformia tentaculata* (6%) and *Platynereis* sp. (6%), but these are not assigned to an NSI ecological group. The "Moderate" Shannon value can be explained by a low evenness between the species

abundance, and the “Moderate” NSI can be explained by the most dominant species being in EG IV.

At our reference station, station 9, the Shannon was slightly higher than the NSI. The Shannon classes for the samples were “Excellent” and “Good”, and the NSI were “Good”. The highest abundance of specimens were of species *Protodorvillea kefersteini* (10%), *Platynereis* sp. (9%), and *Chaetozone* sp. (9%). The evenness was relatively high, and the NSI ecological group of the most abundant species were III and IV (Rygg & Norling, 2013).

The Shannon diversity index gave generally lower classes than did the sensitivity indices. Except for sample 3A and 9B, all the samples had a Shannon class that was either the same as the poorest of the sensitivity classes, or a class down. 3A and 9B were the only samples that showed an opposite pattern with an “Excellent” Shannon value, while the sensitivities were “Good”. The pattern shows, however, that for this land-locked fjord, the diversity and evenness was poorer than the actual quality of the ecosystem that the species and organisms in the samples indicate. Using the Shannon diversity index alone would have given an inaccurate picture of the state of the bottom community in Kviturspollen.

4.4 Development in Kviturspollen Over the Last Years

In 1990, *Oxydromus flexuosus* was the only species dominating (Johannessen et al., 1991). This is a species assigned to the NSI EG III (Direktoratsgruppen vanndirektivet, 2018a). The samples from that year also showed a very low Shannon of 0.55 in average, which would qualify to class “Very poor” on the class limits from Guide 02:2018 (Table 3). It is important to emphasize that the samples collected in 1990 were from the deepest part of the land-locked fjord only, Kv1, so a direct comparison of the ecological state that year might be misleading. In 2013 and 2014 the samples were taken from a shallower station, Kv5, and these results showed a higher average Shannon of 2.65 in 2013, and 3.61 in 2014 (Kvalø et al., 2014, 2015). These results would qualify to “Moderate” and “Good” condition classes. The average Shannon value from all samples from this survey is 2.81, a “Moderate” condition class. The Shannon value in Kviturspollen has therefore not changed markedly since 2014, but there might have been a positive development in the diversity since 1990.

In this study, an average of 310 specimens were found per grab sample in Kviturspollen, which is more than was found in 2013 and 2014. In 2013, an average of 83 specimens were found per

sample, and in 2014, 176 specimens were found per sample, meaning that in this survey, a much higher density of specimens were found. The three most abundant species were *Scalibregma inflatum* (46%), *Capitella capitata* (13%) and *Ophiocten affinis* (8%) in 2013 (Kvalø et al., 2014), and *Pholoe inornata* (20%), *Chaetozone* sp. (13%) and *O. affinis* (10%) in 2014 (Kvalø et al., 2015). In the results from this study, the most abundant species were *Protodorvillea kefersteini* (31%), *Kurtiella bidentata* (23%), and *Platynereis* sp. (7%). There has been a shift in which species are the most abundant in Kviturspollen, but there has not been a clear shift in what Ecological Groups the most abundant species belongs to. The most abundant species from 2013, 2014 and 2021/2022 all belong to NSI EG III and IV, except for one that belongs to EG V. The value of combined index NQI1 has, however, improved.

The NQI1 gave a "Moderate" value of sensitivity and diversity in both 2013 and 2014 (Kvalø et al., 2014, 2015). In this survey, the average NQI1 value of the stations inside Kviturspollen, was 0.65, which is in the "Good" class. This is a one class increase from the results in 2013 and 2014, and could indicate a slight improvement of the ecological status.

4.5 Summary

Land-locked fjords are characterized by their limitation in exchange of oxygen-rich bottom water due to shallow sills, and a high amount of runoff. Kviturspollen is a land-locked fjord south of Bergen, and to increase the water exchange of the land-locked fjord next to Kviturspollen, a canal was opened in 1996 between Vågsbøpollen and a neighboring fjord. This reduced the current in Kviturspollen, but there has not been an obvious reduction in the quality of the ecosystem or oxygen levels in the land-locked fjord after this.

In this thesis, I have surveyed the biodiversity of the soft-bottom fauna, and the oxygen saturation in Kviturspollen. During the field work, we found that the sediment in some stations was anoxic just beneath the surface, although the water itself was oxygen rich. At these two stations, no life was found. This conforms with past results showing that the deeper basins have periodically anoxic bottom water, and it is therefore likely that bottom water in these two stations are anoxic in frequent or long periods.

The samples from our reference station, station 9, showed a clear difference from the samples in Kviturspollen, mainly in species composition, but also in higher values of diversity and sensitivity. There was also a noticeable difference between the two samples from this station,

as one had approximately twice as many organisms as the other. This is in all probability due to a large amount of macroalgae from one of the grabs, containing epizoans and associated fauna not found in the other grab.

A direct comparison of the results from the previous surveys of Kviturspollen with the results found in this thesis, is difficult, as previous surveys only examined one or two stations in the outer part, while this survey has studied 1-3 stations in three parts of Kviturspollen. It is therefore only the average value from this survey that will be used to compare with the previous results. Based on this, the ecological status of Kviturspollen shows no pronounced deterioration or improvement since the canal was opened in 1996. The bottom fauna analyses from the stations with life showed an average medium to low diversity, which is in accordance with results from 2013 and 2014. There is a slight increase in the density of specimens found in the land-locked fjord, and the NQI1 index in this survey also showed an increased average value. The CTD measurements in this survey showed high oxygen levels and no H_2S in the waters. These are improvements from the surveys in 2013 and 2014.

During this survey, there were some areas with high diversity and sensitivity of organisms, and others with no life at all. There was no clear pattern in the status of the samples on a gradient from the inner to the outer basins, but there was an evident increase in the status of the locations that were exposed to the current in Kviturspollen compared to those that were not.

5. Conclusions

In conclusion, Kviturspollen is an area that is clearly affected, without any significant improvements in the ecological status shown in recent years. Despite having a harsh environment for organisms, the land-locked fjord habits a great variety of species. Because the bottom sediment composition in Kviturspollen varies greatly between near locations (Dybern, 1967), there is also a great variation in diversity and sensitivity between close locations. The variations in depth, slope and sediment creates many different habitats, and land-locked fjords like this can therefore function as a habitat to a great diversity of species, including species that are less common in other ecosystems. *Leptosynapta* sp. was an example of this, as it had the highest density in some of the areas of Kviturspollen that had low density of other species and was not found in our reference station outside the land-locked fjord.

This thesis also shows that in areas that are affected and have harsh living conditions, such as land-locked fjords with high amounts of runoff, organic debris and anoxic conditions under the sediment surface, smaller areas within can still have good conditions, such as station 3 and 6 are examples of. This can be due to a different topography than the general area, and higher exposure to currents. Two of our innermost stations were completely lifeless with H_2S in the sediment, which can be explained by periodically anoxic water conditions found by previous surveys. Our results, however, found that the oxygen levels were high in all parts of Kviturspollen.

There has been a shift in the most abundant species in the land-locked fjord, but the average NSI class has not changed after 2013/14. The land-locked fjord is generally at a “Moderate” state, but some areas have a great abundance of species and organisms, and other areas have no benthic life. There are no pronounced improvements in the oxygen conditions, but slight NQI1 value-improvements, and an increased density of specimens found since the last surveys. The inner part of Kviturspollen has very poor community conditions outside the current, while the middle part shows variations between moderate and good conditions in diversity between close locations, also appearing to depend mainly on current exposure. The outermost part of Kviturspollen shows moderate conditions in diversity and sensitivity, but these are still not good. Further surveys of Kviturspollen are needed to document a trend in order to conclude on the ecological status and prospects of the area, as this survey showed no clear improvements since 2014.

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Appendix I. Complete Species List

Species list containing all specimens found in the two grab samples (A and B) at station 3-6, and 9.

	3A	3B	4A	4B	5A	5B	6A	6B	9A	9B
Phoronida										
Phoronida indet.		(+)							(+)	(+)
Nematoda										
Nematoda indet.	(+)	(++)	(+)	(+)	(+)	(+)	(++)	(++)	(+)	(+)
Nemertea										
Nemertea indet.	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Mollusca										
Abra alba			1					1		1
Akera bullata		1								
Corbula gibba	7	11		1			4	1	1	
Crisilla semistriata	9	6	5	13	1	2	6	3		
Eulimella scillae							2			
Hiatella sp.				1						
Kurtiella bidentata	31	177	198	88	13	48	42	19	9	5
Lepidochitona cinereus								1		
Littorinidae sp.		1								
Lucinoma borealis		3					1	1		1
Lutraria sp.		1							1	
Mendicula ferruginosa							1			
Mytilus edulis	3	6		1			2			
Onoba sp.	1	2		13						
Parvicardium pinnulatum	6	1	1	2		1	2	1	2	
Pyramidellidae sp.								1		
Retusa truncatula	5									
Retusa umbilicata							1			
Thyasira flexuosa									5	6
Tonicella rubra									1	
Annelida										
Aonides sp.		3								
Arenicola ecaudata			1							

	3A	3B	4A	4B	5A	5B	6A	6B	9A	9B
Capitella sp.	1				1		18	1		5
Capitellidae sp. 1							8			
Capitellidae sp. 2							2			
Capitellidae sp. 3									10	
Chaetozone sp.	3	1						2	27	
Cirratulidae indet.	2	2					17	23		
Cirriformia tentaculata	5	3					34	44		
Eteone sp.	17	12					1	6	1	
Eulalia sp.							3	2		
Eumida sp.							2			
Exogone sp.							1			
Glycera alba	3							2	3	
Harmothoe mariannae								3		
Harmothoe sp.									2	
Hesionidae indet.	2	6		1			7			1
Hesionidae sp. 1								2		1
Hesionidae sp. 2								1		
Hesionidae sp. 3								1		
Hesiospina sp.		3							5	2
Heteromastus sp.							1			
Heteromastus/ *mediomastus* sp.							5	2		
Lagis koreni	2	1								
Lumbrineridae indet.									2	
Macrochaeta clavicornis	6	9		12			11	5		
Malacoceros sp.									1	
Mediomastus sp.	2					1	20	1		
Nephtyidae indet.								2		
Nereididae indet.								9		
Notomastus sp.							3	2	1	
Oligochaeta sp.	1						6	1		
Orbiniidae sp.	42	10					1	3	21	
Oxydromus flexuosus	4						5			

	3A	3B	4A	4B	5A	5B	6A	6B	9A	9B
Pholoe sp.	38	28	9	3	2	4	20	15	9	
Phyllodoce mucosa								2		
Phyllodoce sp.							1			2
Pista sp.									1	
Platynereis sp.	30	15	7	15		8	66	13	3	24
Polycirrus sp.	4	1					13	4	9	
Polynoidae indet.									1	
Prionospio sp.									2	
Protodorvillea kefersteini	9	38		12		2	424	353	27	4
Psamathe fusca		1					4	3	11	1
Scalibregma inflatum	10							4	6	
Spio sp.	7	1					5	5	1	
Spionidae indet.									1	2
Syllidae sp. 1									1	
Syllidae sp. 2									1	
Syllidia armata	1									
Terebellidae indet.		1								
Echinodermata										
Amphipholis squamata	3	17	1	5			1	2	25	2
Asteroidea indet.						1				
Echinocyamus pusillus	1			1			22	11		
Echinoidea indet.		1								
Hippasteria phrygiana							1			
Holothuroidea indet.									1	
Holothuroidea sp. 1									1	
Leptosynapta inhaerens	7	1	3	7		1				
Leptosynapta bergensis					1					
Leptosynapta sp.				1	1					
Crustacea										
Apherusa bispinosa									3	1
Cheirocratus sundevallii	1			2				2	4	
Crassicorophium bonellii		2						1		

	3A	3B	4A	4B	5A	5B	6A	6B	9A	9B
Crassicorophium sp.		1								
Dexamine spinosa	2									2
Eualus cranchii					1				7	10
Galathea intermedia									9	5
Hippolyte varians									1	
Liocarcinus navigator				1			1	1	1	
Microdeutopus anomalus	13	4	1	9		8		1	1	4
Pagurus bernhardus									1	
Phtisica marina									1	