Western Norway University of Applied Sciences

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BACHELOR'S THESIS

The Barsnesfjord holistic science approach: Implications on the application of the EU Water Framework Directive

Shiraley Kerbusch

Programme	Geology and geohazards
Department	Environmental sciences
Supervisor	Dr. Matthias Paetzel
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Abstract

The current EU Water Framework Directive (WFD) classification of the Barsnesfjord is “Bad”. The final WFD classification includes within the biological quality elements only the Shannon Index (H’) of benthic macro-invertebrates. The chemical quality elements showed a “Very bad” WFD classification based solely on mercury (Hg) found in fish in the distant Aurlandsfjord and Sognefjord outside Balestrand. The analyses of this classification occured exclusively in space.

The improved classification of this thesis increases the amount of quality elements and data. The parameters used for this new Barsnesfjord WFD classification are (a) Biological quality elements: Macro-algae (RSL/RSLA), benthic macro-invertebrates (ES_{100}, H’, NQI 1, ISI_{2012}, NSI), benthic foraminifera (ES_{100}, H’); (b) Chemical quality elements: Inorganic pollutants (trace metals As, Cd, Cr, Cu, Hg, Ni, Zn) and organic pollutants (PAHs, PCBs, TBT); and (c) Physical quality elements: Oxygen and transparency. The analyses of the improved classification of this thesis occurs in space and, where possible, in time (i.e. benthic foraminifera, pollutants and oxygen).

The improved classification of this thesis defines the Barsnesfjord at a “Bad” WFD environmental status with NSI and ISI_{2012} included, and at a "Very bad" WFD environmental status with NSI and ISI_{2012} excluded. A reason for excluding the NSI and the ISI_{2012} is that the classification of these two indexes is a result of few, and thus less reliable data.

The improved classification of this thesis also includes a recommendation to define a WFD classification for “Naturally oxygen deficient fjords”, to help controlling the economic aspects involved in the WFD demand of converting the environmental status from “Bad” into “Good” in the Basnesfjord.

Further, the Sogn og Fjordane County Municipality confirmed that the government only has limited knowledge of the current WFD status of the Barsnesfjord. During an interview, two points emerged to increase the awareness of the authorities involved in water management:

- Producing more knowledge about sources and source areas of the parameters leading to the “Bad” environmental status of the Barsnesfjord. This would increase the pressure on politicians and managers to act.
- Make people who work directly or indirectly with water in Norway more aware of the EU Water Framework Directive. This would allow the authorities to incorporate the WFD demands into their own management plans, and thus into their budget.

Finally, this thesis points out beneficial values for the local society, as possible tools in a WFD based water management. The recommendations based on the results of this thesis are:

- Including a classification for “Naturally oxygen deficient fjords” in the Barsnesfjord environmental investigation, thus lowering the costs involved in converting the environmental conditions in the Barsnesfjord from a “Bad” to a “Good” environmental status.
- Starting a campaign on the recreational value of a clean fjord environment to increase the interest of local people in the environmental issues of the Barsnesfjord.
- Focusing on those parameters that need improvement.
- Setting their first priority on stopping further deterioration.

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1. Introduction

1.1 General introduction

The Water Framework Directive (WFD) of the European Union (EU) aims at protecting and improving the status of aquatic ecosystems, and stimulating sustainable water use throughout their member states and associated countries (European Commission, 2000). The EU implemented the WFD of mainly these reasons:

- Water is vital for people, as well as it forms the basis for food and energy production (European Commission, n.d.). The resulting excessive use of water implies stress to the environment. The WFD tries to reduce this stress.
- Biodiversity and even climate variability depend on the distribution of water. The WFD encourages to responsible management of the water resources.
- Country borders do not stop air and water pollution. This was the reason to implement a European-wide directive that controls the ecological and chemical status of water bodies.

The WFD entered into force in 2000 with successive ratification in the EU countries. Based on the above reasons, the WFD formulated the following major goals (European Commission, 2019):

- Protecting all open and ground waters according to specified "Good" status conditions within given deadlines. The WFD introduced a colour code for environmental classification and status conditions of water bodies as described in Table 1.

Table 1*.The WFD colour code for the environmental status of water bodies, modified after Direktoratsgruppen vanndirektivet (2018a), i.e. the Norwegian implementation of the EU WFD.*

Colour code	Status	Water body conditions
Blue	Very good status	Natural or close to natural
Green	Good status	Affected; no effects harmful to organisms
Yellow	Moderate status	Affected; organisms getting stressed
Orange	Bad status	Strongly affected; clearly reduced biodiversity
Red	Very bad status	Very strongly affected; mostly lethal effects on organisms

- Involving water management of river and water systems across country borders, including common emission limits and quality standards.
- Straightening out laws, giving information to the public and opening up for the opportunity for people to getting involved in decision-making processes.

This thesis is part of a larger marine environmental project investigating the Barsnesfjord, Western Norway, in a holistic approach, i.e. regarding its hydrographic, ecologic, chemical and geologic change over the past 50 years. The investigation contributes to the mapping of the quality of the Barsnesfjord aquatic system with respect to the Vannforskriften, which is the Norwegian implementation document of the European Union Water Framework Directive (English-WFD in Norway, 2015).

The investigation of the Barsnesfjord rose the following issues regarding the application of the WFD in the region:

Water quality

Only limited information exists for a WFD water classification of the Barsnesfjord. An investigation of Paetzel & Schrader (1991; 1992) suggests an influence of the local Årøy hydropower plant on the sedimentation pattern, and thus on the water column of the fjord since the early 1980s.

Paetzel & Dale (2010) interpret an additional climate impact from the fjord sediment record of the past 20 years. Both investigations allow conclusions on a changing hydrography in the Barsnesfjord.

In addition, the Western Norway University of Applied Sciences is taking hydrographic samples (oxygen, temperature, salinity, turbidity) annually since the year 2001. Kaufmann (2014) made some of these hydrographic data available in her Bachelor thesis.

These investigations do not conclude on the environmental status of the Barsnesfjord. In spite of that, the Sogn og Fjordane County Municipality, i.e. the responsible governmental agency for the implementation of the WFD, allocated a WFD "Bad" (orange) environmental status for the ecological condition and a "Very bad" (red) environmental status for the chemical condition to the Barsnesfjord water body. It is one aim of this investigation and this thesis to verify the choice of status classification of the Barsnesfjord.

Fjord definition

The investigations of Paetzel & Schrader (1991; 1992) conclude that the Barsnesfjord is a naturally anoxic (Inner Barsnesfjord) and periodically anoxic (Outer Barsnesfjord) fjord system. The WFD classifies such oxygen conditions of <2 mgO_2/l as "Bad" status, meaning, that these conditions need to improve in the future to meet the WFD requirements.

The EU WFD defines a set of coastal water type conditions, including "Naturally oxygen deficient fjords" (Direktoratsgruppen vanndirektivet, 2018a). However, the WFD classification does not include fjords and transitional land-sea systems of naturally occurring low oxygen concentrations in their calculation of these coastal water status conditions (Direktoratsgruppen vanndirektivet, 2018a).

The application of the WFD classification should thus somehow take care of water systems that cannot improve their "Bad" (orange) environmental status due to the natural character of their occurrence. It will be another aim of this thesis to contribute to the WFD classification by differentiating between a naturally occurring and a human induced "Bad" environmental status of fjord water conditions.

Awareness

The Sogn og Fjordane County Municipality (Christian Pettersen, 2019, *personal communication*) confirmed that the government only has limited knowledge of the current WFD environmental status of the Barsnesfjord. The reason for the lack of awareness is a limited number of governmental controlled investigations on the parameters required by the WFD. Lacking awareness by the government would imply a lacking awareness of the people.

It will be a third aim of this thesis to contribute to the governmental and public awareness of the environmental condition of the Barsnesfjord by communicating research results to the government, and by this adding information to the database for the classification of the Barsnesfjord environmental conditions within the EU WFD. These results will include suggestions on how the government might increase the awareness of the public in the future.

1.2 Problem description and analyses

One of the keys issues of the EU Water Framework Directive is to achieve a "Good" status for all open and ground waters within a given deadline. The first given deadline was in 2015 (European Commission, n.d.). Still sixty percent of the European surface waters have not reached a "Good" status (European Environment Agency, 2018; World Wide Fund for Nature, 2019). One reason for this uncertain classification is the limited presence of data for classification. As an example, the classification of the Barsnesfjord builds upon research in areas outside the Barsnesfjord (Vann-Nett, n.d.). Awareness starts when environmental data are available, in this case challenging the government to providing these data.

Especially in Norway, an additional reason for a "Bad" (orange) environmental status classification of fjord environments might be that the WFD does not apply the category of "Naturally oxygen deficient fjords" in their status condition calculations (Direktoratsgruppen vanndirektivet, 2018a). The Sogn og Fjordane County Municipality agreed in an interview, that the government has a challenge to classify naturally anoxic conditions within the WFD (Christian Pettersen, 2019, *personal communication*).

The resulting challenge splits into two parts: (a) Increasing the environmental awareness by providing a sufficient amount of classification data, and (b) Introducing a revision of the classification of naturally oxygen deficient water bodies. Awareness of the environmental condition of the Barsnesfjord will build up based on these results. To contribute to this awareness, the thesis will focus on the following questions.

1.2.1 Objectives

1. **How will the holistic environmental investigation of the Barsnesfjord affect the environmental status of the fjord within the EU Water Framework Directive?**
    a. What selected biological, chemical and physical quality elements (key parameters) could test the environmental status of the Barsnesfjord within the EU WFD?
    b. Will the results of such an environmental investigation of the Barsnesfjord affect the environmental status of the fjord within the EU WFD?
    c. Is the EU WFD environmental status classification sufficient to properly identify and describe the environmental status of the semi-enclosed, naturally oxygen deficient Barsnesfjord?

2. **Would a changing status influence the environmental awareness of the people living close to the fjord and the involved authorities?**
    a. Are the people living around the fjord aware of the recent environmental status of the Barsnesfjord and the possible change in this status?
    b. What measures could increase this awareness?

3. **What is the beneficial value of this research to society in terms of "People, planet and profit"?**

1.2.2 Objective explanation

Objective 1. How will the holistic environmental investigation of the Barsnesfjord affect the environmental status of the fjord within the EU Water Framework Directive?

The first main objective covers the natural science research part. Answering this question requires summarizing the existing WFD classification and, based on this, choosing environmental key parameters for the Barsnesfjord investigation. These key parameters, the so-called biological, chemical and physical quality elements (Table 2; Direktoratsgruppen vanndirektivet, 2018a) should form the basis for a re-evaluation of the classification of environmental parameters in the Barsnesfjord environment.

- ***Objective 1a.*** *What selected biological, chemical and physical quality elements (key parameters) could test the environmental status of the Barsnesfjord within the EU WFD?*

  The WFD key parameters consist of biological quality elements, supported by chemical, physical and hydro-morphological quality elements as listed in Table 2 (Chapter 2). In the first place, this thesis selects quality elements related to a direct and numerical status evaluation. The choice of quality elements should be sufficient to evaluate the environmental status of the fjord. Key parameters include (a) Biological macroscopic and microscopic quality elements: Macro-algae, benthic macro-invertebrates, and benthic foraminifera. (b) Chemical quality elements: Inorganic pollution, organic pollution. (c) Physical quality elements: Hydrography, focusing on oxygen concentrations and transparency. (d) Hydro-morphological parameters are not part of this investigation that concentrates on water and sediment quality.

- ***Objective 1b.*** *Will the results of such an environmental investigation of the Barsnesfjord affect the environmental status of the fjord within the EU WFD?*

  The thesis will use the numerical results of Objective 1a for a classification of the environmental status of the Barsnesfjord according to EU WFD standards. This will confirm, revise, or add on former WFD environmental classifications of the Barsnesfjord. The resulting classification will form the basis for answering Objective 1c regarding the application of the categorization of "Naturally oxygen deficient fjord" environments.

- ***Objective 1c.*** *Is the EU WFD category of "Coastal waters" sufficient to properly identify and describe the environmental status of the semi-enclosed, naturally oxygen deficient Barsnesfjord?*

  The first step in answering this question will be summarizing the EU WFD classification of water bodies within their existing categorization of coastal waters. The thesis will apply the category of "Naturally oxygen deficient fjords" on the environmental status classification of the Barsnesfjord conditions. This application should result in a revised environmental classification of the Barsnesfjord.

Objective 2. Would a changing status influence the environmental awareness of the people living close to the fjord and the involved authorities?

The second main objective involves interviewing the responsible governmental authority, providing supplementary data to the numerical data set of Objective 1. It will attempt an application of the numerical data set on creating an environmental awareness of people and decision makers.

Answering this objective requires setting up an interview with the involved authority, i.e. the Sogn og Fjordane County Municipality.

- ***Objective 2a.*** *Are the people living around the fjord aware of the recent environmental status of the Barsnesfjord, and the possible change in this status?*

  The interview will focus on the following topics:

  - The awareness on the current environmental status of the Barsnesfjord.
  - The awareness on the significance of the environmental status classification of the Barsnesfjord within the EU Water Framework Directive.
  - The awareness of the people's own responsibility in changing and/or maintaining the environmental status of the Barsnesfjord.

- ***Objective 2b.*** *What measures could increase this awareness?*

  It is the major task of this objective to formulating recommendations on how authorities and the people of the region can increase their engagement in the process of defining, changing, and/or maintaining the environmental status of the Barsnesfjord.

Objective 3. What is the beneficial value of this research to society in terms of "People, planet and profit"?

In combination of Objective 1 and Objective 2, this thesis will contribute to understand the connection between social, environmental and economic aspects in society, also termed as "People, planet and profit". Elkington (1994) first described these corner stones of sustainability as "The Triple Bottom Line (TBL)" putting a focus on how to measure sustainability (Elkington, 1994; Elkington & Rowlands, 1999).

According to Elkington (1994), sustainable research should involve a balance between "People, planet and profit":

- There is a good chance that stakeholders and decision makers will follow up results of a research, if these results can make a positive contribution to the economic sphere.
- Research that benefits the environment might lead to an improvement of the environment if the resulting proposed change is economically feasible.
- For changes to take place there must be sufficient public support. In order to generate carrying capacity, i.e. general acceptance it is useful to make it clear to people how they benefit from a change.

1.3 Environmental setting

1.3.1 Fjords

The scientific definition of a fjord is "a deep, high-latitude estuary which had been (or is presently being) excavated or modified by land-based ice" (Syvitski et al., 1987).

The formation of the Norwegian fjords started during the Middle Cenozoic time, about 35 million years before the present (35 my BP), when the Norwegian mainland was uplifted by up to 2000 m during the plate tectonic opening of the North Atlantic (Holtedal, 1967). This elevation formed a highland plateau called the Paleic surface (Figure 1.1).

Water started to drain from that plateau towards the sea in the west by eroding and incising the landscape (Figure 1.2), following the weakest, westward stretching tectonic zones of the bedrock. This river erosion formed V-shaped valleys. Deepening and widening of these valleys (Figure 1.3) occurred successively during the alternation of 23 glacial and interglacial periods since the onset of the Quaternary glaciations about 2 my BP (Ramberg et al., 2008).

When this glacial valley erosion reached sea level, erosion carried on below sea level. This over-deepening process (Figure 1.3) resulted in a glacially shaped marine estuary, i.e. a fjord per definition (Syvitski et al., 1987). Glacial over-deepening (i.e. deepening below sea surface) eroded the fjord valley (Figure 1.4) of the Sognefjord down to 1.308 m below sea level during the past 2 million years (Nesje & Williams, 1994).

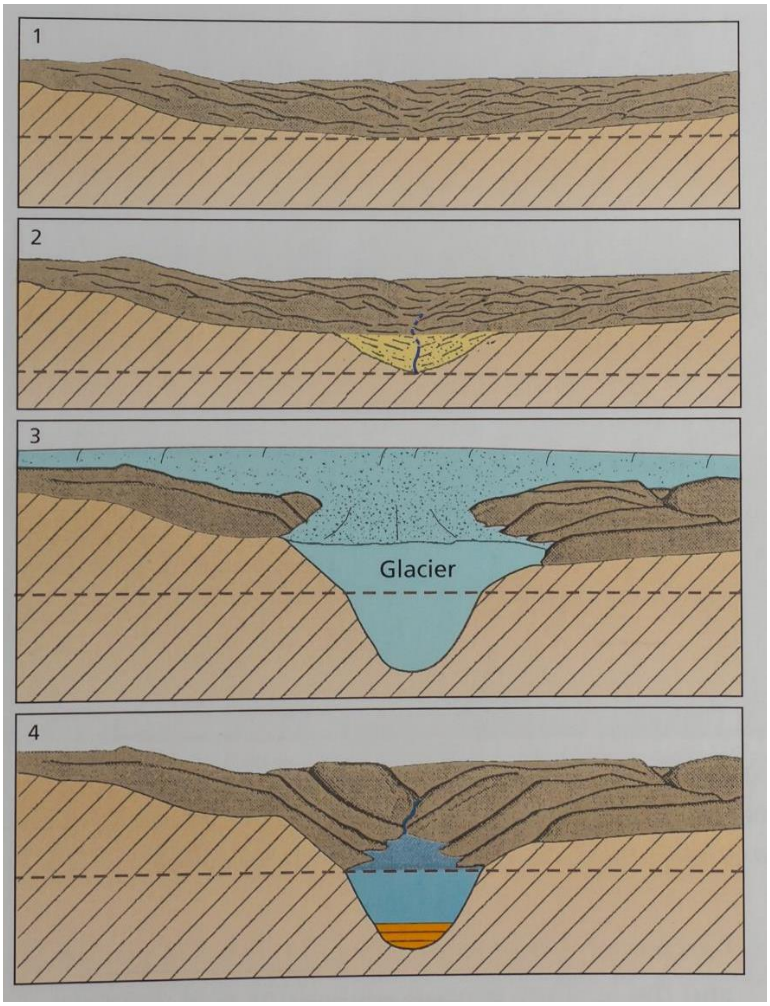

Figure 1. *Principal sketch of fjord formation, indicating (1) the uplifted Paleic surface, (2) the river incision, (3) the glacial over-deepening, and (4) the final fjord product (Ramberg et al., 2008).*

The hydrographical structure of Norwegian fjords consists usually of three different layers (Figure 2). Freshwater supply from rivers forms the brackish surface water layer. The thickness of this layer depends on the size of the fjord and the amount of freshwater supply. It varies mostly between one and five meters. The intermediate water layer marks the transition between the upper brackish water layer and the deeper basin water. The intermediate layer has generally the same properties as the water outside the fjord at the same depth. The basin water reaches from below sill depth down to the fjord bottom. The depth of the sill depends on the morphology of the respective fjord, and can range between a few meters and up to several hundred meters water depth (Aksnes et al., 2019).

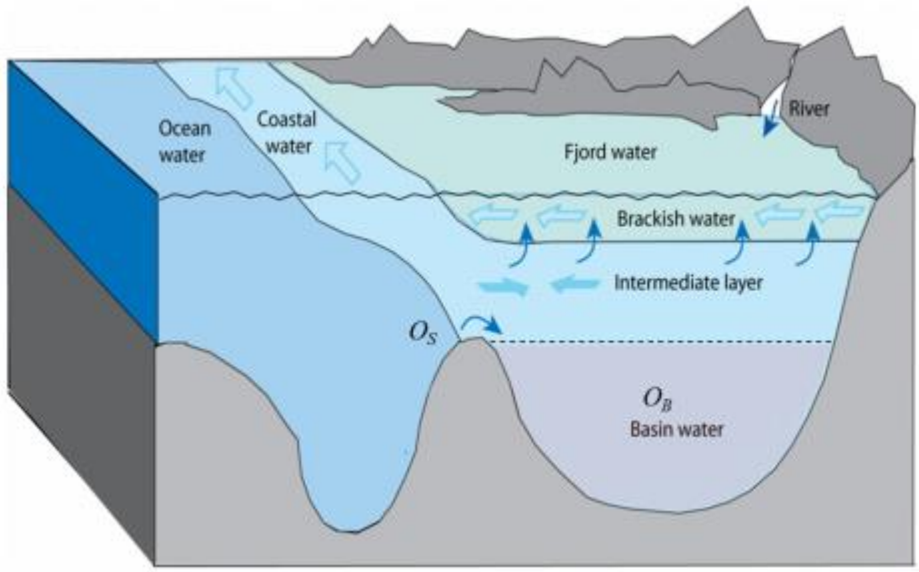

Figure 2. *Principle water layers of semi-enclosed and silled Norwegian fjord basins. O_S indicates elevated oxygen concentrations of the open ocean water; O_B indicates diminished oxygen concentrations of fjord basin waters (Aksnes et al., 2019).*

1.3.2 The Barsnesfjord

The Barsnesfjord, located in Western Norway, consists of the Inner- and Outer Barsnesfjord basin (Figure 3). A 29 m deep sill separates the Inner Barsnesfjord basin from the Outer Barsnesfjord basin (Paetzel & Schrader, 1991). The Inner Barsnesfjord is 66 m deep and permanently anoxic below 62 m water depth, while the Outer Barsnesfjord is 88 m deep and periodically anoxic at the fjord bottom (Paetzel & Dale, 2010). The Outer Barsnesfjord goes over into the 260 m deep Sogndalsfjord, separated by a 7,5 m deep sill. Paetzel & Schrader (1991; 1992) and Paetzel & Dale (2010) describe the environmental and the general hydrographic setting of the Barsnesfjord basins in detail.

The Barsnesfjord receives its freshwater supply from the Jostedalsbre glacier system to the north throughout a catchment area stretching over 429 km^2. On its way to the south, the water of the catchment area passes in order the 170 m deep Lake Veitastrondvatnet (south of Veitastrond), the 62 m deep Lake Hafslovatnet (west of Hafslo), and finally the River Årøyelv with its outlet into the northeastern Inner Barsnesfjord basin (Figure 3; Paetzel & Dale, 2010).

The steadily increasing use of hydropower at the Lake Hafslovatnet affects the water masses of the Barsnesfjord since 1982 (Kaufmann, 2014; Mong et al., 2019).

In addition, Hassum & Røyrvik (2019) found an enhanced impact of organic and inorganic pollutants from a local garbage dump into the Lake Hafslovatnet that also might affect the Barsnesfjord water body.

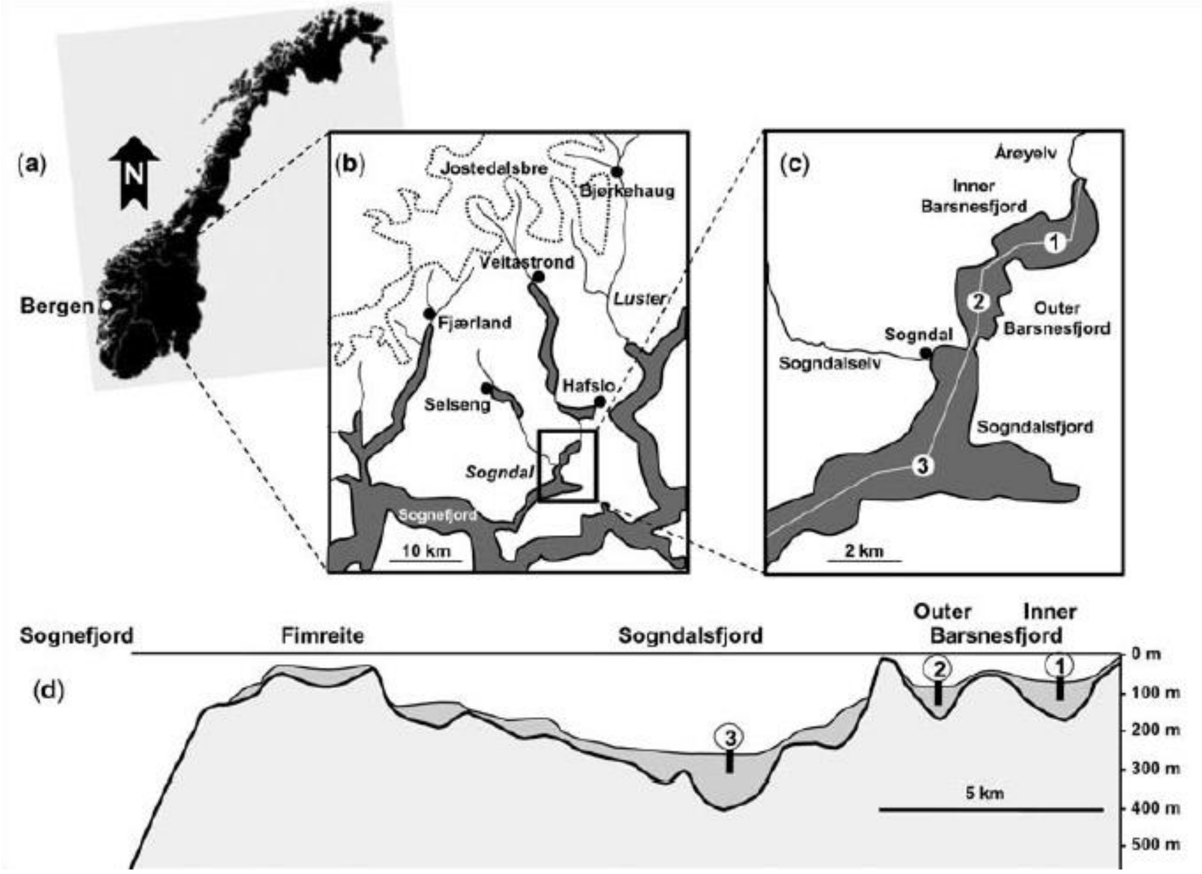

Figure 3. *Location map (a-c) and bathymetry (d) of the fjords in the Sogndal region. The catchment area of the Barsnesfjord system includes the Jostedalsbre glacier to the north, passing southward through the villages of Veitastrond and Hafslo into the River Årøyelv. Numbers 1, 2, and 3 indicate the deepest parts of the Inner Barsnesfjord (66 m), the Outer Barsnesfjord (82 m) and the Sogndalsfjord (260 m), respectively. The white line of Figure 3c marks the echo sounder profile line as shown in the transect of Figure 3d. Figure 3 adopted from Paetzel & Dale (2010).*

2 Methods

2.1 Introducing WFD quality elements

Table 2 shows an overview of the quality elements as formulated within the Norwegian implementation of the EU Water Framework Directive, i.e. the Vannforskriften (Direktoratsgruppen vanndirektivet, 2018a).

Quality elements identify parameters that are useful for classification of the environmental status of a water body. The left column of Table 2 indicates these parameters as biological, chemical, physical and hydro-morphological quality elements, specified in the second column. The third column of Table 2 is listing the quality elements used within this investigation. Grey letters indicate quality elements that are not part of this thesis.

***Table 2.** Biological, chemical, physical and hydro-morphological quality elements (Column 1) for water classification according to the Norwegian implementation of the EU WFD, i.e. the **Vannforskriften** (Column 2), and quality classification performed in this investigation (Column 3). Parameters written in grey letters indicate no investigation. Table modified after Direktoratsgruppen vanndirektivet (2018a).*

Main WFD classification quality elements	**Parameters and indexes indicated by the Vannforskriften**	**Parameters and indexes used in this investigation**
Biological quality elements		
Macro-algae	Littoral communities: RSL/RSLA Lower growth limit communities: MSMDI	Littoral communities: RSL/RSLA None
Soft bottom fauna: Benthic macro-invertebrates and benthic foraminifera	Species diversity: ES_{100}, H’ Sensitivity: ISI_{2012}, NSI Composite index: NQI 1	Benthic macro-invertebrates and benthic foraminifera: ES_{100}, H’ Benthic macro-invertebrates: ISI_{2012}, NSI Benthic macro-invertebrates: NQI 1
Phytoplankton	Chlorophyll A	None
Eelgrass	Eelgrass	None
Chemical quality elements which support the biological elements		
Water region specific substances	Inorganic pollutants: As, Cd, Cr, Cu, Hg, Ni, Zn Organic pollutants: PAH, PCB, TBT	Inorganic pollutants: As, Cd, Cr, Cu, Hg, Ni, Zn Organic pollutants: PAH, PCB, TBT
Organic content	Total organic carbon (TOC)	None
Nutrients	Total nitrogen, nitrite, nitrate+ Total phosphorous, phosphate Ammonium	None None None
Physical quality elements which support the biological elements		
Hydrography	Oxygen Transparency Salinity Temperature	Oxygen Transparency None None
Sediment	Grain size	Grain size
Hydro-morphological quality elements which support the biological elements		
	Percent influence on the substrate: • Depth and Structure of coastal zone substrates • Structure of the tidal zone, included water currents and exposure	None

2.2 Sampling of quality elements

Figure 4 shows the sampling locations of the different biological, chemical and physical quality elements. Water and sediment sampling took place using the research vessel Knurr from the Skjærsnes Aquaculture station in Sogndal, 2nd September 2019. Table 3 summarizes the samples for the quality elements taken at the different sample locations, including the sample location coordinates in longitude and latitude.

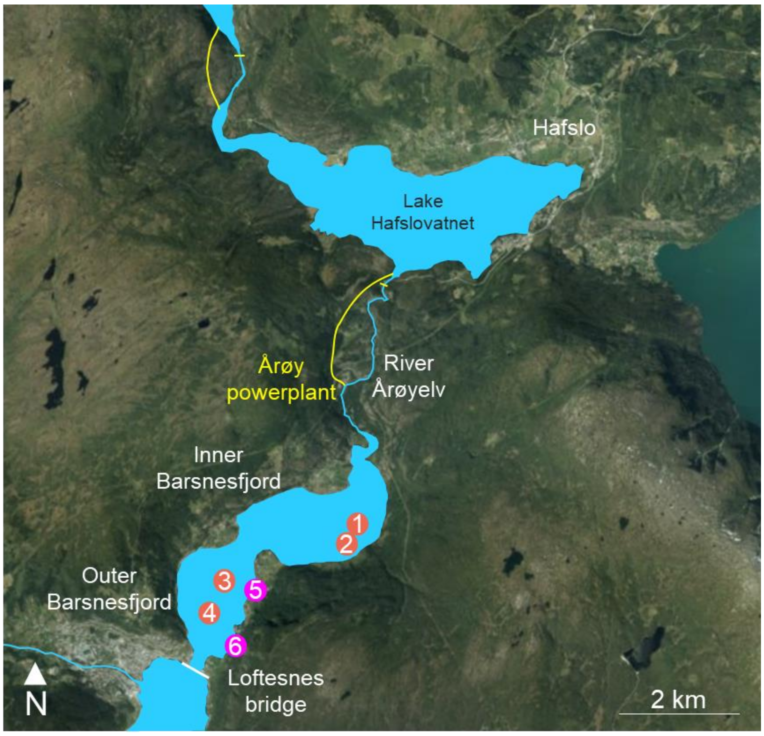

Figure 4. *Location map of the fjord bottom (1-4), water (1 & 4) and shore (5 & 6) samples taken in the Inner and Outer Barsnesfjord 2nd September 2019. Årøy powerplant refers to Årøy hydropower plant. For details see **Table 3**. Aerial photograph from "Norge i bilder", n.d. (https://www.norgeibilder.no/)*

Table 3. *Samples for biological, chemical and physical quality element analyses taken in the Barsnesfjord at sampling locations 1 to 6 corresponding to the location map of Figure 4. Location coordinates are in eastern longitude (E) and northern latitude (N).*

#	Quality elements samples	Longitude (E)	Latitude (W)	Water depth
1	CTD hydrography Benthic foraminifera Benthic macro-invertebrates	07° 09,891'	61° 15, 378'	64,1 m
2	Organic and inorganic pollutants	07° 08,814'	61° 15, 197'	60,5 m
3	Benthic foraminifera Benthic macro-invertebrates	07° 07,542'	61° 14, 687'	80,0 m
4	CTD hydrography Organic and inorganic pollutants	07° 07,413'	61° 14, 408'	80,7 m
5	Macro-algae	07° 08,089'	61° 14, 614'	Tidal flat
6	Macro-algae	07° 07,661'	61° 13, 983'	Tidal flat

The following sampling equipment (Figure 5) retrieved hydrographic and sediment samples from the two Barsnesfjord basins (Figure 3):

- A Niemistö gravity corer (Niemistö, 1974; Figure 5A) retrieved sediment cores with intact sediment water interfaces for the analysis of benthic foraminifera and pollutants.
- A Van Veen grab (Van Veen, 1933; Figure 5E) retrieved sediment surfaces for the analysis of benthic macro-invertebrates.
- A STD/CTD Model SD204 SAIV A/S Multi Parameter Sensor (SAIV A/S Environmental Sensors & Systems, n.d.; Figure 5B) measured oxygen, salinity, and temperature of the water column.
- A Nansen bottle (as described by Dietrich et al., 1980; Figure 5C) retrieved additional water samples for the measurement of oxygen and temperature of the water column.
- A Secchi disc (Secchi Disk study, n.d. Figure 5D) measured the transparency or turbidity of the water column.

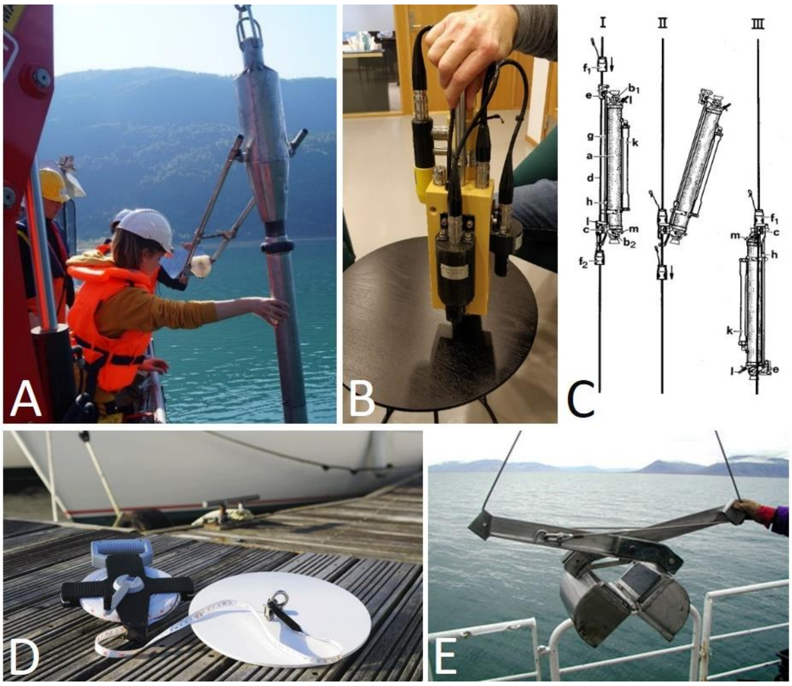

Figure 5. *(A) The Niemistö gravity corer; (B) The SD 204 with optical sensors (oxygen, salinity, temperature); (C) The Nansen bottle (image Dietrich et al., 1980); (D) The Secchi disc (image "Secchi Disk study", n.d. http://www.secchidisk.org/); (E) The Van Veen grab (image "Recommended sampling & sorting methods, n.d. http://www.iopan.gda.pl/projects/biodaff/EMBS-08.html)*

2.3 Biological quality elements

The WFD biological quality elements include macro-algae and soft bottom fauna. The soft bottom fauna consists of benthic macro-invertebrates and benthic foraminifera. The WFD classification of the biological quality elements builds upon the mean "normalized Ecological Quality Ratio (nEQR)" of each of these quality elements (macro-algae, benthic macro-invertebrates and benthic foraminifera). The lowest mean nEQR of these three quality elements results in a numerical value that determines the WFD biological classification index.

The calculation of the different nEQR follows generally two steps.

- Step 1 determines the prerequisites for calculating a mean nEQR that are different for each biological quality element. These prerequisites are (summarized from Table 2):
    - For macro-algae RSL/RSLA
    - For benthic macro-invertebrates ES_{100}, H', ISI_{2012}, NSI, NQI 1
    - For benthic foraminifera ES_{100}, H'

- Step 2 is the calculation of the final mean nEQR for each of these biological quality elements.

- Step 3 is to classify the water body. The lowest final mean nEQR value from the biological quality elements determines the final classification.

2.3.1 Biological quality element macro-algae

About using macro-algae

According to the Vannforskriften (Direktoratsgruppen vanndirektivet, 2018a), macro-algae are recognizable without technical help. They grow on rocks, gravelly substrates and other solid structures, as well as on algae and animals along coasts. The different species have various growth zones. Macro-algae cannot move if the living conditions change. This makes them good indicators for variations in environmental living conditions. Species distribution and growth zones depend on:

- Light
- Temperature
- Salinity
- Exposure to waves
- Availability of nutrients

Like in all ecosystems, there is a competition between species for the best place. The algae composition thus reflects the ability of the respective species to adapt to a given physical environment (Direktoratsgruppen vanndirektivet, 2018a). In addition, macro-algae are useful as an indication of the trophic level of the water body.

Sampling of macro-algae

Fieldwork and sampling of macro-algae requires:

- Sampling needs to take place during the period July to September.
- Sampling should include minimum two sampling locations per water body.
- The stations need to be typical sites for that water body.
- Sampling stations are 8 to 15 meter wide.
- The vertical sampling should reach from the supralittoral to the upper sublittoral zone, or alternatively reach down to 1 m depth below seafloor.
- The sampling time should be minimum 30 minutes per station.

In the field, the first action is to describe the location, using the shore description form of Direktoratsgruppen vanndirektivet (2018b), see Appendix A. This description has to take place at low tide. The description results in a specific "**Shore description number**" for that location.

The next action during the fieldwork is to register and classify all macro-algae as close as possible to the species level. The determination of the species abundance follows the species determination scale from 1 to 6:

1. Single specimens
2. Spread (0-5% coverage)
3. Frequent (>5-25% coverage)
4. Common (>25-50%coverage)
5. Abundant (>50-75% coverage)
6. Dominant (>75-100 % coverage)

Macro-algae biological quality element – Determination 1: RSL/RSLA

Within the Vannforskriften (Direktoratsgruppen vanndirektivet, 2018a), the macro-algae consist of two different types of communities, the littoral community, and the lower growth limit community. Only littoral communities are of interest within this investigation, divided into a Reduced Species List (RSL) and a Reduced Species List with Abundance (RSLA).

The RSL is an older classification system used within fjords influenced by freshwater. The RSL method solely documents the presence of species, whereas the RSLA method in addition quantifies some of these species. This RSL/RSLA calculation involves multiple measurements.

Preparation for the RSL/RSLA reduced species list determination includes:

1. **Double-check the names of the species** found at the different locations, using the webpage http://www.algaebase.org (Guiry, 1996)
2. Use Figure 6 to define the **eco-region** (by letter) and the **coastal water type** (by number) of the region of interest. This will define the boundary conditions for the calculation.

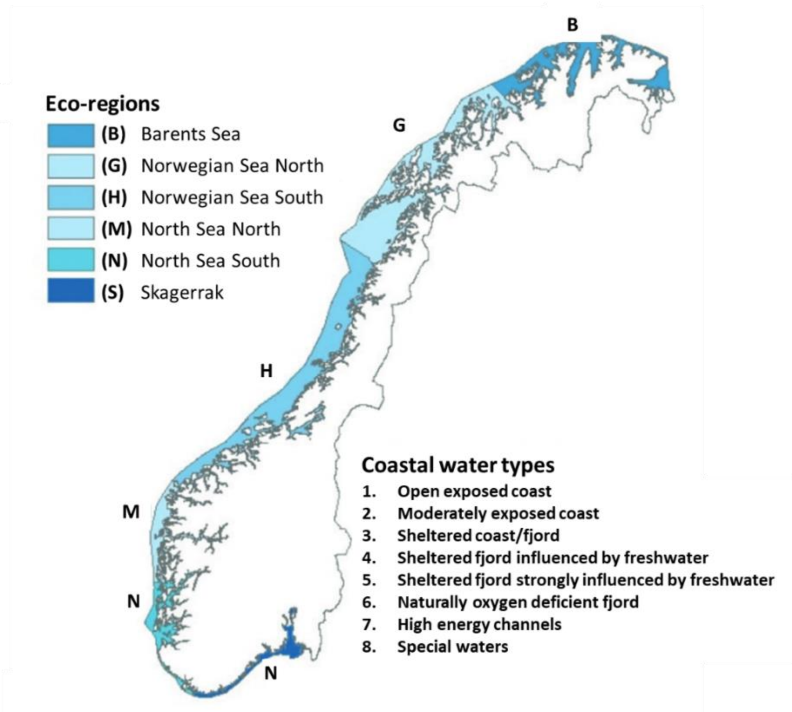

Figure 6. *Eco-regions (letters) and coastal water types (numbers) of the Norwegian coast as implemented in the Vannforskriften (Direktoratsgruppen vanndirektivet, 2018a).*

3. Use the “**Shore description number**” of the fieldwork (Appendix A) to determine the shore potential **factor F for normalization of the richness in species** in Table 4.

Table 4. *Relationship between the shore description number and the corresponding factor F for normalization of the richness in species (Direktoratsgruppen vanndirektivet, 2018a).*

Shore description number	Predicted species richness	F = Shore potential factor for normalisation of species richness
5	22,66	1,72
6	23,62	1,65
7	24,70	1,58
8	25,89	1,51
9	27,22	1,44
10	28,70	1,36
11	30,36	1,29
12	32,20	1,21
13	34,25	1,14
14	36,53	1,07
15	39,08	1,00
16	41,91	0,93
17	45,07	0,87
18	48,58	0,80
19	52,50	0,74
20	56,87	0,69

The RSL/RSLA reduced species lists cover the water types 1 to 6 within ecoregions H (Norwegian Sea South), M (North Sea North) and N (North Sea South) of Figure 6 (Table 5). Note that no RSL/RSLA reduced species list belongs to water type 6: “Naturally oxygen deficient fjords”. In such case, the missing RSL/RSLA applies from the water type of the closest salinity.

Table 5. *RSL/RSLA reduced species lists for water types of the eco-region H, M and N of Figure 6. Note that “Naturally oxygen deficient fjords” do not belong to an RSL/RSLA reduced species list of their own (Direktoratsgruppen vanndirektivet, 2018a).*

#	**Water type description** (from Figure 6)	**RSL/RSLA reduced species list**
1 & 2	Open and moderately exposed coast	RSLA 1-2
3	Sheltered coast/fjord	RSLA 3
4	Sheltered fjord influenced by freshwater	RSL 4
5	Sheltered fjord strongly influenced by freshwater	RSL 5
6	Naturally oxygen deficient fjord	**None**; choose water type of closest salinity

In general, the RSL/RSLA reduced species list calculation includes the following species groups and parameters (Direktoratsgruppen vanndirektivet, 2018b):

- Red algae in %

- Green algae in % and as sum (Σ)
- Brown algae in % and as sum (Σ)
- Normalized species richness (from Table 4)
- Ecological Species Group (ESG) ratio ESG1/ESG2
    - ESG1
        - Multi-year species
        - Species that grow later in the succession
        - Succession and re-succession of macro-algae
    - ESG2
        - Single-year species
        - Species that grow earlier in the succession
        - Fast growing species
- Opportunistic species

The different RSL/RSLA type determinations include only selected parts of these species groups and parameters, as illustrated in Table 6.

Table 6. *Species groups and parameters included in the various RSL/RSLA index determinations (in dark grey colour). Table modified after Direktoratsgruppen vanndirektivet (2018a).*

Parameters	RSLA 1-2	RSLA 3	RSL 4	RSL 5
Normalized species richness				
Green algae species (%)				
Red algae species (%)				
ESG1/ESG2 ratio				
Opportunistic species (%)				
Brown algae species (Σ)				
Green algae species (Σ)				
Brown algae species (%)				

The Barsnesfjord falls into the water type category "Naturally oxygen deficient fjord", i.e. water type 6 (Figure 6). No RSL/RSLA reduced species list does exist for this water type (Table 5). As specified in Table 5, this water type must adopt the RSL/RSLA reduced species list of the water type that has a salinity closest to water type 6 (Direktoratsgruppen vanndirektivet 2018b). According to the Vann-Nett, i.e. the Norwegian web site for reporting and mapping WFD data of Norwegian water bodies (Vann-Nett, n.d.), the RSL 5 reduced species list would fit best with the Barsnesfjord salinity conditions.

Based on the above prerequisites, the determination of the index number for the RSL 5 reduced species list takes place. The calculation of the **Normalized species richness** follows Formula 1.

Formula 1

$$Normalized\ Species\ Richness = Number\ of\ species * F(Shore\ potential\ factor)$$

The calculation of the percentage of **green algae** and **red algae**, as well as the calculation of the percentage of the **opportunistic species** follow Formulas 2a-c, respectively.

Formula 2

a. $$Percentage\ green\ algae = \frac{Number\ of\ green\ algae}{Total\ number\ of\ all\ individuals} * 100$$

b. $$Percentage\ red\ algae = \frac{Number\ of\ red\ algae}{Total\ number\ of\ all\ individuals} * 100$$

c. $$Percentage\ opportunistic\ species = \frac{Number\ of\ opportunistic\ species}{Total\ number\ of\ all\ individuals} * 100$$

The final part of the RSL 5 determination includes the calculation of the Ecological Status Group (ESG) to which the registered species belong. Direktoratsgruppen vanndirektivet (2018b) divides the registered species within RSL5 into the ESG groups ESG 1 and ESG 2. Calculation of the ration between ESG 1 and ESG 2 follows Formula 3.

Formula 3

$$\frac{ESG\ 1}{ESG\ 2} Ratio = \frac{Number\ of\ species\ within\ ESG\ \ 1}{Number\ of\ species\ within\ ESG\ 2}$$

The macro-algae Determination 2 will use the RSL 5 numbers calculated for the parameters as shown in Table 7.

Macro-algae biological quality element – Determination 2: EQR & nEQR

The next step is to calculate and establish the **normalized Ecological Quality Ratio (nEQR)** of the biological quality elements. There are two different scenarios, and thus two different formulas to calculate the nEQR.

- **The first scenario** uses Formula 4. Formula 4 applies for the RSL/RSLA parameters: Normalized species number; Percentage of red and green algae; Total occurrence of brown algae; ESG 1/ESG 2 ratio. Table 7 provides the class ranges and class limits of the different RSL 5 parameters. If the EQRs of these parameters indicate a “Very good” to “Moderate” environmental status, there is a negative correlation with eutrophication, i.e. the eutrophication is low.

  Formula 4 (values and limits for each specific RSL parameter)

  $$EQR = \left\{\left(\frac{Value - Lowest\ class\ limits}{Class\ range}\right) * EQR\ class\ range\right\} + Lowest\ EQR\ class\ limit$$

- **The second scenario** uses Formula 5. Formula 5 applies for the RSL/RSLA parameters: Percentage of green algae; Number of green algae; Percentage of opportunistic species. Table 7 provides the class ranges and class limits of the different RSL 5 parameters. If the EQRs of these parameters indicate a “Very good” to “Moderate” environmental status, there is a positive correlation with eutrophication, i.e. the eutrophication is high.

Formula 5 (values and limits for each specific RSL parameter)

$$EQR = Higher\ EQR\ class\ limit - \left\{\left(\frac{Value - Upper\ class\ limit}{Class\ range}\right) * EQR\ class\ range\right\}$$

Table 7. *Class limits for RSL 5 based on the EQR calculations of formulas 4 and 5. Table from Direktoratsgruppen vanndirektivet (2018a).*

RSL	Status	Upper EQR class limit	Lower EQR class limit	EQR class range	Upper class range	Lower class range	Class range
Normalized richness #species*F	Very good	1,0	>0,8	0,2	30	>18	12
	Good	0,8	>0,6	0,2	18	>9	9
	Moderate	0,6	>0,4	0,2	9	>5	4
	Bad	0,4	>0,2	0,2	5	>3	2
	Very bad	0,2	>0	0,2	3	0	3
% species green algae %green/tot	Very good	1,0	>0,8	0,2	0	<30	30
	Good	0,8	>0,6	0,2	30	<36	6
	Moderate	0,6	>0,4	0,2	36	<44	8
	Bad	0,4	>0,2	0,2	44	<60	16
	Very bad	0,2	>0	0,2	60	100	40
% species red algae %red/tot	Very good	1,0	>0,8	0,2	100	>29	71
	Good	0,8	>0,6	0,2	29	>20	9
	Moderate	0,6	>0,4	0,2	20	>15	5
	Bad	0,4	>0,2	0,2	15	>9	6
	Very bad	0,2	>0	0,2	9	0	9
ESG1/ESG2	Very good	1,0	>0,8	0,2	1	>0,65	0,35
		0,8	>0,6	0,2	0,65	>0,50	0,15
	Moderate	0,6	>0,4	0,2	0,50	>0,35	0,15
	Bad	0,4	>0,2	0,2	0,35	>0,10	0,25
	Very bad	0,2	>0	0,2	0,10	0	0,10
% species opportunists %opp/tot	Very good	1,0	>0,8	0,2	0	<16	16
	Good	0,8	>0,6	0,2	16	<23	7
	Moderate	0,6	>0,4	0,2	23	<36	13
	Bad	0,4	>0,2	0,2	36	<41	5
	Very bad	0,2	>0	0,2	41	100	59

Macro-algae biological quality element – Determination 3: Environmental condition

- Finally, the determination of the environmental condition of the biological quality elements occurs by calculating the mean EQR of all the RSL/RSLA parameters.
- Note: The EQR of the red algae and the ESG 1/ESG 2 ratio should not become part of the calculation of the mean nEQR, if the number of species in the reduced species list is lower than 14. The reason is the resulting uncertainty between eutrophication and these EQR values if the number of species is low.
- The environmental condition of the biological quality elements is to classify at each location based on the mean nEQR according to Table 8.

Table 8. *Classification of the EQR and nEQR for the RSL/RSLA shore index, resulting in the classification of the environmental conditions based on the biological quality elements. Table from Direktoratsgruppen vanndirektivet (2018a).*

EQR/nEQR value	Environmental condition of the biological quality elements
1,00-0,80	Very good
0,80-0,60	Good
0,60-0,40	Moderate
0,40-0,20	Bad
0,20-0,00	Very bad

2.3.2 Biological quality element soft bottom fauna – Benthic macro-invertebrates

Benthic macro-invertebrates, often shortened to "benthic invertebrates" or simply "benthos", as well as the microorganism group of benthic foraminifera belong to the soft bottom fauna. Rygg & Norling (2013) describe the use of soft bottom fauna in the WFD classification of water bodies (Direktoratsgruppen vanndirektivet 2018a; 2018b). Soft bottom fauna generally may exist at locations with fine-grained bottom sediment. Because it is relatively immobile, the composition of the soft bottom fauna gives a good indication of the environmental condition of a water body. This is especially the case regarding effects of eutrophication, organic matter production and sedimentation. Soft bottom fauna analysis includes the diversity in species, the sensitivity of species and a combined index.

About using benthic macro-invertebrates

Benthic macro-invertebrates are fauna with a lack of a spine and are visible without technical help. They live in aquatic environments at or around soft bottoms. These soft bottoms can consist of fine sand, silt or mud, i.e. organic matter rich silty clay (Direktoratsgruppen vanndirektivet, 2018a). They include benthic fauna permanently living in the aquatic environment, as well as larval stages of a variety of land-living insects (United States Environmental Protection Agency, 2016).

Benthic macro-invertebrates are easy to collect, they are mostly overwintering and their living conditions relate to the environmental condition of the water body. This makes them useful indicators for the biological state of a water body (Direktoratsgruppen vanndirektivet, 2018a). They have a varied acceptance to pollution, and because of their limited mobility, they cannot escape from pollution. The population number and composition of benthic macro-invertebrates relates to the quality of the water (United States Environmental Protection Agency, 2016). A loss of sensitive species would indicate a reduced ecological state of the water body (Direktoratsgruppen vanndirektivet, 2018a).

Sampling of benthic macro-invertebrates

Sampling of benthic macro-invertebrates took place by taking bottom surface sediments using a Van Veen grab (Figure 5.E). The size of each sample corresponded to 1000 cm^3. The two sampling locations of the Inner Barsnesfjord and the Outer Barsnesfjord (Figure 4) consisted of three grab casts, i.e. three repetitive samples at each location.

Sampling procedure onboard included sieving the samples first through a 5 mm sieve, and then through a 1 mm sieve, and successively preserving both fractions.

Preservation of the samples occurred with 75% ethanol. With this percentage of ethanol, the benthic macro-invertebrates will not decompose or being dissolved.

After cleaning of the samples in the laboratory, identification and counting of the single species followed using binoculars. The calculation of the biodiversity index does not include the counted number of dead specimens.

Benthic macro-invertebrate biological quality element – Determination 1: H'

The most common index for the determination of species diversity is the Shannon index (H'), also called "Shannon's diversity index", "Shannon-Wiener index", "Shannon-Weaver index" or "Shannon entropy" (Spellerberg & Fedor, 2003). It determines biodiversity values that account for the species that are present in a soft bottom sample. The results are quantitative, and show the species distribution, the species richness and the species evenness: The more dominant few (down to one) species are, the lower the biodiversity. Formula 6 calculates the Shannon index H' (Pedersen et al., 2016):

Formula 6 (Pedersen et al. 2016)

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

where
N_i = number of individuals of species i.
N = total number of individuals.
S = total number of species.

Benthic macro-invertebrate biological quality element – Determination Step 2: NQI 1 & AMBI

The Norwegian Quality Index (NQI 1) is a combined index of species richness and the sensitivity of species that reports Norwegian soft bottom fauna conditions to the European Union. Prior to the NQI 1 calculation, it is necessary to determine the Azti Marine Biotic Index (AMBI).

The AMBI is a tolerance index, classifying the species in Ecological Groups (EG; Table 9).

Table 9. *Classification of species in the AMBI system (Rygg & Norling, 2013).*

Ecological group (EG)	Description	Tolerance value
I	Sensitive species	0
II	Indifferent species	1,5
III	Tolerant species	3
IV	Opportunistic species	4,5
V	Pollution indicating species	6

The AMBI calculates quantitatively the number of individual species, specified solely for the Norwegian conditions of NQI 1. The results of NQI 1 have a value between 0 and 1. Formula 7 calculates the NQI 1 (Pedersen et al., 2016).

Formula 7 (Pedersen et al. 2016)

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

where

N = number of individuals

S = number of species

AMBI = Formula 8 *(Pedersen et al. 2016)*

Formula 8 (Pedersen et al. 2016)

$$AMBI = \sum_{i}^{S}\left[\frac{N_i * AMBI_i}{N_{AMBI}}\right]$$

where

$AMBI_i$ = tolerance value (0 – 1,5 – 3 – 4,5 – 6 see Table 9)

N= number of individuals

S = total number of species

N_i = number of individuals of species i

Benthic macro-invertebrate biological quality element – Determination 3: ES_{100}

Hulbert's diversity index (ES_{100}) determines the expected number of species within a random sample of 100 individuals. Formula 9 calculates the ES_{100} index (Pedersen et al., 2016).

Formula 9 (Pedersen et al. 2016)

$$ES_{100} = \sum_{i}^{S}\left[1 - \frac{\left(\frac{N - N_1}{100}\right)}{\left(\frac{N}{100}\right)}\right]$$

where

N_i = number of individuals of species i.

N = total number of individuals.

S = total number of species.

Benthic macro-invertebrate biological quality element Determination 4: ISI_{2012}

The Indicator Species Index (ISI_{2012}) determination results in qualitative data of sensitivity, according to the standardization in 2012 (Rygg & Norling, 2013).

The ISI_{2012} considers sensitivity only at species level and not according to the number of individuals. The ISI_{2012} thus determines the average sensitivity of a species in a sample. Formula 10 calculates the ISI_{2012} (Pedersen et al., 2016).

Formula 10 (Pedersen et al. 2016)

$$ISI_{2012} = \sum_{i}^{S} \left[\frac{ISI_i}{S_{ISI}}\right]$$

where

ISI_i = value of the species

S_{ISI} = number of species with a sensitivity value

S = total number of species

Benthic macro-invertebrate biological quality element – Determination 5: NSI

The Norwegian Sensitivity Index (NSI) is similar to the AMBI, with the difference that the NSI determines the sensitivity of individuals with the Norwegian fauna as a basis. It also includes an objective statistical method. There is a list of 591 species which all have a given sensitivity value. The NSI determines the mean sensitivity value of all the individuals in a sample. Formula 11 calculates the NSI (Pedersen et al., 2016).

Formula 11 (Pedersen et al. 2016)

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

where

N_i = number of individuals

NSI_i = the value of species i

N_{NSI} = the number of species with a sensitivity value

S = total number of species

Benthic macro-invertebrate biological quality element – Determination 6: Environmental condition

The calculation of the mean nEQR uses the mean values of all five indexes, as summarized in Table 10.

Table 10. *Summary table of all indexes for calculation the mean nEQR of benthic macro-invertebrates.*

Index	What does it measure?	Formula
H'	Diversity of species	$H' = -\sum_{i}^{S}\left[\left(\frac{N_i}{N}\right) * log_2\left(\frac{N_i}{N}\right)\right]$
NQI 1	Diversity and sensitivity of species	$NQI\ 1 = \left[0{,}5 * \left(1 - \frac{AMBI}{7}\right) + 0{,}5 * \left(\frac{\left[\frac{\ln(S)}{\ln(\ln(N))}\right]}{2{,}7}\right) * \left(\frac{N}{N+5}\right)\right]$
AMBI	Sensitivity and tolerance of species	$AMBI = \sum_{i}^{S}\left[\frac{N_i * AMBI_i}{N_{AMBI}}\right]$
ES100	Diversity of species	$ES_{100} = \sum_{i}^{S}\left[1 - \frac{\left(\frac{N - N_1}{100}\right)}{\left(\frac{N}{100}\right)}\right]$
ISI_{2012}	Sensitivity of species	$ISI_{2012} = \sum_{i}^{S}\left[\frac{ISI_i}{S_{ISI}}\right]$
NSI	Sensitivity of individuals	$NSI = \sum_{i}^{S}\left[\frac{N_i * NSI_i}{N_{NSI}}\right]$

Note that a low number of benthic macro-invertebrate individuals is unfavourable for the determination of the NSI and the ISI_{2012} (Borgersen et al., 2020). In that case, the biodiversity calculation excludes these indexes. In general, the final mean nEQR calculation of the benthic macro-invertebrates also should ignore all indexes that result in a "zero" value. Borgersen et al. (2020) suggest that a grab sample should include a minimum of three species/taxa, and a minimum of six individuals; the number of species/taxa not assigned with a sensitivity value (in a sample) should be lower than 20%.

It is worth to mention that the application of all indexes, and thus of the mean nEQR of benthic macro-invertebrate biological quality elements results in a classification of the Norwegian eco-regions (Figure 7) into five classification categories instead of possible 16 categories (Pedersen et al., 2016). This is due to the similarity of the benthic macro-invertebrate communities within certain coastal water types, as indicated in Figure 7 (Pedersen et al., 2016).

Eco-region (from Figure 6)	**Coastal water type** (from Figure 6)			
	1	2	3	4/5
Skagerrak (S)				
North Sea South (N) and North (M)				
Norwegian Sea South (H) and North (G)				
Barents Sea (B)				

Figure 7. *Coastal water type classification of the Norwegian eco-regions based on the nEQR of the benthic macro-invertebrates. Five shades of grey indicate the five coastal water types of the different eco regions (Pedersen et al., 2016). Eco-regions and Coastal water types from Figure 6.*

2.3.3 Biological quality element soft bottom fauna – Benthic foraminifera

As mentioned in Chapter 2.3.2, not only benthic macro-organisms belong the soft bottom fauna, but also the microorganism group of benthic foraminifera (Rygg & Norling, 2013). Like the benthic macro-organisms, the benthic microorganisms are relatively immobile and give a good indication of the environmental condition of a water body, in terms of eutrophication, pollution and sensitivity (Direktoratsgruppen vanndirektivet, 2018a; 2018b).

<u>About using benthic foraminifera</u>

The species distribution of macro-invertebrates in surface sediments is sufficient to calculate the nEQR for that biological quality element. In contrast, the environmental interpretation of the benthic foraminifer distribution depends on the evolution of the benthic foraminifer community from one environmental state into another (Boltovskoy & Wright, 1976; Direktoratsgruppen vanndirektivet, 2018a).

The reason for this is that the distribution of benthic foraminifera might greatly vary along gradients within the same water body, e.g. along the gradient from an outer towards an inner fjord environment. Thus, it would be meaningful to add a temporal gradient to the spatial gradient of a foraminifer composition (Direktoratsgruppen vanndirektivet, 2018a).

In addition, some fjord basins naturally have low oxygen content in the deep water. It is difficult to distinguish these from fjord basins where the oxygen content is low due to human activity. It is often the case that anthropogenic activity produces an additional reduction in oxygen content where the bottom water circulation is naturally restricted. In such basins, the benthic fauna can be very poor or completely lacking. The classification system does not include these sites (Direktoratsgruppen vanndirektivet, 2018a).

Dated sediment cores offer the opportunity to determine such temporal (oxygen and pollution) gradients back in time. This would result in a natural reference of the foraminifer composition in deeper (and thus old) sediments, which makes it possible to interpret the recent foraminifer composition of the surface (and thus young) sediments (Direktoratsgruppen vanndirektivet, 2018a).

Thus, core sampling is useful to determine the reference state backward in time, here based on fossil foraminifers (Alve et al., 2009; Dolven et al., 2013). In addition, this method is tracking changes in the ecological status over time. Dolven et al. (2013) applied this method in the Inner Oslofjord, while Hess & Alve (2014) used the method in the Horten harbour, and Duffield et al. (2017) applied it in the Lysefjord.

Benthic foraminifera and benthic macro-invertebrates classify the environmental status of a water body in a similar way (Pedersen et al., 2016). The reference sample of the benthic foraminifera would give additional long-term information at a given location. It is appropriate to use the benthic foraminifer composition in water bodies where the overall assessment of the area indicates a "Moderate" or "Bad" ecological status, in order to check the evolutional dimension of this environmental status (Pedersen et al. 2016).

Pedersen et al. (2016) recommend using this retrospective benthic foraminifer method to determine the natural reference state in areas of surface samples with suspected deviation from the natural reference background. In practice, the natural reference state should affect the state classification by adjusting the index class boundaries before calculating the mean nEQR (Direktoratsgruppen vanndirektivet, 2018a).

Sampling of benthic foraminifera

A Niemistö gravity corer (Figure 5A) retrieved one ca. 50 cm long sediment core from each of the Barsnesfjord basins (Figure 4; Table 3). Subsampling in the laboratory included cutting the core into alternating 1 cm thick slices, subsampling every 2 cm in the Inner Barsnesfjord, and subsampling every 4 cm in the Outer Barsnesfjord over the entire length of the sediment cores, as illustrated in Figure 8.

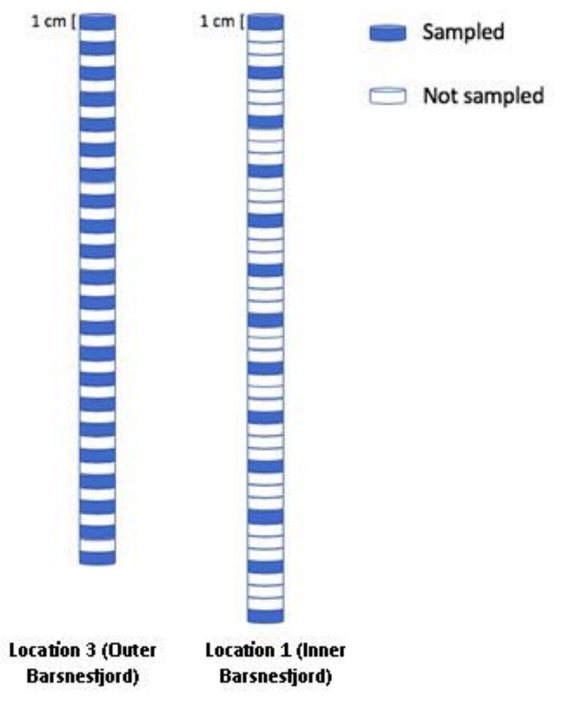

Figure 8. *Sediment core subsampling for the benthic foraminifer analysis. Blue slices represent subsamples; white slices represent areas that were not subsampled.*

Counting of the benthic foraminifera occurred across the following sieve sizes:

- From 2 mm to 250 µm; counting 100% of the species
- From 250 µm to 125 µm; counting 25% of the species, and multiplying by four, due to a high number of individuals
- From 125 µm to 63 µm; no counting due to the excessively high number of individuals

Normalization of the counts equalized the subsamples, as the volume of the subsamples differed between 5 ml and 7 ml. A wooden petri dish counter (Torbjørn Dale design 2016; *personal communication*) made it easier to count the benthic foraminifer species (Figure 9).

Figure 9. *Wooden petri dish counter; Torbjørn Dale design 2016 (personal communication)*

Identification of the benthic foraminifera took place using a Leica binocular, and identifying according to Loeblich & Tappan (1987).

Benthic foraminifer biological quality element – Determination 1: H' & ES_{100}

Counting involved all benthic foraminifer species within a sample and identifying the most common species of these. Every species has its own sensitivity, contributing to biodiversity and the quality status of the water body of the Barsnesfjord.

The used indexes are the Shannon index (H') and the ES_{100} index, using the same procedure and formulas as for the benthic macro-invertebrates, i.e. Formula 6 for the Shannon index, and Formula 9 for the ES_{100} index.

Benthic foraminifer biological quality element – Determination 2: Environmental condition

The calculation of the mean nEQR uses the mean values of both indexes, where the lowest index defines the environmental condition of the water body according to the WFD environmental classification.

2.4 Chemical quality elements

The chemical quality elements consist mainly of environmental pollutants. Environmental pollutants are chemical elements that have the characteristics to be of risk for the health condition of organisms. Other properties from environmental pollutants include that they are:

- None decomposable
- Able to accumulate in organisms
- Toxic in elevated concentrations
- Widely spread

There are two different types of pollutants, organic and inorganic pollutants. They occur in freshwater and saltwater. Organic pollutants can be toxic even at low concentrations.

The WFD defines a list of prioritized polluting element concentrations according to their five-step classification from “Very good” to “Very bad” environmental conditions, summarized in Table 1. These substances are of significant risk for aquatic environments. Within the EU Water Framework Directive, monitoring of pollutants can occur in water, in sediment and in biota. This thesis only includes pollutant monitoring in sediment. The WFD classification of the environmental condition focuses on the sole concentration and their hazardous effects on organisms.

Sampling for organic and inorganic pollutant analyses

A Niemistö gravity corer (Figure 5A) retrieved one ca. 50 cm long sediment core from each of the Barsnesfjord basins (Figure 4; Table 3) solely for pollutant investigation. Subsampling of the sediment cores occurred onboard directly after sampling, including:

- Cutting the cores from top to bottom into three successive, 15 cm long sections (with labeling Top: 0-15 cm; Middle: 15-30 cm; Bottom 30-45 cm sediment depth).
- Sealing the subsamples into sampling glasses (pre-cleaned by and provided from Eurofins environmental Testing Norway AS laboratories in Moss, Norway).
- Sending the sampling glasses for inorganic and organic pollutant analyses to the Eurofins environmental Testing Norway AS laboratories in Moss, Norway, upon arrival at the HVL.

2.4.1 Chemical quality elements – Inorganic pollutants and classification

Inorganic pollutants mostly involve trace metals and heavy metals, distributed into the aquatic environment mainly by runoff from combustion engines, agriculture, industry and waste from households. They can enter organisms in two ways: (a) Contacting the skin; and (b) Eating and drinking contaminated food or water.

Inorganic pollutant analysis included the trace metals: Arsenic As, Lead Pb, Cadmium Cd, Copper Cu, Chromium Cr, Mercury Hg, Nickel Ni and Sink Zn, which are selected hazardous trace metals according to Norwegian standard pollution investigations of sediments.

Tables 11 shows the classification of sediments according to their concentrations of the inorganic pollutants involved in the Eurofins analysis (Direktoratsgruppen vanndirektivet, 2018a; Miljødirektoratet, 2016).

Table 11. *Table of inorganic pollutants modified after Direktoratsgruppen vanndirektivet (2018a). Classes 1 to 5 correspond to the WFD colour code classification of Blue: Class I "Very good"; Green: Class II "Good"; Yellow: Class III "Moderate"; Orange: Class IV "Bad"; Red: Class V "Very bad". Note that the classification focuses in addition on the harmful and toxic effects of the different concentrations on organisms (Miljødirektoratet, 2016). Concentrations are in unit dry matter.*

		Class I Very good	Class II Good	Class III Moderate	Class IV Bad	Class V Very bad
Substances trace & heavy metals	**Unit**	**Background**	**No toxic effects**	**Chronic toxic effects**	**Acute toxic effects**	**Severe toxic effects**
Arsenic	mg/kg	0-15	15-18	18-71	71-580	>580
Cadmium	mg/kg	0-0,2	0,2-2,5	2,5-16	16-157	>157
Chromium	mg/kg	0-60	60-660	660-6.000	6.000-15.500	>15.500
Copper	mg/kg	0-20	84		84-147	>147
Lead	mg/kg	0-25	25-150	150-1.480	1.480-2.000	>2.000
Mercury	mg/kg	0-0,05	0,05-0,52	0,52-0,75	0,75-1,45	>1,45
Nickel	mg/kg	0-30	30-42	42-271	271-533	>533
Zink	mg/kg	0-90	90-139	139-750	750-6.690	>6.690

2.4.2 Chemical quality elements – Organic pollutants and classification

Organic pollutants mostly involve three major groups, i.e. Polycyclic Aromatic hydrocarbons (PAH), Polychlorinated Biphenyls (PCB) and Tributyltin (TBT).

Polycyclic aromatic Hydrocarbons (PAH)

Polycyclic aromatic Hydrocarbons (PAH) are a diverse group of chemicals that naturally occur in marine ecosystems. PAHs are hydrocarbons that contain only carbon and hydrogen and are composed of multiple aromatic rings. PAHs originate from organic products such as crude oil, coal, dyes, medicines, pesticides, plastics, and roofing tar. PAHs can form from incomplete combustion of fuels used in cars or industry.

Polycyclic Aromatic Hydrocarbons analysis included sixteen PAHs – PAH (16) – with sixteen hazardous PAHs according to Norwegian standard pollution investigations of sediments (Miljødirektoratet, 2016).

Tables 12 shows the classification of sediments according to their concentrations of the organic PAH (16) pollutants involved in the Eurofins analysis (Direktoratsgruppen vanndirektivet, 2018a; Miljødirektoratet, 2016).

Table 12. *Table of PAH (16) organic pollutants modified after Direktoratsgruppen vanndirektivet (2018a). Classes 1 to 5 correspond to the WFD colour code classification of Blue: Class I "Very good"; Green: Class II "Good"; Yellow: Class III "Moderate"; Orange: Class IV "Bad"; Red: Class V "Very bad". Note that the classification focuses in addition on the harmful and toxic effects of the different concentrations on organisms (Miljødirektoratet, 2016). Concentrations are in unit dry matter.*

		Class I Very good	Class II Good	Class III Moderate	Class IV Bad	Class V Very bad
Substances PAH (16)	**Unit**	**Background**	**No toxic effects**	**Chronic toxic effects**	**Acute toxic effects**	**Severe toxic effects**
Naphthalene	µg/kg	0-2	2-27	27-1.754	1.754-8.769	>8.769
Acenaphtalene	µg/kg	0-1,6	1,3-33	33-85	85-8.500	>8.500
Acenaphtene	µg/kg	0-2,4	2,4-96	96-195	195-19.500	>19.500
Fluorene	µg/kg	0-6,8	6,8-150	150-694	694-34.700	>34.700
Phenantrene	µg/kg	0-6,8	6,8-780	780-2.500	2.500-25.000	>25.000
Antracene	µg/kg	0-1,2	1,2-4,6	4,6-30	30-295	>295
Fluorantene	µg/kg	0-8	400		400-2.000	>2.000
Pyrene	µg/kg	0-5,2	5,2-84	84-840	840-8.400	>8.400
Benzo(a)antracene	µg/kg	0-3,6	3,6-60	60-501	501-50.100	>50.100
Crysene (Triphenylene)	µg/kg	0-4,4	280		280-2.800	>2.800
Benzo(b)fluorantene	µg/kg	0-90	140		140-10.600	>10.600
Benzo(k)fluorantene	µg/kg	90	135		135-7.400	>7.400
Benzo(a)pyrene	µg/kg	0-6	6-183	183-230	230-13.100	>13.100
Indeno[1,2,3-cd]pyrene	µg/kg	0-20	63		63-2.300	>2.300
Dibenzo[a,h]antracene	µg/kg	0-12	12-27	27-273	273-2.730	>2.730
Benzo[ghi]perylene	µg/kg	18	84		84-1.400	>1400

Polychlorinated biphenyls (PCB)

Polychlorinated biphenyls (PCB) are biphenyls composed of geometrically ordered chains of aromatic carbon and hydrogen ring structures. Polychlorinated biphenyls separate from each other by the number of three and up to seven chlorine components. These do range in order from three to seven chlorine (Cl) components, i.e. trichloro-biphenyl (three Cl), tetrachloro-biphenyl (four Cl), pentachloro-biphenyl (five Cl), hexachloro-biphenyl (six Cl) and heptachlorobiphenyl (seven Cl). They are integrated and hazardous compounds of any organic macro- and microplastic; for details see Miljostatus (n.d.) https://miljostatus.miljodirektoratet.no/tema/miljogifter/prioriterte-miljogifter/polyklorerte-bifenyler-pcb/.

Polychlorinated Biphenyl (PCB) analysis included seven PCBs – PCB (7) – with seven selected hazardous PCBs according to Norwegian standard pollution investigations of sediments.

Tables 13 shows the classification of sediments according to their concentrations of the organic PCB (7) pollutants involved in the Eurofins analysis (Direktoratsgruppen vanndirektivet, 2018a; Miljødirektoratet, 2016).

Table 13. *Table of PCB (7) organic pollutants modified after Direktoratsgruppen vanndirektivet (2018a). Classes 1 to 5 correspond to the WFD colour code classification of Blue: Class I "Very good"; Green: Class II "Good"; Yellow: Class III "Moderate"; Orange: Class IV "Bad"; Red: Class V "Very bad". Note that the classification focuses in addition on the harmful and toxic effects of the different concentrations on organisms (Miljødirektoratet, 2016). Concentrations are in unit dry matter. Note also that only the sum of the seven selected PCB concentrations defines the environmental condition of the water body. PCB 28 = Trichloro-biphenyl (three Cl); PCB 52 = Tetrachloro-biphenyl (four Cl); PCB 101 & PCB 118 = Pentachloro-biphenyls (five Cl); PCB 138 & PCB 153 = Hexachloro-biphenyl (six Cl); PCB 180 = Heptachloro-biphenyl (seven Cl).*

		Class I Very good	Class II Good	Class III Moderate	Class IV Bad	Class V Very bad
Substances PCB (7)	**Unit**	**Background**	**No toxic effects**	**Chronic toxic effects**	**Acute toxic effects**	**Severe toxic effects**
PCB 28	mg/kg					
PCB 52	mg/kg					
PCB 101	mg/kg					
PCB 118	mg/kg					
PCB 138	mg/kg					
PCB 153	mg/kg					
PCB 180	mg/kg					
Sum PCB (7)	mg/kg	Not natural	0-4,1	4,1-43	43-430	>430

Tributyltin (TBT)

Tributyltin (TBT) is a group of toxins that contains of a tin atom, which has carbon bonds with one up to four organic components. TBT is unstable and normally combined with other elements, forming for example: tributyltin oxide, tributyltin benzoate, tributyltin chloride, tributyltin methacrylate, and many more (Scales, 2014).

Tributyltin was the main compound in anti-fouling paint (used for hulls of boats). Released into the environment, TBT is very toxic for organisms even at very low levels (Table 14). Since 2008, global laws prohibited the use of TBT in anti-fouling paint (Scales, 2014).

Tributyltin TBT analysis included the analysis of Monobutyltin cations (MBT), Dibutyltin-Sn (DBT-Sn) and Tributyltin-Sn (TBT-Sn). Table 14 shows the classification of sediments according to their concentrations of the organic TBT pollutants involved in the Eurofins analysis (Direktoratsgruppen vanndirektivet, 2018a; Miljødirektoratet, 2016).

There are two WFD environmental classifications in use for TBT, i.e. TBT (including MBT, DBT-Sn & TBT-Sn) and TBT (for administrative use in Norway).

TBT is very toxic in low amounts to various types of marine organisms. The threshold value in sediment is therefore set at 0.002 and 0.032 µg/kg. These values are almost impossible to analyze because they are so low. Due to the moderate degradability of TBT in sediment, these values are exceeded almost everywhere (Breedveld et al., 2018).

The TBT "Administrative use in Norway" -values allow much higher concentrations than the TBT values (including MBT, DBT-Sn & TBT-Sn). This makes it easier to detect TBT. It will also ensure that active shipyards in Norway get a better WFD environmental classification (Breedveld et al., 2018).

Table 14. *Table of WFD environmental classification based on TBT organic pollutants, modified after Direktoratsgruppen vanndirektivet (2018a). Classes 1 to 5 correspond to the WFD colour code classification of Blue: Class I "Very good"; Green: Class II "Good"; Yellow: Class III "Moderate"; Orange: Class IV "Bad"; Red: Class V "Very bad". Note that the classification focuses in addition on the harmful and toxic effects of the different concentrations on organisms (Miljødirektoratet, 2016). Concentrations are in unit dry matter.*

		Class I Very good	Class II Good	Class III Moderate	Class IV Bad	Class V Very bad
Substance TBT	**Unit**	**Background**	**No toxic effects**	**Chronic toxic effects**	**Acute toxic effects**	**Severe toxic effects**
TBT Including MBT, DBT-Sn & TBT-Sn	µg/kg	Not natural	0-0,002	0,002-0,016	0,016-0,032	>0,032
TBT Administrative use in Norway	µg/kg	0-1	1-5	5-20	20-100	>100

2.5 Physical quality elements

The physical quality elements, i.e. the hydrographic parameters, here including oxygen and transparency (i.e. Secchi depth), are supportive parameters of natural variability on an annual and even seasonal basis. For a correct calculation, measurements should stretch over a minimum of three successive years including at least one winter and one summer measurement.

2.5.1 Physical quality elements – Oxygen and transparency

<u>About using oxygen and transparency</u>

Oxygen concentrations in fjord waters provide information about the survival conditions of organisms and thus have an influence on the species richness and diversity of species in that water body.

Transparency, i.e. light will influence primary productivity condition, which form the basis for photosynthesis and thus for all life in a water body.

Figure 10 illustrates the interconnection between the physical quality elements oxygen (green background) and transparency (blue background), and the biological quality elements (white background); Yellow background indicates external parameter influence (Working Group 2.4 - Coast, 2003).

According to Figure 10, oxygen deficiency and decreased transparency, i.e. decreased light conditions due to increased turbidity has a deteriorating influence on the benthic community, and thus on the entire structure of the aquatic ecosystem.

The four categories of Figure 10 further indicate the mutual influence between the physical and biological quality elements (Categories I-III), the hydro-morphological quality elements (Category I), and the chemical quality elements (Category IV):

- **Category I** (light yellow colour in Figure 10): External factors might influence the entire ecosystem due to changing hydrographic conditions (physical quality elements), hydrodynamic settings (water currents and water stratification) and climate change.

- **Category II** (light blue colour in Figure 10): Increased nutrient enrichment enhances turbidity, and enhanced turbidity will decrease the production of micro- and macro-organisms in the water body.
- **Category III** (light green colour in Figure 10): Increased nutrient enrichment enhances organic matter decomposition, and enhanced organic matter decomposition will reduce oxygen concentrations in the water body. Reduced oxygen concentrations will decrease the production of micro- and macro-organisms in the water body.
- **Category IV** (light red colour in Figure 10): This category includes the chemical quality elements, i.e. the toxic effect of organic and inorganic pollutants. Increased concentrations of pollutants will deteriorate the living conditions of organisms in a water body.

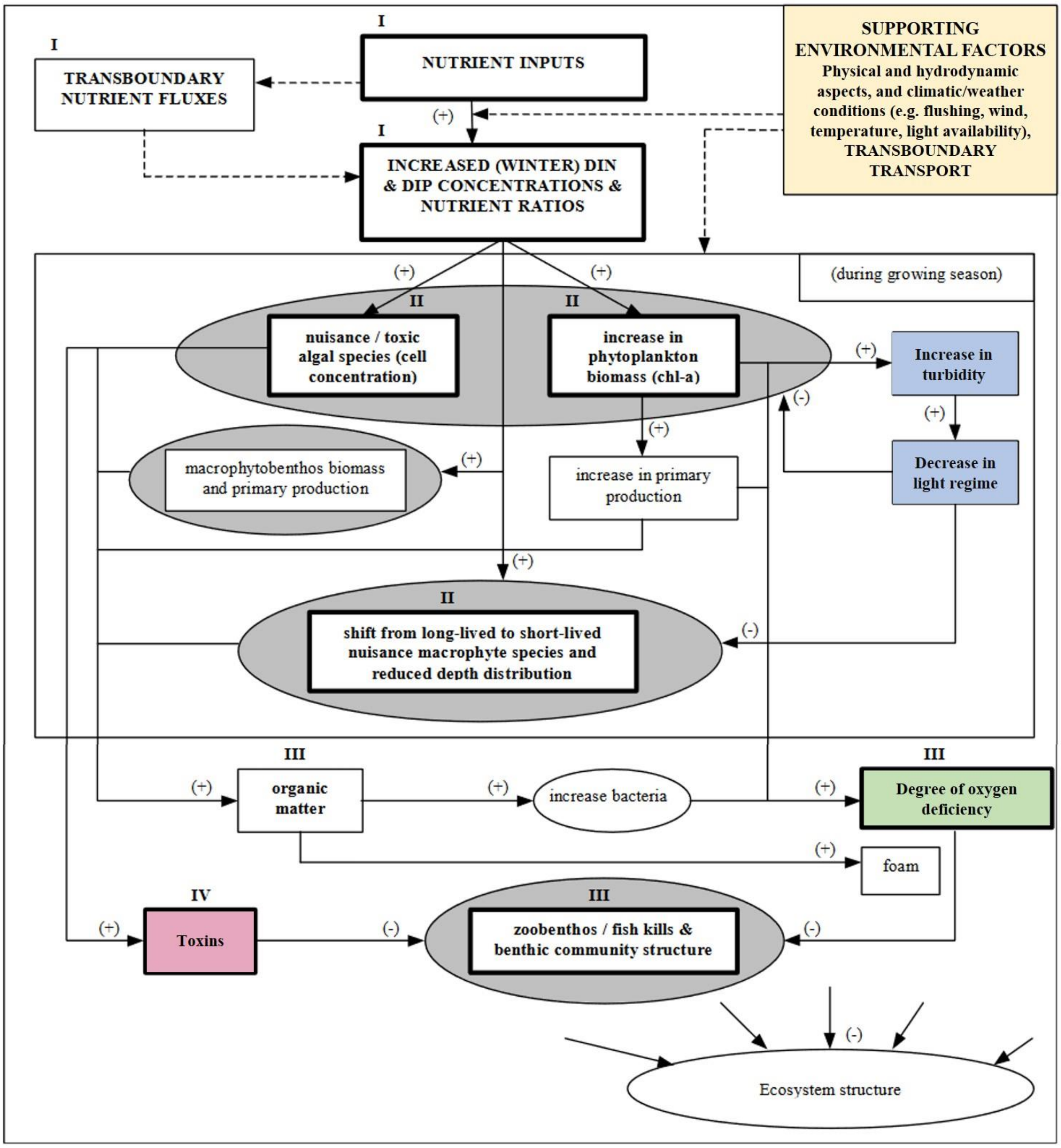

Figure 10. *The interrelationship between physical quality elements (**Category II** – Light blue background: Transparency/Turbidity**; Category III** – Light green background: Oxygen) and biological quality elements (White background). In addition, yellow background indicates external factors (**Category I** – Light yellow background: Including the remaining physical quality elements, hydrodynamics and climate change). **Category IV** – Light red background: Includes the chemical quality elements, i.e. the toxic levels of pollutants. Figure adopted from Working Group 2.4 - Coast (2003).*

Sampling and measuring water

Prior to the year 2000, Nansen water bottles (Figure 5C) provided the water material for hydrographic measurements at pre-defined water depths. After the year 2000, a CTD (conductivity-temperature-depth) sensor (Figure 5B) provided the continuous hydrographic water measurements throughout the entire water column of the Barsnesfjord. The CTD measures oxygen, temperature, density, and salinity continuously every two seconds while lowered through the water column.

Physical quality element oxygen – environmental condition

Direktoratsgruppen vanndirektivet (2018a) defines the environmental condition according to the oxygen content in a water body based on direct oxygen concentration measurements (Table 15).

The unit for the oxygen concentration is mgO_2/l, calculated from mlO_2/l by multiplying with a factor of 1,42. Note that the oxygen concentration determination occurred using the Winkler titration prior to the year 2000, and using the CTD-sensor after the year 2000.

Oxygen saturation indicates how high percentage of oxygen is in the water at a salinity of 33 PSU (‰) and a water temperature of 6°C.

Table 15. *Table of WFD environmental classification based on oxygen concentration and oxygen saturation, modified after Direktoratsgruppen vanndirektivet (2018a). Classes 1 to 5 correspond to the WFD colour code classification (Table 1).*

Parameter	**Unit**	Class I Very good	Class II Good	Class III Moderate	Class IV Bad	Class V Very bad
Oxygen Concentration	mgO_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

Physical quality element transparency – environmental condition

Direktoratsgruppen vanndirektivet (2018a) defines the environmental condition according to transparency (or turbidity) based on the direct measurements of the visual depth (Secchi depth) regarding a salinities of 5 and 18 PSU (‰) as indicated in Table 16.

Table 16. *Table of WFD environmental classification based on the Secchi (i.e. visual) depth, modified after Direktoratsgruppen vanndirektivet (2018a). The classification accounts for summer conditions (June to August) of the surface water layer of a water body. Classes 1 to 5 correspond to the WFD colour code classification (Table 1).*

Parameter	**Salinity (PSU)**	Class I Very good	Class II Good	Class III Moderate	Class IV Bad	Class V Very bad
Secchi depth	5	>7	7-4,5	4,5-2,5	2,5-1,5	<1
Secchi depth	18	>7,5	7,5-6	6-4	4-2,5	<2,5

2.6 Interview

Interview performed at the Sogn og Fjordane County Municipality

A semi-structured interview will give a first overview about how the responsible county authority invites the people of the region to participate in the implementation of the Vannforskriften, i.e. the EU Water Framework Directive. The responsible authority is the Sogn og Fjordane County Municipality (Sogn og Fjordane Fylkeskommune). The interview with the county authority should also allow a conclusion on how this authority translates the data set provided by this investigation into the environmental classification of the Barsnesfjord.

Another expression for a semi-structured interview is a qualitative interview. This type of interview processes general questions formulated prior to the interview. This allows the interviewer to deepen given questions, which can result in a more detailed information (Dingemanse, 2015). The interview at the Sogn og Fjordane County Municipality was an exploratory investigation, giving useful information possible further and in-depth interviews. This information could include wishes, expectations and requirements.

The interview with the Sogn og Fjordane County Municipality took place with regional WFD coordinator Christian Pettersen on the 21st of November 2019. In this position, Christian Pettersen is responsible for the implementation of the Water Framwork Directive in the Sogn og Fjordane County Municipality (Vannområdekoordinator). The main coordinator would be the first person giving information on the ongoing project status, including ideas and points of attention (Fischer & Julsing, 2019).

The main topics during the exploratory interview with the Sogn og Fjordane County Municipality were:

- Current classification of the Barsnesfjord.
- Discussion of results as presented in this thesis.
- Strategies and plans to get and to maintain a WFD classification of “Good” environmental conditions.

The questions asked during the exploratory interview were:

1. What standards define a water body to as being classified as “Good” (green) as opposed to “Bad” (orange)?
2. What were the factors that determined that the Barsnesfjord environmental classification as “Bad” (orange)?
3. Does more information (e.g. a database) exist about the Barsnesfjord to base this “Bad” (orange) condition on, which is not available at the Norwegian WFD website, perhaps from visual observation or external research?
4. Give some comment on how far the data presented in this thesis could be of value, and what additional future investigations would be necessary according to the WFD ambitions of creating a “Good” (green) environmental condition in the Barsnesfjord.
5. Are there any plans/strategies for reaching this “Good” (green) environmental condition, and what are these plans/strategies?
6. What are the plans/strategies for monitoring to keeping a “Good” (green) environmental condition?

3. Results

3.1 Biological quality elements

3.1.1 Macro-algae environmental condition

The Barsnesfjord belongs to eco-region M North Sea North (Figure 6). With regard to the water type, the Barsnesfjord is an oxygen-depleted fjord. No RSL/RSLA list exists for this water type. Thus, the RSL/RSLA list used is that of the water type with the closest salinity.

Vann-Nett (n.d.) defines the Barsnesfjord as mesohaline (i.e. salinity of 5-18 PSU), representing coastal water type 5 (Figure 6), a (sheltered) fjord strongly influenced by freshwater. The RSL 5 reduced species list describes this water type, and thus the Barsnesfjord. The RSL 5 forms the basis for the calculations of the normalized species richness, the percentage red algae, the percentage green algae, the ESG1/ESG2 ratio and the percentage of opportunistic species.

Applying Appendix A, results in a **Shore Description Number of 8** for Location 5 and Location 6 (Figure 4), corresponding to a **Shore Potential factor F = 1.51** for both locations (Table 4).

Location 5 revealed six macro-algae species. The brown algae *Ascophyllum nodosum and Fucus vesiculosus* were dominant; the green algae *Ulva linza* occurred spread and *Ulva intestinalis* was common; the red algae *Polysiphonia ribillosa* was common and *Hildebrandia rubra* occurred spread; for abundance specification see Table 17. Location 6 revealed the same species apart from *Polysiphonia ribillosa*, which did not occur at Location 6.

Table 17. *Occurrence of macro-algae species at Barsnesfjord Location 5 and 6. The "x" indicates the species occurring at the two locations. The "x" also indicates whether the species belong to the Ecological Species Group ESG1 or ESG2.*

Species	Location 5	Location 6	ESG 1	ESG 2
Brown algae				
Ascophyllum nodosum	x	x	x	
Fucus vesiculosus	x	x	x	
Green algae				
Ulva linza	x	x		x
Ulva intestinalis	x	x		x
Red algae				
Polysiphonia ribillosa	x			x
Hildebrandia rubra	x	x	x	

In the next step, the calculation of the normalized Ecological Quality Ratio (nEQR) for the macro-algae uses the **Shore Description number**, the **Shore Potential,** and the **Abundance** list (Table 17). Table 18 illustrates the basic values for Location 5 and Location 6 for the calculation of the nEQR for the macro-algae.

Table 18. *Basic parameter values of Location 5 and Location 6 in the Barsnesfjord for the calculation of the normalized Ecological Quality Ration (nEQR) of the macro-algae, using Formula 1 (Normalized species richness), Formula 2 (Green and red algae; opportunistic species) and Formula 3 (ESG1/ESG2 ratio). The colours indicate the classification of the environmental condition of the single parameters according to the colour code of the Water Framework Directive (Table 1).*

Parameters	Classification Location 5	Classification Location 6
Normalized species richness	9,06	7,55
% green algae	33%	40%
% red algae	33%	40%
ESG1/ESG2	1	1,5
% opportunistic species	33%	40%

Table 19 shows the EQR calculations for the parameters that indicate a negative correlation between the parameters and eutrophication, using Formula 4, including the colour classification for both locations.

Table 19. *EQR of Location 5 and 6 using Formula 4. Colour code follows the WFD classification for environmental conditions (Table 1). Note that the EQR for the Normalized species richness of Location 1 is directly at the boundary between a "Moderate" classification (Yellow colour: >0,4-0,6 in Table 8) and a "Good" classification (Green colour: >0,6-0,8 in Table 8).*

Parameters	EQR Location 5	EQR Location 6
Normalized species richness	0,601	0,528
% red algae	0,812	0,831
ESG1/ESG2	1	1,291

Table 20 shows the EQR calculations for the parameters that indicate a positive correlation between the parameters and eutrophication, using Formula 5, including the colour classification for both locations.

Table 20. *EQR of Location 5 and 6 using Formula 5. Colour code follows the WFD classification for environmental conditions (Table 1).*

Parameters	EQR Location 5	EQR Location 6
% Green algae	0,689	0,500
% Opportunistic species	0,472	0,240

3.1.2 Benthic macro-invertebrate environmental conditions

Table 21 shows the six identified benthic macro-invertebrate species at Location 1: Inner Barsnesfjord and Location 3: Outer Barsnesfjord (Figure 4). The anoxic Inner Barsnesfjord reveals two benthic macro-invertebrate individuals, while the Outer Barsnesfjord reveals 13 benthic macro-invertebrate individuals.

Table 21. *Total number of individuals of benthic macro-invertebrate species at Location 1 (light grey, Inner Barsnesfjord) and Location 3 (dark grey, Outer Barsnesfjord); three repetitive samples at each location. Numbers in grey fields indicate the number of individuals in the indicated sample.*

	Location 1: Inner Barsnesfjord			**Location 3: Outer Barsnesfjord**		
Species	Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3
Pectinaria koreni				3	2	
Thysanoessa species	1					
Boreomysis megalops					1	
Diastylis species		1				
Glycera species				1	1	2
Capitella capitata						3
Total number of individuals	**2**			**13**		

These benthic macro-invertebrate species (Table 21) form the basis for calculation of the five indexes: NQI 1, H', ES_{100}, NSI and ISI_{2012}. Each of these indexes results in an average value and a nEQR value for all three samples taken at both locations (three samples at Location 1: Inner Barsnesfjord; three samples at Location 3: Outer Barsnesfjord). Table 22 shows the results and the classification of the benthic macro-invertebrates. The colour code corresponds to the WFD classification of environmental conditions (Table 1).

The **NQI 1** index illustrates the quality of the species diversity and sensitivity. For the Inner Barsnesfjord, there are no numbers and classifications because of the low number of species. For the Outer Barsnesfjord, Sample 1 and 3 got a “Bad” environmental condition (orange), while Sample 2 got a “Moderate” environmental condition (yellow). The average value and the nEQR value of the NQI 1 index indicate a “Bad” (orange) environmental condition for the Outer Barsnesfjord (Table 22).

The Shannon Index **H’** and the **ES_{100}** index indicate the species diversity qualitatively (Table 10).

For the Inner Barsnesfjord, the average value and the nEQR value of both indexes indicate a “Very Bad” environmental condition (red). For the Outer Barsnesfjord, the average value and the nEQR of the H’ index indicates a “Bad” environmental condition (orange), while the average value and the nEQR value of the ES_{100} index indicates a “Very bad” (red) environmental condition (Table 22).

The NSI and the ISI_{2012} indexes indicate the sensitivity of species to environmental change (Table 10). For the Inner Barsnesfjord, the average value and the nEQR reveal for both indexes a “Very good” (blue) environmental condition. Note that the Inner Barsnesfjord no individuals with an NSI and ISI_{2012} values are measured in Sample 1 and 3 (Table 22).

The Outer Barsnesfjord shows more variation in the classification. Sample 1 and 2 classify into ”Very good” (blue) environmental conditions within both indexes. Sample 3 show for the NSI a “Bad” (orange), and for the ISI_{2012} a “Very bad” (red) environmental condition. In spite of this, the average and the nEQR value of the NSI and the ISI_{2012} indicates a “Very good” (blue) environmental condition for the Outer Barsnesfjord (Table 22).

Table 22. *The NQI 1, H', ES_{100}, NSI and ISI_{2012} indexes for the benthic macro-invertebrates of Location 1: Inner Barsnesfjord and Location 2: Outer Barsnesfjord, and the resulting nEQR values. The colour code corresponds to the WFD classification of environmental conditions in aquatic environments (Table 1).*

NQI 1		**Location 1 Inner Barsnesfjord**		**Location 3 Outer Barnesfjord**	
	Calculation Formula 7 & 8	**Sample 1**	*too few individuals*	**Sample 1**	0,407
		Sample 2	*too few individuals*	**Sample 2**	0,527
		Sample 3	*no individuals*	**Sample 3**	0,335
	Average				0,423
	nEQR		*not to calculate*		0,323
H'		**Location 1 Inner Barsnesfjord**		**Location 3 Outer Barnesfjord**	
	Calculation Formula 6	**Sample 1**	0	**Sample 1**	0,811
		Sample 2	0	**Sample 2**	1,500
		Sample 3	*no individuals*	**Sample 3**	0,971
	Average		0		1,094
	nEQR		0		0,235
ES_{100}		**Location 1 Inner Barsnesfjord**		**Location 3 Outer Barnesfjord**	
	Calculation Formula 9	**Sample 1**	1	**Sample 1**	1,990
		Sample 2	1	**Sample 2**	2,981
		Sample 3	*no individuals*	**Sample 3**	1,990
	Average		1		2,321
	nEQR		0,040		0,093
NSI		**Location 1 Inner Barsnesfjord**		**Location 3 Outer Barnesfjord**	
	Calculation Formula 11	**Sample 1**	*no individuals*	**Sample 1**	29,513
		Sample 2	29,200	**Sample 2**	28,880
		Sample 3	*no individuals*	**Sample 3**	13,716
	Average		29,200		24,036
	nEQR		1,008		0,801
ISI_{2012}		**Location 1 Inner Barsnesfjord**		**Location 3 Outer Barnesfjord**	
	Calculation Formula 10	**Sample 1**	*no individuals*	**Sample 1**	11,333
		Sample 2	9,540	**Sample 2**	13,435
		Sample 3	*no individuals*	**Sample 3**	4,092
	Average		9,540		9,620
	nEQR		0,845		0,849

3.1.3 Benthic foraminifera environmental conditions

Benthic foraminifera counting occurred in the sediment cores of the Inner Barsnesfjord (Location 1; Figure 4) and the Outer Barsnesfjord (Location 3; Figure 4).

Figure 11 shows the depth distribution of the most dominating benthic foraminifera species (*Stainforthia fusiformis*, *Textularia earlandi*, *Leptohalysis gracilis* and *Scaccammina* species) at Location 1 in the Inner Barsnesfjord. For better comparison between Location 1 and Location 3, the counts of the foraminifera relate to the volume of 10 ml sediment sample. Note that the maximum cumulative count for the benthic foraminifer individuals does not exceed 350 by number. The number of 350 is low, compared to the >2500 cumulative counts/10 ml at Location 3: Outer Barsnesfjord. This is probably due to the overall lower oxygen concentration in the Inner Barsnesfjord compared to the

Outer Barsnesfjord. The sediment dating of pre-1982 and post-1982 originates from Paetzel & Schrader (1991) and Paetzel & Dale (2010). The investigation of Bucher (2020) accounts for the interpretation of the slide event relating it to the building process of the Årøy hydropower at the River Årøyelv (Figure 11). Bucher (2020) also suggests that the overall decreasing counts of the foraminifer species are due to the steadily increasing use of the hydropower plant after 1982.

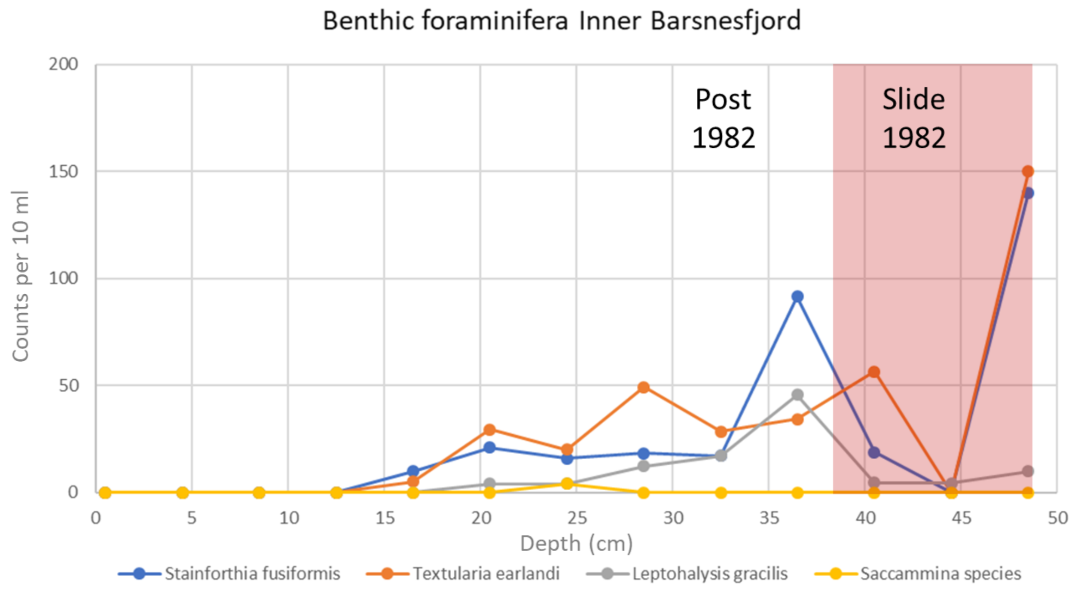

Figure 11. *Counts of the dominating benthic foraminifer species in the sediment core of Location 1: Inner Barsnesfjord. Red shaded area indicates deposition from a slide event that occurred in 1982. The post-1982 area above 38 cm indicates a gradual decrease in the number and diversity of the benthic foraminifera. This decrease coincides with the startup of the Årøy hydropower plant (Figure 4). Note that the maximum count of the most dominant species is 150. Dating from Paetzel & Schrader (1991) and Paetzel & Dale (2010). Sedimentology and slide event determination from Bucher (2020).*

Figure 12 shows the depth distribution of the most dominating benthic foraminifer species (*Stainforthia fusiformis*, *Textularia earlandi*, *Leptohalysis gracilis*, *Bulimina marginata* and *Nonionellina* species) in the sediment core of Location 3: Outer Barsnesfjord. Note that the maximum cumulative count for the benthic foraminifer individuals exceeds 2500 by number. The number of >2500 counts is high, compared to the cumulative counts of <350 at Location 1: Inner Barsnesfjord. This is probably due to the overall higher oxygen concentration in the Outer Barsnesfjord compared to the Inner Barsnesfjord.

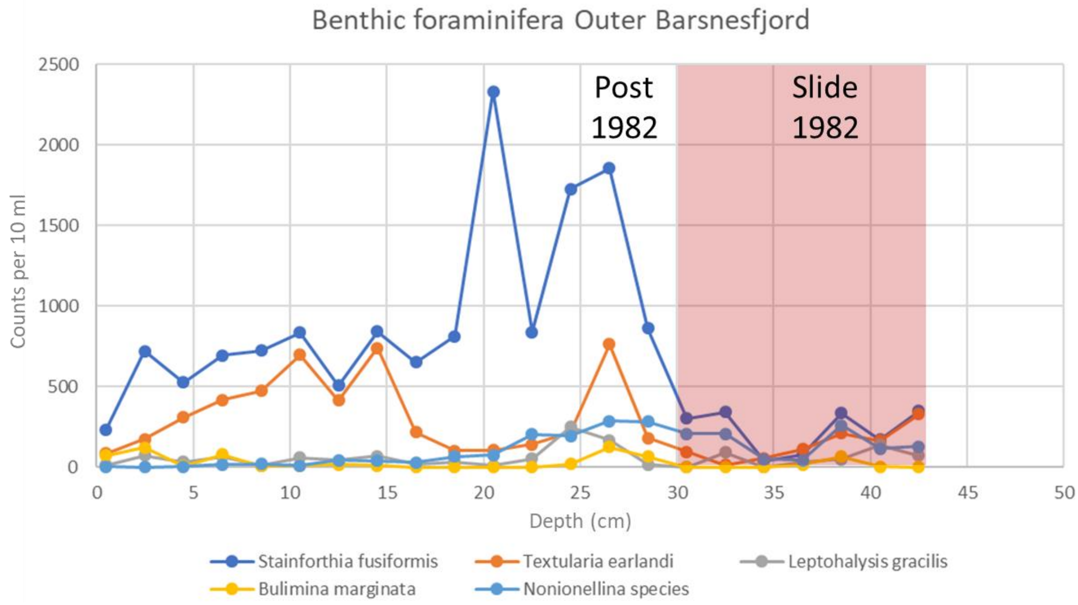

Figure 12. *Counts of the dominating benthic foraminifera species in the sediment core of Location 3: Outer Barsnesfjord. Red shaded area indicates deposition from a slide event that occurred in 1982. The post-1982 area above 30 cm indicates a gradual decrease in the number and diversity of the benthic foraminifera. This decrease coincides with the startup of the Årøy hydropower plant (Figure 4). Note that the maximum count of the most dominant species is almost 2.500. Dating from Paetzel & Schrader (1991) and Paetzel & Dale (2010). Sedimentology and slide event determination from Bucher (2020).*

For the classification of the environmental conditions from benthic foraminifera, only the H' and ES_{100} indexes are useable, as no sensitivity data exist for benthic foraminifera species (Table 23). The Inner Barsnesfjord scores for both indexes are "Very bad" environmental conditions (red), while the Outer Barsnesfjord has a "Moderate" (yellow) environmental condition for the H' index, and a "Bad" (orange) environmental condition for the ES_{100} index.

Table 23. *The mean nEQR environmental condition classification from benthic foraminifera of the Inner Barsnesfjord (Location 1) and the Outer Barsnesfjord (Location 2). The colour code corresponds to the WFD classification of environmental conditions in aquatic environments (Table 1).*

Benthic foraminifer classification				
Index	**Location 1: Inner Barsnesfjord**		**Location 3: Outer Barsnesfjord**	
H' Formula 6	Average	0,838	Average	2,153
	nEQR	0,186	nEQR	0,427
ES_{100} Formula 9	Average	2,217	Average	9,473
	nEQR	0,089	nEQR	0,379

The sedimentation rate in both Barsnesfjord basins is about 1 cm/year (Paetzel & Schrader 1991; Paetzel & Dale, 2010). This means that each benthic foraminifer sample corresponds to about one year of sedimentation. Thus, it is possible to determine the change in environmental conditions in both Barsnesfjord basins by comparing the 1982 benthic foraminifer nEQR with the nEQR of 2019, as illustrated in Table 24. In this way, the evolution of the environmental conditions in the Barsnesfjord becomes visible:

- The Inner Barsnesfjord: From "Bad" to "Very bad" (orange/red) environmental conditions in 1982 to "Very bad" (red) environmental condition in 2019 (Table 24)
- The Outer Barsnesfjord: From "Very good" (blue) to "Moderate" (yellow) environmental conditions in 1982 to "Very bad" (red) environmental conditions in 2019 (Table 24).

Table 24. *The mean nEQR environmental condition classification from benthic foraminifera of the Inner Barsnesfjord (Location 1) and the Outer Barsnesfjord (Location 2) for the year 2019 (lower table) and the year 1982 (upper table). The colour code corresponds to the WFD classification of environmental conditions in aquatic environments (Table 1).*

Benthic foraminifer classification – comparison between 1982 and 2019				
Index	**Location 1: Inner Barsnesfjord**		**Location 3: Outer Barsnesfjord**	
H' 1982	36-37 cm	1,703	26-27 cm	4,134
	nEQR	0,378	nEQR	0,919
ES_{100} 1982	36-37 cm	3,975	26-27 cm	12,103
	nEQR	0,159	nEQR	0,484
H' 2019	0-1 cm	0	0-1 cm	0,618
	nEQR	0	nEQR	0,137
ES_{100} 2019	0-1 cm	0	0-1 cm	4,977
	nEQR	0	nEQR	0,199

3.2 Chemical quality elements

3.2.1 Inorganic pollutants

Table 25 shows the trace metal concentrations in three horizons (Top: 0-15 cm; Middle: 15-30 cm; Bottom 30-45 cm sediment depth) of sediment cores retrieved at Location 2: Inner Barsnesfjord, and Location 4: Outer Barsnesfjord (Figure 4, Table 3). All samples range within "Very good" environmental condition (blue – natural background values) and "Good" environmental conditions (green – above background but not toxic).

Table 25. *Trace metal concentrations in sediment cores (Top: 0-15 cm; Middle 15-30 cm; Bottom: 30-45 cm sediment depth) at Location 2: Inner Barsnesfjord and Location 4: Outer Barsnesfjord. The colour code corresponds to the WFD classification of environmental conditions in aquatic environments (Table 1).*

	Inner Barsnesfjord Location 2			**Outer Barsnesfjord Location 4**		
	0-15 cm	**15-30 cm**	**30-45 cm**	**0-15 cm**	**15-30 cm**	**30-45 cm**
Trace and heavy metals	mg/kg dry matter	mg/kg dry matter	mg/kg dry matter	mg/kg dry matter	mg/kg dry matter	mg/kg dry matter
As Arsenic	7,70	5,80	6,80	9,40	10,00	12,00
Pb Lead	24,00	9,70	10,00	18,00	14,00	19,00
Cd Cadmium	0,57	0,45	0,42	0,49	0,41	0,30
Cu Copper	24,00	22,00	20,00	22,00	24,00	28,00
Cr Chromium	21,00	18,00	17,00	18,00	23,00	29,00
Hg Mercury	0,03	0,02	0,01	0,09	0,04	0,03
Ni Nickel	23,00	20,00	20,00	19,00	23,00	29,00
Zn Zinc	120,00	92,00	92,00	120,00	110,00	130,00

3.2.2 Organic pollutants PAH and TBT

Table 26 shows the Polycyclic Aromatic Hydrocarbon (PAH) and Tributyltin (TBT) concentrations in three horizons (Top: 0-15 cm; Middle: 15-30 cm; Bottom 30-45 cm sediment depth) of sediment cores retrieved at Location 2: Inner Barsnesfjord, and Location 4: Outer Barsnesfjord (Figure 4, Table 3). Most samples range within "Very good" environmental condition (blue – natural background values) and "Good" environmental conditions (green – above background but not toxic).

Only the surface sample concentrations (Top: 0-15 cm) of Benzo(ghi)perylene at Location 2, and the surface sample concentrations (Top:0-15 cm) of Indeno[1,2,3-cd]pyrene at Location 4 reveal a "Bad" environmental condition (orange – acute toxic effects).

Most surface samples (Top: 0-15 cm sediment depth) with concentrations above detection limit contain slightly elevated PAH concentrations at both locations. The overall environmental condition reveals a "Bad" (orange) environmental status of the organic PAH pollutants for the entire Barsnesfjord.

TBT concentration stayed below the detection limit in all samples. Note that the detection limit of TBT in this investigation was <2,5 µg/kg which is a concentration two orders of magnitude higher than the TBT "Very bad" environmental condition of >0,032 µg/kg. Thus, the TBT concentrations are inconclusive regarding the environmental condition of the Barsnesfjord basins.

Table 26. *PAH (16) and TBT concentrations in sediment cores (Top: 0-15 cm; Middle 15-30 cm; Bottom: 30-45 cm sediment depth) at Location 2: Inner Barsnesfjord and Location 4: Outer Barsnesfjord. The colour code corresponds to the WFD classification of environmental conditions in aquatic environments (Table 1). "bdl" = below detection limit. Note that the TBT concentrations are inconclusive (see explanation in the text).*

	Inner Barsnesfjord Location 2			**Outer Barsnesfjord Location 4**		
	0-15 cm	**15-30 cm**	**30-45 cm**	**0-15 cm**	**15-30 cm**	**30-45 cm**
PAH (16) & TBT	µg/kg dry matter	µg/kg dry matter	µg/kg dry matter	µg/kg dry matter	µg/kg dry matter	µg/kg dry matter
Naphthalene	*bdl*	*bdl*	*bdl*	*bdl*	*bdl*	*bdl*
Acenaphtalene	*bdl*	*bdl*	*bdl*	*bdl*	*bdl*	*bdl*
Acenaphtene	*bdl*	*bdl*	*bdl*	*bdl*	*bdl*	*bdl*
Fluorene	*bdl*	*bdl*	*bdl*	*bdl*	*bdl*	*bdl*
Phenantrene	*bdl*	*bdl*	*bdl*	0,024	*bdl*	*bdl*
Antracene	*bdl*	*bdl*	*bdl*	*bdl*	*bdl*	*bdl*
Fluorantene	0,031	*bdl*	*bdl*	0,056	0,021	*bdl*
Pyrene	0,036	*bdl*	*bdl*	0,066	0,023	*bdl*
Benzo(a)antracene	0,015	*bdl*	*bdl*	0,032	*bdl*	*bdl*
Chrysene (Triphenyl)	0,010	*bdl*	*bdl*	0,025	*bdl*	*bdl*
Benzo(b)fluorantene	0,067	*bdl*	*bdl*	0,100	0,041	0,010
Benzo(k)fluorantene	0,022	*bdl*	*bdl*	0,037	0,015	*bdl*
Benzo(a)pyrene	0,027	*bdl*	*bdl*	0,049	0,017	*bdl*
Indeno[1,2,3-cd]pyrene	0,051	*bdl*	*bdl*	0,082	0,038	*bdl*
Dibenzo[a,h]antracene	*bdl*	*bdl*	*bdl*	0,011	*bdl*	*bdl*
Benzo[ghi]perylene	0,440	*bdl*	*bdl*	0,068	0,031	*bdl*
Tributyltin See note in text	***bdl***	***bdl***	***bdl***	***bdl***	***bdl***	***bdl***

3.2.3 Organic pollutants PCB

Table 27 shows the Polychlorinated biphenyl (PCB) concentrations in three horizons (Top: 0-15 cm; Middle: 15-30 cm; Bottom 30-45 cm sediment depth) of sediment cores retrieved at Location 2: Inner Barsnesfjord, and Location 4: Outer Barsnesfjord (Figure 4, Table 3). The sum for PCB (7) was not determined as all PCB concentration range below the detection limit.

Table 27. *PCB (7) concentrations in sediment cores (Top: 0-15 cm; Middle 15-30 cm; Bottom: 30-45 cm sediment depth) at Location 2: Inner Barsnesfjord and Location 4: Outer Barsnesfjord. No colour code and WFD environmental classification applies as all concentrations are below detection limit (bdl).*

	Inner Barsnesfjord Location 2			**Outer Barsnesfjord Location 4**		
	0-15 cm	**15-30 cm**	**30-45 cm**	**0-15 cm**	**15-30 cm**	**30-45 cm**
PCB (7)	mg/kg dry matter	mg/kg dry matter	mg/kg dry matter	mg/kg dry matter	mg/kg dry matter	mg/kg dry matter
PCB 28	*bdl*	*bdl*	*bdl*	*bdl*	*bdl*	*bdl*
PCB 52	*bdl*	*bdl*	*bdl*	*bdl*	*bdl*	*bdl*
PCB 101	*bdl*	*bdl*	*bdl*	*bdl*	*bdl*	*bdl*
PCB 118	*bdl*	*bdl*	*bdl*	*bdl*	*bdl*	*bdl*
PCB 138	*bdl*	*bdl*	*bdl*	*bdl*	*bdl*	*bdl*
PCB 153	*bdl*	*bdl*	*bdl*	*bdl*	*bdl*	*bdl*
PCB 180	*bdl*	*bdl*	*bdl*	*bdl*	*bdl*	*bdl*
Sum PCB (7)	***Not determined***	***Not determined***	***Not determined***	***Not determined***	***Not determined***	***Not determined***

3.3 Physical quality elements

3.3.1 Oxygen

Table 28 shows the oxygen concentrations in the water column of the Inner Barsnesfjord (Upper Table, Location 1) and the Outer Barsnesfjord (Lower Table, Location 4) over the last 100 years. Measurements occurred at 0 m, 5m, 10 m, 20 m, 30 m, 40 m, 50 m and 60 m water depth in the Inner Barsnesfjord, and at 0 m, 5m, 10 m, 20 m, 30 m, 40 m, 50 m, 60 m and 75 m water depth in the Outer Barsnesfjord.

Oxygen concentration numbers are in mgO_2/l and represent annual measurements combined to decadal averages. Oxygen raw data originate from unpublished data of Torbjørn Dale (2020, *personal communication*).

In the Inner Barsnesfjord, the number of measurements vary from n=6 to n=11 measurements per decade. No oxygen measurements took place in the Inner Barsnesfjord prior to the year 2000, apart from n=1 measurement during the decade 1979-1970.

In the Outer Barsnesfjord, the number of measurements vary from n=4 to n=29 measurements per decade. Note that the only n=1 measurement forms the basis for the oxygen concentrations of the entire decade 1979-1970. No measurements took place in the Outer Barsnesfjord during the decade 1969-1960.

The environmental condition of oxygen concentrations in the Inner Barsnesfjord was “Moderate” (yellow) to “Bad” (orange) and “Very bad” (red) below 30 to 40 m water depth through the three measured decades. Colour coding follows the WFD colour codes for the environmental status (Table 1).

The environmental condition of oxygen concentrations in the Outer Barsnesfjord was "Very good" (blue) down to 60 m water depth from the 1920s until the 1950s. Since the 1970s, the environmental condition of the oxygen concentrations in the Outer Barsnesfjord gradually deteriorated, with "Very Good" (blue) environmental conditions only down to 30-40 m water depth during the last decades. Colour coding follows the WFD colour codes for the environmental status (Table 1).

Table 28. *Oxygen concentrations (in mgO_2/l) of the Inner Barsnesfjord water column (Location 1; upper table at 0-60 m water depth) and the Outer Barsnesfjord water column (Location 4; lower table at 0-75 m water depth). Oxygen concentrations in 10-year averages; raw data from Torbjørn Dale (2020, personal communication; unpublished data). Note that the number of measurements per year and depth vary greatly from n=1 to n=29. The colour code corresponds to the WFD classification of environmental conditions in aquatic environments (Table 1).*

Inner Barsnesfjord (Location 1) – Oxygen concentrations in mgO_2/l									
Years	0 m	5 m	10 m	20 m	30 m	40 m	50 m	60 m	
2019-2010	9,9	8,6	8,4	6,0	4,7	4,1	2,9	2,0	
2009-2000	9,8	9,8	9,7	5,9	3,8	3,2	2,1	1,3	
1979-1970	10,7		10,3	5,3	4,2				
Outer Barsnesfjord (Location 4) – Oxygen concentrations in mgO_2/l									
Years	0 m	5 m	10 m	20 m	30 m	40 m	50 m	60 m	75 m
2019-2010	8,6	8,4	8,0	6,1	5,1	4,7	4,5	4,2	3,5
2009-2000	9,5	9,1	9,3	6,6	4,2	3,8	3,5	2,9	0,1
1999-1990	12,3	10,9	8,9				3,2		
1989-1980	12,5	10,7	9,0	6,9	5,6	5,3		5,7	
1979-1970	10,5		10,3	6,3	4,1		4,4		3,6
1969-1960									
1959-1950		10,8	10,3	6,0	6,0	5,9	5,1	3,9	2,6
1949-1940		10,9	10,3	6,5	6,5	5,9	5,6	5,3	3,6
1939-1930		10,3	9,8	6,6	6,6	6,2	5,6	5,3	4,1
1929-1920	12,0	11,0	10,2	6,2	6,2	5,9	5,4	5,0	2,9

3.3.2 Transparency

Table 29 shows the transparency of the water column in the Inner Barsnesfjord (Location 1) and the Outer Barsnesfjord (Location 4) in September 2019, using a Secchi disk (Figure 5D).

Due to only one measurement, the Secchi depth is not conclusive regarding the development of the environmental condition of the Barsnesfjord basins in terms of transparency or turbidity. For the fall 2019, the environmental condition based on transparency was "Good" (green) in the Inner Barnesfjord and "Moderate" (Yellow) in the Outer Barsnesfjord. Colour coding follows the WFD colour codes for the environmental status (Table 1).

Table 29. *Transparency of the water column as determined by using the Secchi disk (Figure 5D). Measurements are from September 2019. The colour code corresponds to the WFD classification of environmental conditions in aquatic environments (Table 1).*

	Inner Barsnesfjord – Location 1	**Outer Barsnesfjord – Location 4**
Transparency	7,5 m	5,5 m

3.4 Interviews

The interview with Christian Petersen at the Sogn og Fjordane County Municipality took place in the beginning of November. First preliminary results of this investigation already existed at that time, influencing some of the interview questions.

The structure of the summary of this interview includes (a) Questions and answers, and (b) Additional information gained through the interview.

3.4.1 Questions and answers

Question 1: What standards define a waterway to as being "Good" as opposed to "Bad"?

Investigations of a water body within the Water Framework Directive include multiple parameters. First step would be to define the water type; second step would be defining certain characteristics of that water type and decide which parameters to use for the investigation. Calculation of boundary conditions will result in the classification of the water body according to the environmental condition "Very good" (blue), "Good" (green), "Moderate" (yellow), "Bad" (orange) or "Very bad" (red).

Some parameters include pre-defined indexes for e.g. algae and benthic organisms. The value you get there does not depend on the water type. This is the ideal situation, but there are not enough researchers and capacity to do this for several thousand water bodies in Norway. Alone in the Sogn og Fjordane county there are around 1200 water bodies. In the ideal situation, we should take water and biological samples from all the water bodies. To reduce the number of water bodies, we need to interpolate information or use an expert judgment over comparable water bodies.

Follow up question: What is the baseline of this adjustment?

I cannot really say that if you know that there is sewage coming into a fjord that you can put it automatically in this or that environmental condition.

We have other information about the water bodies as well, like what kind of human activities affect this water body. That means that the authority responsible for that kind of impact should investigate it and try to quantify the results somehow.

Only few of the WFD parameters are available from the Barsnesfjord.

A very good parameter is the mercury. Mercury in fish is one of these parameters used for the determination of the environmental condition in the Barsnesfjord. However, the fish did not originate from the Barsnesfjord, it came from the Aurlandsfjord (located on the opposite, i.e. south side of the main fjord) and Balestrand (located at the main fjord to the west). None is close to the northern tending Barsnesfjord. The best theory now is that the mercury comes in with the precipitation and that it accumulates in the fjord.

<u>Follow up question</u>: If mercury is coming in with the precipitation, how does this mercury come in the precipitation?

As far as I know, we do not have any local sources that could explain the distribution of this problem and the high concentrations in fish.

A bad thing is in this case that mercury is in a state that makes it easy to accumulate in organisms.

<u>Question 2: What were the factors that determined that the Barsnesfjord is "Bad"?</u>

We have the mercury, which we then anticipate also exists in the Barsnesfjord. We have the ecological part, which indicates a "Bad" condition, i.e. the Shannon index.

<u>Follow up question</u>: But my question would always be that the Barsnesfjord as such is more or less anoxic at the bottom of natural reasons. Naturally, a bottom fauna should be rare or absent in the Barsnesfjord. This would automatically result in a "Bad" or "Very bad" condition according to the Shannon index. Is a natural anoxic condition equal to a "Bad" environmental condition?

No, no of course not. There is some information that is telling us something about how trustworthy the data is. In the Barsnesfjord it is the lowest possible, the management does not have good data. It is quite rough; it is not the water body with the highest priority.

In conclusion, the data quality is poor. Based on the little we know, the Barsnesfjord has a "Bad" (orange) condition, but it could easily become better or worse with more data. We do not really know. I do not think the county governors want to put it in a "Good" environmental condition before they have more data.

<u>Question 3: Do you have more information (database) about the Barsnesfjord on which this condition is based, which is not on the website? Perhaps from visual observation or external research?</u>

It depends. You cannot really look separately at a fjord or a river at the inner part of the fjord, at least when it comes to salmon and sea trout. I do not think there are big local problems for fish in the fjord; but on their way out to the ocean, they might meet many challenges.

In addition, small boat harbours provide well-known problems, at least inside the harbours and maybe in the closest area around it. Inside those harbours, TBT or boat paint might pollute the sediment. I will guess that is only a local problem. I do not think these pollutants spread out that much. It is not special for that area; you have small harbours all over Norway. If you sum it up it will be a big issue.

<u>Question 4: We would appreciate some comment on how far the data from our project could be of value and what additional future investigations would be necessary according to your ambitions of creating a "Good" fjord.</u>

The work that you are doing and the work the students have done earlier is very useful. I think we (and the county governors) are aware of that.

Most of it will be useful, I think. We are very interested in salinity change and water currents, and hydrological changes in the Sognefjord (due to hydropower plants).

Question 5: Are there any plans/strategies to make the Barsnesfjord "Green"?

Look at the Vann-Nett webpage. There should be a list of actions for improving the conditions; but right now, there is nothing.

Question 6: What are these plans/strategies?

People can work with improvements of the quality without us knowing it, or without the system showing it. Most initiatives are outside the WFD. Small step should lead to reach the goal until 2033.

The original plan was to reach this goal in 2021. This is not possible anymore; for now, it would be 2033.

To our excuse, we came from a state where there was not much knowledge about the environmental conditions in any of the water bodies in the county. We are now at a state where we have at least a better knowledge. This might lead to claim the opposite condition in some water bodies (compared to the Barsnesfjord) where we now go from a previously "Good" condition into a worse condition due to more knowledge and the availability of more data.

We work in six-year periods. During the current period, we always evolve a new water management plan for the coming six-year period.

Question 7: What are the plans/strategies to keep it green?

Water bodies with a "Good" environmental condition should not get worse again. There are criteria. The authorities should not only work with improving the conditions but should also be aware of preventing the water bodies from getting into a worse condition again. Water management plans should help, and the WFD rules would make that easier.

3.4.2 Additional information gained from the interview

- Young people are mostly surprised on the result from an HVL investigation that indicated that leakage from a garbage dump threatens the Lake Haflsovatnet, and thus the Barsnesfjord, not long ago (in 2018). Astonishingly, many of such dumping sites are located close to water. So, then it is a high risk for spreading. Of course, if the pollution already has reached a lake or a fjord it is even worse. It is a very costly thing to do something about it. It is not that difficult to produce knowledge about it, but it is extremely expensive to do something physically about it. I guess if this kind of knowledge accumulates over the years, there will be an increased pressure on politicians and management to do more about it.
- Hydropower is very important for the county in many ways. Thus, it is very unlikely that there will be major changes in the way we produce hydropower. We are trying to work in a way to create changes and not only to create data about impacts that we cannot do much about. However, we are not going to make ourselves blind for that.

- Vannforskriften gives a classification scheme and we must use that; we cannot use parameters that are not part of this system. We can tell the responsible people that they should work for including more parameters. However, we cannot decide ourselves what kind of data we can use, and in which way.
- It is much more expensive to get good data for a fjord water body than for a lake or a river, at least for the region around the Sognefjord. If you look at all the water bodies, you will see that the data for the lakes and the streams are quite okay. Coasts and fjords have mostly the poorest data quality. The reason behind it is that it is more expensive, and that makes is more difficult to investigate it.
- We try to implement the way of WFD-thinking to all the authorities that are working with water directly or indirectly, like building more sewage treatment plants, and so on. If they can put it in their budget, it would be a big advantage. It would be easier to work with it for the different authorities if they have it in their plans somehow. Again, awareness is quite important.
- First, we need awareness, and then we need more “Good” (green) and less “Bad” (orange) water bodies. If that starts to succeed, there would be a new focus on the Water Framework Directive. You would then have a gradual improvement.

4. Discussion

4.1 Answering Objective 1: How will the holistic environmental investigation of the Barsnesfjord affect the environmental status of the fjord within the EU Water Framework Directive?

Figure 13 shows the approach of answering Objective 1. The basis for this thesis and investigation is the EU Water Framework Directive. From there, the approach follows two roads. The first road summarizes the current classification of the Barsnesfjord and the parameters included. The second road summarizes the classification according to this investigation of the Barsnesfjord and the parameters included. Next step is to define the differences and similarities between the current classification and the classification derived from this investigation. The final step is to apply the differences to defining a new classification of the WFD environmental conditions of the Barsnesfjord. This re-classification forms the basis to discuss how to involve "Naturally oxygen deficient fjords" into this classification.

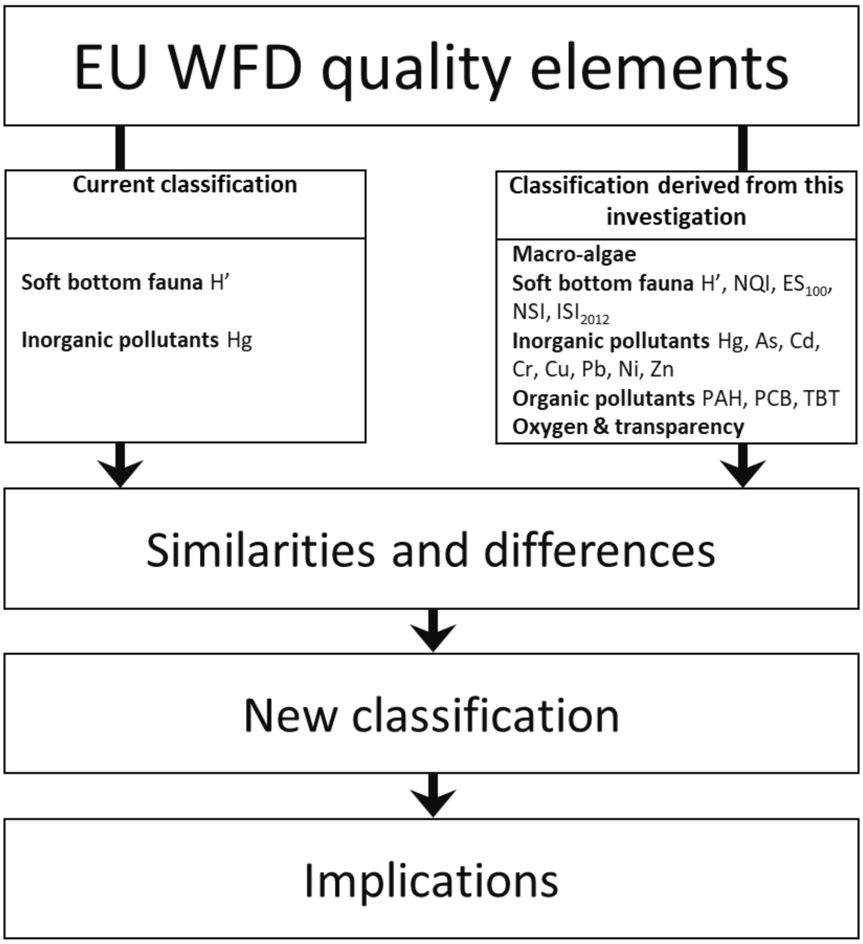

Figure 13. *The approach of answering Objective 1, based on the EU Water Framework Directive. From there, the current classification and the classification derived from this investigation lead to a comparison of these classifications, leading to a new classification. This new classification implies possible consequences for future investigations.*

4.1.1 Current classification

The parameters used for the current Barsnesfjord classification (from pre-2008; not specified, Vann-Nett n.d.) was a “Very bad” (red) chemical quality element classification of mercury (Hg) found in fish in the Aurlandsfjord and the Sognefjord outside Balestrand (Figure 14, Figure 15). In addition, a biological quality element classification indicated a “Bad” (orange) status, solely based on the Shannon index of benthic macro-invertebrates (Figure 14; Christian Petersen, 2019, *personal communication*).

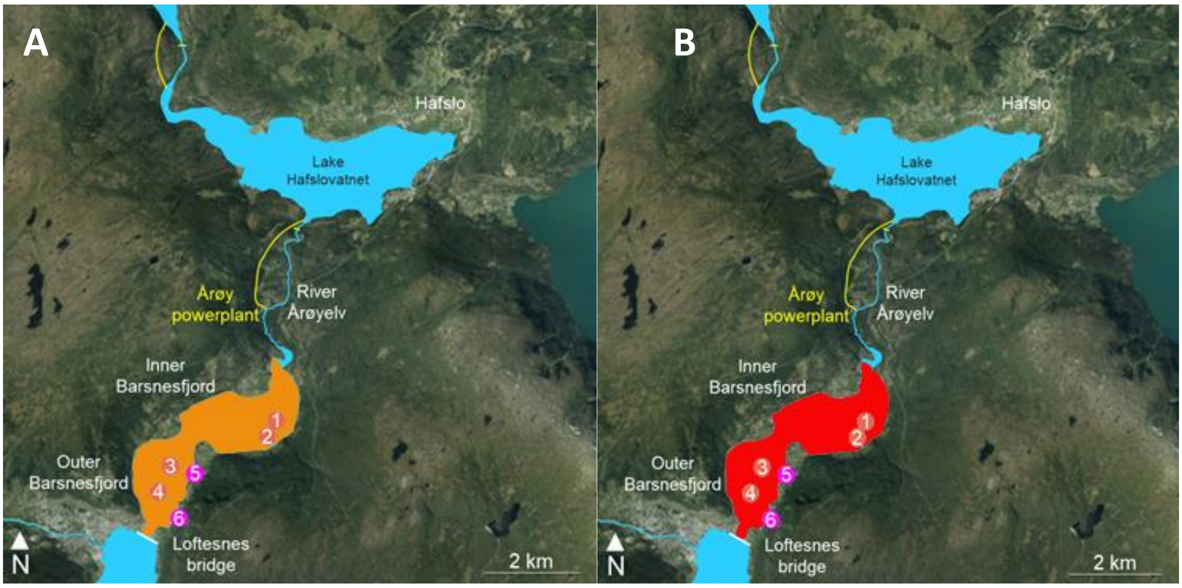

Figure 14. *(A) Current WFD biological quality element classification based on the Shannon index. (B) Current WFD chemical quality element classification based on mercury in fish from Balestrand and the Aurlandsfjord (Figure 15). Aerial photograph from “Norge i bilder“, n.d. (https://www.norgeibilder.no/)*

Figure 15. *Mercury (Hg) found in fish in the Sognefjord, outside Balestrand and in the Aurlandsfjord. White square shows the Barsnesfjord at distance to the registered Hg locations. Aerial photograph from “Norge i bilder“, n.d. (https://www.norgeibilder.no/)*

Solely mercury (Hg) in fish marks the chemical quality elements. There is no argument why mercury affects the fish at those two locations, or why the authorities choose fish at distance to the Barsnesfjord to define the Barsnesfjord chemical quality elements (Christian Petersen, 2019, *personal communication*).

4.1.2 Classification derived from this investigation

Table 2 shows the coastal water quality elements within the EU WFD including all investigated parameters (Direktoratsgruppen vanndirektivet, 2018a). This chapter will discuss the choice of parameters in this investigation prior to a total inventory. In principle, this investigation solely includes parameters that lead to a direct WFD classification. The only exemption is the transparency (see physical quality elements).

The chosen key parameters – biological quality elements

The biological quality elements consist of four parameters: Macro-algae, soft bottom fauna, eelgrass, and phytoplankton (Table 2). Within this thesis, the investigation only includes macro-algae and the soft bottom fauna.

Eelgrass does not exist in the Barsnesfjord (Matthias Paetzel, 2019, *personal communication*).

The Barsnesfjord consist of coastal water type 6, "Naturally oxygen deficient fjord". The Direktoratsgruppen vanndirektivet (2018a) does not define quality parameters for coastal water type 6, and thus the coastal water type of the closest salinity, i.e. coastal water type 5 (sheltered fjord strongly influenced by freshwater) forms the basis for the Barsnesfjord quality element investigation. Coastal water type 5 does not include the investigation of phytoplankton (Direktoratsgruppen vanndirektivet, 2018a).

This investigation – macro-algae

All EQRs gave a result for the macro-algae. However, the total number of species found at the locations is lower than 14. This leads to the exclusion of the percentage red algae and the ESG1/ESG2 ratio from the final nEQR calculation. The resulting final nEQR identifies the WFD classification of the environmental condition of the Barsnesfjord according to the occurrence of macro-algae, indicating a "Moderate" (yellow) environmental condition (Table 30).

Table 30. *Final nEQR of Location 5 and 6 using the mean value of all parameters involved. Note the exclusion of the percentage red algae and the ESG1/ESG2 ratio due to low species numbers (<14). Colour code follows the WFD classification for environmental conditions (Figure 1).*

Parameters	nEQR Location 5	nEQR Location 6
Classification of both locations	0,587	0,423
Average classification of the Barsnesfjord	0,505	

The mostly "Very good" to "Good" environmental status of the parameters in Table 19 (i.e. Normalized species richness, % red algae and ESG1/ESG2 ratio) suggests low eutrophication. However, the

“Moderate” environmental status of the normalized species richness suggests a beginning tendency towards higher eutrophication.

The mostly “Moderate” to “Bad” environmental status of the parameters in Table 20 (i.e. % Green algae and % Opportunistic species) suggests low eutrophication. However, the “Good” environmental status of the green algae suggests a beginning tendency towards higher eutrophication.

This investigation – benthic macro-invertebrates

The nEQR of the NSI and the ISI_{2012} of the inner Barsnesfjord falls into the category of “Very good” (blue) environmental condition, resulting in a “Moderate” (yellow) mean environmental status if the inner basin. However, this classification is a result of the occurrence of only one individual from one single species in one sample. Because the classification of these two indexes is a result of so little data, it is not reliable to include it in the final classification (Direktoratsgruppen vanndirektivet, 2018a).

With the exclusion of the NSI and the ISI_{2012} indexes from the Inner Barsnesfjord nEQR, the final mean nEQR of the benthic macro-invertebrates reveals a “Very bad” (red) environmental condition for the Inner Barsnesfjord and a “Moderate” (yellow) environmental condition for the Outer Barsnesfjord.

Table 31. *The mean nEQR environmental condition classification from benthic macro-invertebrates of the Inner Barsnesfjord (Location 1) and the Outer Barsnesfjord (Location 2). Note the difference between the NSI/ISI_{2012} included and excluded at Location 1. The colour code corresponds to the WFD classification of environmental conditions in aquatic environments (Table 1).*

Index	Location 1: Inner Barsnesfjord		Location 2: Outer Barsnesfjord	
NQI	nEQR	*not to calculate*	nEQR	0,323
H’	nEQR	0,000	nEQR	0,235
ES_{100}	nEQR	0,040	nEQR	0,093
NSI	nEQR	1,008	nEQR	0,801
ISI_{2012}	nEQR	0,845	nEQR	0,849
Mean	***nEQR***	***0,473***	***nEQR***	***0,461***
Mean without NSI and ISI_{2012}	***nEQR***	***0,020***		

This investigation – benthic foraminifera

The results of this study confirm what the dating of Bucher (2020) suggests. There is a decrease in benthic foraminifera observed between 1982 and 2019 (Table 32).

Table 23 presents the calculated nEQR over depth and time of the whole samples from the Inner and the Outer Barsnesfjord. The Inner Barsnesfjord classifies as ”Very bad” (red) in 2019, coming from an already “Bad” (orange) environmental condition in 1982. The Outer Barsnesfjord also classifies as “Very Bad” (red) environmental conditions in 2019, coming from “Good” (green) environmental condition in 1982 (Table 32).

This may be due to the difference in the oxygen concentrations in the Outer Barsnesfjord (Table 28 and Figure 10). However, since the Inner Barsnesfjord reveals bad condition already in the 1980s, the suggestion of naturally occurring anoxic conditions, and thus a naturally occurring “Very bad” (red) environmental condition for benthic foraminifera sounds reasonable.

On the other hand, the WFD classification of environmental conditions applies for the current situation, resulting in a final nEQR for benthic foraminifera of “Very bad” environmental conditions based on the classification from 2019 (Table 32).

This raises the question if naturally occurring “Very bad” (red) environmental conditions should fall into the “Very bad” WFD category, requiring to become a “Good” (green) status in the future, or if these natural “Very bad” (red) environmental conditions should just be acceptable as the normal condition of this fjord, not requiring an improvement.

Table 32 *The mean nEQR environmental condition classification from benthic foraminifera of the Inner Barsnesfjord (Location 1) and Outer Barsnesfjord (Location 2) for 1982 and 2019. The colour code corresponds to the WFD classification of environmental conditions in aquatic environments (Table 1).*

Benthic foraminifer classification – mean nEQR comparison between 1982 and 2019				
Year	**Location 1: Inner Barsnesfjord**		**Location 3: Outer Barsnesfjord**	
1982 mean	nEQR	0,269	nEQR	0,702
2019 mean	nEQR	0	nEQR	0,168

The chosen key parameters – chemical quality elements

The chemical quality elements support the understanding of the biological quality elements. The total organic carbon does not appear in the final WFD classification (Direktoratsgruppen vanndirektivet, 2018a), which is why this parameter does not occur in this study.

To be able to include the classification of the nutrients in the final WFD classification, there must be measurements of at least three consecutive years (Direktoratsgruppen vanndirektivet, 2018a). Such data is not available, which led to an exclusion of the phytoplankton as a quality element indicator.

Thus, the chemical quality elements of this investigation consist exclusively of all defined inorganic and organic pollutants that form the basis of the final WFD classification (Direktoratsgruppen vanndirektivet, 2018a).

This investigation – inorganic and organic pollutants

For pollutants, the worst value measured in a sample results in the WFD environmental classification determined for the entire water body.

Most surface samples (Top: 0-15 cm sediment depth) contain slightly elevated trace metal concentrations at both locations (Table 25). The overall environmental condition reveals a “Good” (green) environmental status for inorganic pollutants for the entire Barsnesfjord. However, if the raising in trace metal concentration continues, the quality will deteriorate in the future.

In both, the Inner and Outer Barsnesfjord there is one organic pollutant with a “Bad” (orange) classification (Table 26, Figure 10). This leads to the classification for the organic pollutants as “Bad” (orange) environmental conditions accounting for the entire Barsnesfjord, based on the chemical quality elements.

The chosen key parameters – physical quality elements

Within the physical quality elements, only oxygen and transparency result in a numerical classification. Temperature, salinity and sediment parameters would be supporting parameters that will not lead to a classification of their own (Direktoratsgruppen vanndirektivet, 2018a).

This investigation – oxygen

The oxygen concentration investigations of the Inner Barsnesfjord do not stretch over as many decades as those from the Outer Barsnesfjord. However, the tendencies are clear (Table 28).

The oxygen concentrations in the Inner Barsnesfjord below 30 to 40 meter water depth (Table 28) support the idea that the Inner Barsnesfjord is permanently anoxic below 60 m water depth (Paetzel & Schrader 1991; Paetzel & Dale 2010) over a time span of the last 20 to 50 years, suggesting naturally occurring low oxygen conditions in the Inner Barsnesfjord.

Again (as for the benthic foraminifera), this raises the question for the Inner Barsnesfjord if naturally occurring “Very bad” (red) or “Bad” (orange) environmental conditions should fall into “Bad” WFD category, requiring becoming a “Good” (green) status in the future. Alternatively, it would not require any improvement if these natural “Very bad” (red) or “Bad” (orange) environmental conditions should just be acceptable as the natural condition of this fjord.

In contrast, the oxygen concentrations of the Outer Barsnesfjord show a clear deterioration trend over the last 100 years (Table 28). This trend moves from generally “Very good” (blue) environmental conditions down to 60 m water depth before 1950 to “Moderate” (yellow) and even “Bad” (orange) environmental conditions below 50 m water depth during the last three decades. This supports the idea that the Outer Barsnesfjord developed more periodically anoxic conditions, and thus indicates a deterioration during the last decades (Paetzel & Schrader 1991; Paetzel & Dale 2010).

This investigation – turbidity

Although the WFD classification requires measurements in three subsequent years (Direktoratsgruppen vanndirektivet, 2018a), this investigation includes the measurements of transparency. Following up the transparency during the years to come will form the basis for using the transparency parameter in the future.

The transparency reveals “Good” environmental conditions in the Inner Barsnesfjord and “Moderate” environmental conditions in the Outer Barsnesfjord. However, this one measurement does not allow any conclusion on the environmental status of the Barsnesfjord, as stated above.

Summary, and the new classification of the Barsnesfjord

The combination of the results from the current classification and the classification resulting from this investigation provides the foundation for the new WFD classification of the environmental conditions in the Barsnesfjord.

Figure 16 (Inner Barsnesfjord) and Figure 17 (Outer Barsnesfjord) indicate how to arrive at the new WFD ecological and thus environmental status of the Barsnesfjord. It is important to have in mind that the biological quality elements determine the overall WFD environmental status when this is classified as “Moderate”, “Bad” or “Very bad” (Direktoratsgruppen vanndirektivet, 2018a).

In the Inner Barsnesfjord, the combined biological quality elements indicate a "Very bad" (red) environmental status, as visible in Figure 16 (the "Moderate" (yellow) and the "Bad" (orange) classification in brackets indicates the excluded NSI and ISI_{2012} classification). The transparency contains brackets due to the lack of data. The chemical and physical quality elements are supportive components for the biological quality elements (Direktoratsgruppen vanndirektivet, 2018a), thus confirming, but not directly leading to the overall strongly affected ecological and environmental status of the Inner Barsnesfjord.

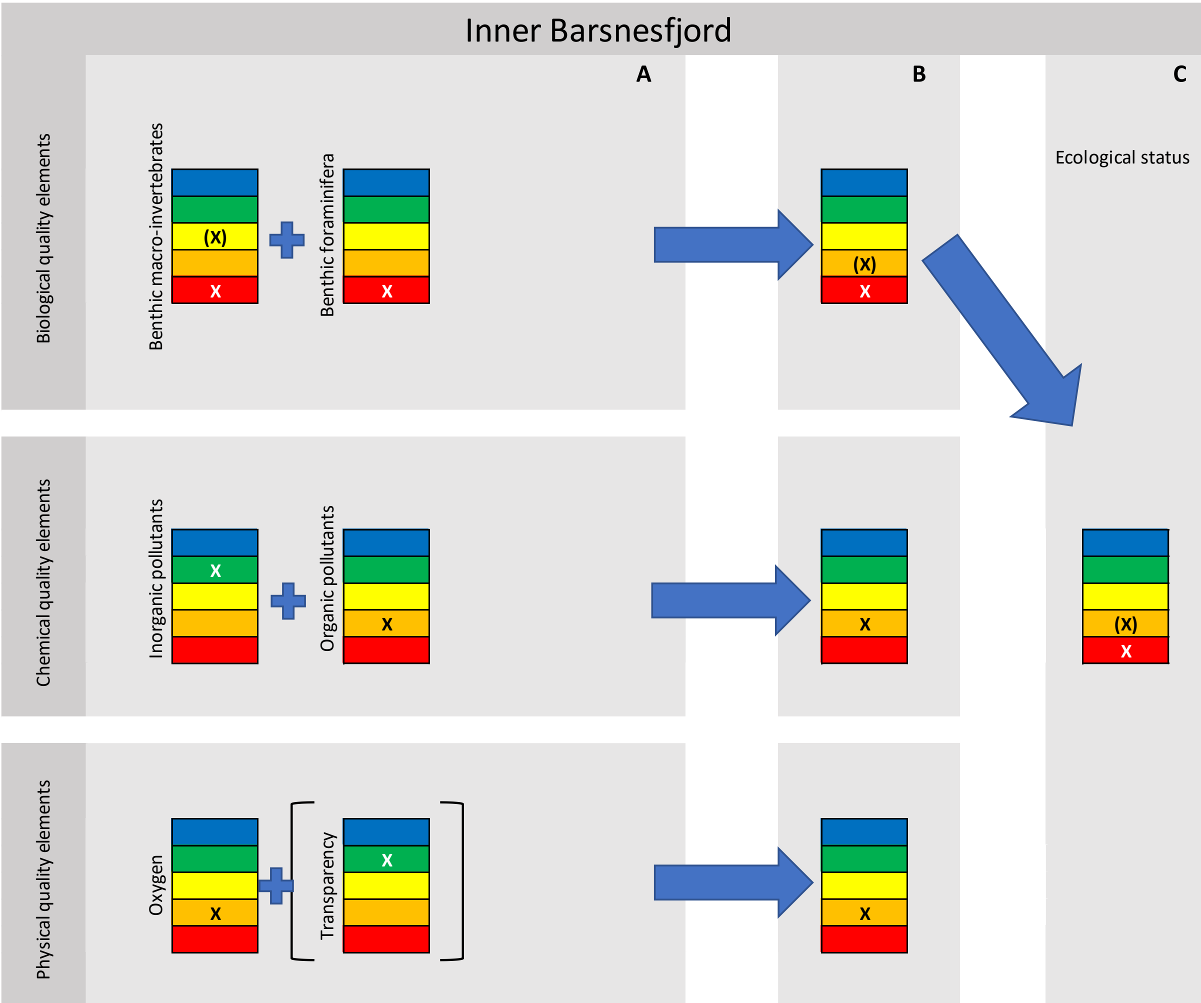

Figure 16. *The final WFD classification of the Inner Barsnesfjord. Column A shows the classifications of the measured parameters within the biological, chemical and physical quality elements of the Inner Barsnesfjord. The "Moderate" (yellow) classification in brackets includes the NSI and* ISI_{2012} *classification. Transparency contains large brackets as the lack of data prohibits its use for classification. Column B shows the classification per quality element with all parameters combined. The "Bad" (orange) classification in brackets includes the NSI and* ISI_{2012} *classification. To get from Column A to Column B, the worst values of the parameters within the quality elements determine the classification for that specific quality element. Column C is the final classification for the Inner Barsnesfjord with all quality elements combined. The "Bad" (orange) classification in brackets includes the NSI and* ISI_{2012} *classification.*

In the Outer Barsnesfjord, the combined biological quality elements indicate a "Bad" (orange) environmental status, as visible in Figure 17. The transparency contains brackets due to the lack of data. The chemical and physical quality elements are supportive components for the biological quality elements (Direktoratsgruppen vanndirektivet, 2018a), thus confirming but not directly leading to the overall affected ecological and environmental status of the Outer Barsnesfjord.

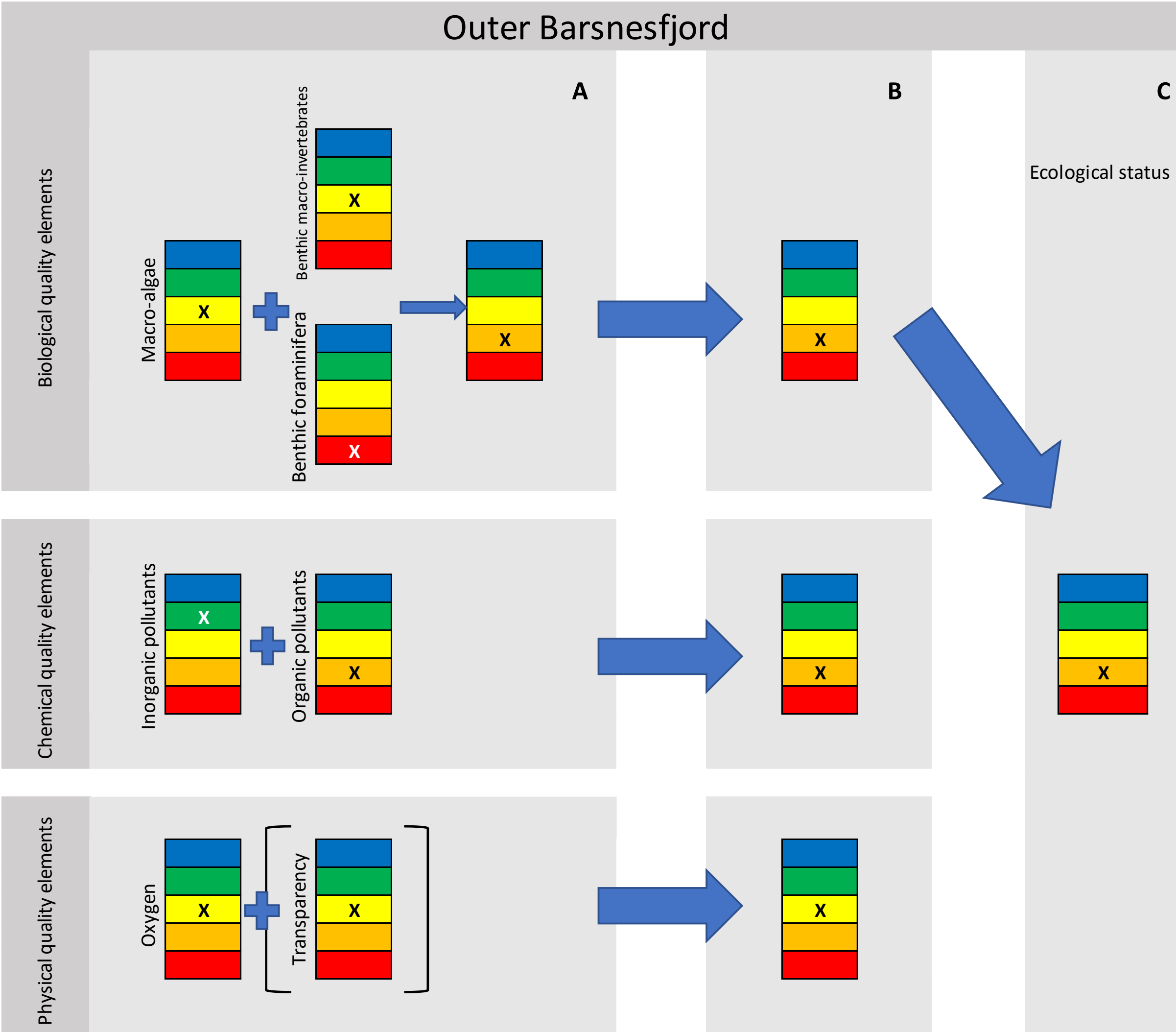

Figure 17. *The final WFD classification of the Outer Barsnesfjord. Column A shows the classifications of the measured parameters within the biological, chemical, and physical quality elements of the Inner Barsnesfjord. Transparency contains large brackets as the lack of data prohibits its use for classification. Column B shows the classification per quality element with all parameters combined. To get from Column A to Column B, the worst values of the parameters within the quality elements determine the classification for that specific quality element. Column C is the final classification for the Outer Barsnesfjord with all quality elements combined.*

This new classification of the Barsnesfjord indicates a very clear distinction between the Inner and Outer Barsnesfjord. The condition differ due to the 24 m deep sill that separates the two fjord basins from each other (Paetzel & Schrader, 1991; 1992; Paetzel & Dale, 2010). This natural separation is also the reason why the Inner Barsnesfjord basin is anoxic of natural reasons, i.e. due to naturally limited water exchange. The same reason makes it difficult to convert the environmental status of the Inner Barsnesfjord into “Good” (green) environmental conditions.

Similarities and differences between the current classification and the classification based on this investigation.

It is challenging to make a good comparison between the current classification and the classification of this investigation, because the Inner and the Outer Barsnesfjord classification of this investigation appears separately from each other. In contrast, the current classification looks at both Barsnesfjord basins as one.

Independent of this, the chemical quality elements indicate that the environmental status needs an adjustment from “Very bad” (red) environmental conditions (in the current classification) to “Bad” (orange) environmental conditions (in the classification of this investigation).

On the other hand, the status based on the biological quality elements has gone from “Bad” (orange) environmental conditions (in the current classification) to “Very bad” (red) environmental conditions (in the classification of this investigation). This is mostly due to the inclusion of all soft bottom fauna indexes of the benthic macro-invertebrates and the benthic foraminifera.

Looking at the entire Barsnesfjord system, the “Bad” (orange) status does not change between the current classification and the classification of this investigation, as long as the classification of the inner Barsnesfjord includes the NSI and the ISI_{2012}. If removed, the environmental status changes from "Bad" (orange) to "Very bad" (red).

However, the classification of this investigation provides additional and more detailed data than is the case in the current classification. The classification of this investigation provides thus an enhanced reliability.

4.1.3 Remarks on the classification of “Naturally oxygen deficient fjords”

The Water Framework Directive describes the coastal water type 6 (Figure 6), as “Naturally oxygen deficient fjord”. However, the WFD does not include this water type into its classification system for defining the environmental condition of a water body.

The description of the Inner Barsnesfjord as naturally oxygen deficient and thus as naturally poor in soft bottom fauna strongly suggests including a classification that also accounts for coastal water type 6.

Especially within the biological quality elements, it is important to develop a separate classification for “Naturally oxygen deficient fjords”. The reason for this is that it revolves around the numbers and sensitivity of the (benthic) species. Since (benthic) species require oxygen, the number of species found in a naturally oxygen deficient water body should be low of natural reasons.

It might not be very cost effective to try converting a fjord with a WFD status of “Very bad” (red) environmental condition into a “Good” (green) environmental condition, if these “Very bad” (red) environmental conditions reflect natural conditions.

4.2 Answering Objective 2: Would a changing status influence the environmental awareness of the people living close to the fjord and the involved authorities?

The interview with the Sogn og Fjordane County Municipality showed that the County Municipality is aware of the fact that little environmental data exists for the Barsnesfjord (Christian Pettersen, 2019, *personal communication*). All information added by this investigation increases the knowledge about the actual quality status of the Barsnesfjord environmental condition. This investigation points out the actual problems. Solving these problems should lead to an improvement of the environmental conditions.

The responsible authorities are aware of the significance of the environmental status classification, as they work with it daily. However, due to insufficient research, capacity and high costs, it is difficult for them to make a classification for all water bodies without interpolating data or using expert judgment for the classification.

Due to the lack of information available at the time of the interview, they were unaware of who was responsible for what part of the environmental status.

During the interview, two points emerged to increase the awareness of the authorities involved in water management.

- Producing more knowledge about dumping sites located close to water bodies and pointing out consequences for a "Bad" environmental status of the environment. This would increase the pressure on politicians and managers to act.
- Make people who work directly or indirectly with water in Norway more aware of the EU Water Framework Directive. This would allow the authorities to incorporate the WFD demands into their own management plans, and thus into their budget.

4.3 Answering Objective 3: What is the beneficial value of this research to society in terms of "People, planet and profit"?

The aim of this objective was to formulate suggestions on how to increase the awareness of people, managers, and politicians on the ongoing EU Water Framework Directive classification process of water bodies. This awareness should include involving people in the classification process, and convincing decision makers and politicians on the cost effectiveness of environmental water body investigations.

People

The interview with Christian Pettersen (2019, *personal communication*) at the Sogn og Fjordane County Municipality revealed that the involved authorities could only use parameters formulated in the WFD in water body investigations.

On the other hand, the authorities could advise decision makers to include new parameters in the WFD environmental classification, e.g. the Sogn og Fjordane County Municipality could recommend to politicians to include the classification for "Naturally oxygen deficient fjords" in WFD environmental investigations.

Further, the Sogn og Fjordane County Municipality could start a campaign on the recreational value of a clean fjord environment to increase the interest of local people in the environmental issues of the Barsnesfjord. A “Good” (green) environmental status would probably increase the people’s interest in using the Barsnesfjord area for recreation. It would probably also increase the willingness of these people to keep the Barsnesfjord in this “Good” (green) condition.

Planet

The classification of this investigation concludes that the Barsnesfjord is in a “Bad” (orange) to “Very bad” (red) WFD environmental condition. The investigation also points out which parameters need improvement, thus forming the basis for developing strategies towards an improved environmental status of the Barsnesfjord.

Over the last 40 years, the Barsnesfjord environmental condition slowly deteriorated. The first priority should thus be stopping further deterioration. This would in the first place require adjustments in the use of hydropower to improve the oxygen, nutrient and freshwater conditions in the Barsnesfjord, and thus improving the living conditions of macro-algae and soft bottom fauna in the fjord.

Such regulation would also include avoiding the transport of harmful substances from identified point sources at the Lake Haflovatnet that might drain these substances into the Barsnesfjord (Hassum, & Røyrvik, 2019). This would diminish the supply of inorganic and organic pollutants into the Barsnesfjord.

Profit

These tasks would already improve the environmental condition of the Barsnesfjord. However, the application of strategies towards an environmental improvement of water bodies always involves costs. Jonker (2018) demands a balance in environmental effect and economic value.

To illustrate this, it might be useful to discuss the oxygen situation of the Barsnesfjord.

Oxygen conditions deteriorated in the intermediate water layer above 60 m water depth in the Inner and Outer Barsnesfjord since the 1980s. Kaufmann (2014) and Mong et al. (2019) point out that the gradually more excessive use of hydropower most probably is the reason for these lower oxygen concentrations in the entire Barsnesfjord. Minor adjustments in the use of hydropower at low cost might already ameliorate the situation.

On the other hand, this investigation suggests that the bottom water layer below 60 m water depth is permanently anoxic in the Inner Barsnesfjord and periodically anoxic in the Outer Barsnesfjord due to naturally restricted water circulation, as also found by Paetzel & Schrader (1991; 1992) and Paetzel & Dale (2010). Improving this naturally “Bad” (oxygen) oxygen condition would only be possible at comparatively high cost. It might even mean, “Tilting at windmills” against nature.

The introduction of a WFD environmental classification system for the coastal water type 6 “Naturally oxygen deficient fjords” would allow low oxygen concentrations to naturally occur in the bottom waters of such fjord systems. This would imply that a “Naturally oxygen deficient fjord” system is in a natural environmental condition, and thus would get a “Good” (green) WFD environmental status.

Thus, the improvement of the Barsnesfjord oxygen concentration could occur at low costs, if only the WFD could introduce a classification system that allows a “Naturally oxygen deficient fjord” to stay at naturally oxygen deficient conditions.

5. Conclusion

This investigation provides an improved Water Framework Directive classification of the environmental status of the Barsnesfjord using a holistic dataset consisting of

- Pre-defined biological, chemical and physical quality elements.
- A time resolution of appropriate parameters (foraminifera, oxygen, pollution) to define evolutional stages through time towards the current environmental condition.
- A recommendation to add a WFD classification for “Naturally oxygen deficient fjords”.
- An overall increasing volume of the database for the WFD classification.

This investigation contributes to fill in the lack of information about the Barsnesfjord environmental status at the responsible authorities, and increasing the awareness of decision makers, and thus people, by providing

- An identification of shortcomings within the current WFD classification of the environmental condition in the Barsnesfjord.
- Information on what quality elements the people need to be aware.
- A basis for increasing the efficiency of future management plans.
- A suggestion on how to lower costs by avoiding improvements of fjords that of natural reasons fall into the “Bad” or “Very bad” WFD environmental categories.

“First, we need awareness –

Then, we need more “Good” and less “Bad” water bodies.”

Christian Pettersen (2019), personal communication

6. References

Aksnes,D.L., Aure, J., Johansen,P.-O., Johnsen, G.H., & Salvanes, A.G.V. (2019). *Multi-decadal warming of Atlantic water and associated decline of dissolved oxygen in a deep fjord.* Retrieved on 15 April 2020, from http://bio.uib.no/te/papers/Aksnes_2019_Multi-decadal_warming_of_Atlantic_water.pdf

Alve, E., Lepland, A., Magnusson, J., & Backer-Owe, K. (2009). Monitoring strategies for re-establishment of ecological reference conditions: Possibilities and limitations. *Marine Pollution Bulletin, 59*(8-12), 297-310.

Boltovskoy, E., & Wright, R. (1976). *Recent foraminifera* (First edition). The Hague, Springer Verlag.

Borgersen, G.,Hektoen, M., Melsom, F., & Todt, C. (2020). Uttesting av sensitivitetsindeksene ISI2018 og NSI2018, og en revidert artsliste med sensitivitetsverdier for bløtbunnsfauna. Retrieved on 26 May 2020, from https://www.miljodirektoratet.no/globalassets/publikasjoner/m1696/m1696.pdf

Breedveld, G., Ruus, A., Bakke, T., Kibsgaard, A., & Arp, H.P. (2018). *Veileder for risikovurdering av forurenset sediment; M-409.* Retrieved on 28 May 2020, from https://www.miljodirektoratet.no/globalassets/publikasjoner/m1132/m1132.pdf

Bucher, A. (2020). Environmental change of the last 40 years as recorded in Barsnesfjord sediments, Western Norway. Bachelor Thesis, Western Norway University College, *Unpublished.*

Dietrich, G., Kalle, K., Krauss, W., & Siedler, G. (1980). *General oceanography – An introduction* (2nd Edition). New York: John Wiley and Sons (Wiley-Interscience).

Dingemanse, K. (2015, september 8). *Soorten interviews*. Rretrieved on 3 April 2020, from, https://www.scribbr.nl/onderzoeksmethoden/soorten-interviews/.

Direktoratsgruppen vanndirektivet. (2018a). *Veileder 02:2018 Klassifisering av miljøtilstand i vann: Økologisk og kjemisk klassifiseringssystem for kystvann, grunnvann, innsjøer og elver. Direktoratsgruppen for gjennomføring av vannforskriften.* Retrieved on 13 January 2020, from http://www.vannportalen.no/globalassets/nasjonalt/dokumenter/tema-a-a/klassifisering/klassifiseringssystemet-veileder/klassifiseringsveileder_print_02.2018.pdf

Direktoratsgruppen vanndirektivet. (2018b). Vedlegg til Veileder 02:2018 Klassifisering av miljøtilstand i vann: Økologisk og kjemisk klassifiseringssystem for kystvann, grunnvann, innsjøer og elver. Direktoratsgruppen for gjennomføring av vannforskriften. Retrieved on 3 April 2020, from https://www.vannportalen.no/globalassets/nasjonalt/dokumenter/veiledere-direktoratsgruppa/md_klassifiseringsveileder_vedlegg_2019_pr.pdf

Dolven, J., Alve, E., Rygg, B., & Magnusson, J. (2013). Defining past ecological status and in situ reference conditions using benthic foraminifera: A case study from the Oslofjord, Norway. *Ecological Indicators, 29*(C), 219-233.

Duffield, C.J., Alve, E., Andersen, N., Andersen, T.J., Hess, S., & Strohmeier, T. (2017). Spatial and temporal organic carbon burial along a fjord to coast transect: A case study from Western Norway. *The Holocene, 27*(9), 1325-1339.

Elkington, J. (1994). Towards the Sustainable Corporation: Win-Win-Win Business Strategies for Sustainable Development. *California Management Review, 36*(2), 90-100.

Elkington, J., & Rowlands, I.H. (1999). Cannibals with forks: The Triple Bottom Line of 21st century business. *Alternatives Journal 25*(4), 42-43.

English-WFD in Norway. (2015, 17 June). Retrieved on 13 January 2020, from https://www.vannportalen.no/english/

European Commission. (2000, 23 October). Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. Retrieved on 11 January 2020, from https://eur-lex.europa.eu/eli/dir/2000/60/oj

European Commission. (2019, 07 August). Introduction to the EU Water Framework Directive. Retrieved on 13 January 2020, from https://ec.europa.eu/environment/water/water-framework/info/intro_en.htm

European Commission. (n.d.). The EU Water Framework Directive. Retrieved on 20 January 2020, from https://ec.europa.eu/environment/pubs/pdf/factsheets/wfd/en.pdf

European Environment Agency. (2018). European waters: Assessment of status and pressures 2018. Retrieved on 13 January 2020, from https://www.eea.europa.eu/publications/state-of-water

Fischer, T., & Julsing, M. (2019). *Onderzoek doen! Kwantitatief en kwalitatief onderzoek* (3e druk). Groningen: Noordhoff Uitgevers.

Guiry, M.D. (1996). Retrieved on 17 April 2020, from http://www.algaebase.org

Hassum, M., & Røyrvik, M.P. (2019). Depositional signals in and around Lake Hafslovatnet (Western Norway) over the past 40 years (Bachelor thesis). Department of Environmental Sciences, Western Norway University of Applied Sciences, Sogndal. Retrieved on 20 January 2020, from https://hvlopen.brage.unit.no/hvlopen-xmlui/bitstream/handle/11250/2630624/Signaler%20fra%20avsetning%20av%20forurensede%20stoffer%20i%20og%20rundt%20Hafslovatnet%2c%20Vest-Norge%20de%20siste%2040%20%c3%a5rene.pdf?sequence=1&isAllowed=y

Hess, S., & Alve, E. (2014). *Undersøkelser av den historiske oksygenutviklingen og naturtilstanden i Horten Indre Havn* (Report). Institutt for Geofag: Universitetet i Oslo, Oslo. Retrieved on 17 April 2020, from https://docplayer.me/68701357-Undersokelser-av-den-historiske-oksygenutviklingen-og-naturtilstanden-i-horten-indre-havn.html

Holtedahl, H. (1967). Notes on the formation of fjords and fjord-valleys. *Geografiska Annaler. Series A. Physical Geography, 49*(2/4): 188-203.

Jonker, J. (2018, April 6). *People, Planet, Profit (Triple Bottom Line of Triple P)*. Retrieved on 21 January 2020, from https://www.managementimpact.nl/strategie/artikel/2018/04/people-planet-profit-triple-bottom-line-triple-p-10115091?vakmedianet-approve-cookies=1&_ga=2.187916136.1559399887.1573036592-744802909.1573036592

Kaufmann, S. (2014). *A 100 year hydrographical record of the Barsnesfjord, Western Norway, and its environmental application* (Bachelor thesis). Department of Environmental Sciences: Western Norway University of Applied Sciences, Sogndal. Retrieved on 21 January 2020, from https://hvlopen.brage.unit.no/hvlopen-xmlui/bitstream/handle/11250/226720/Kaufmann_Sabrina.pdf?sequence=1&isAllowed=y

Loeblich, A.R., & Tappan, H. (1987). Foraminiferal Genera and their Classification. New York: Van Nostrand Reinhold Company.

Miljødirektoratet. (2016). *Grenseverdier for klassifisering av vann, sediment og biota: Veileder M608/2016*. Retrieved on 17 April 2020, from https://www.miljodirektoratet.no/globalassets/publikasjoner/M608/M608.pdf

Miljostatus. (n.d.). *Polyklorerte bifenyler (PCB).* Retrieved on 1 May 2020, from https://miljostatus.miljodirektoratet.no/tema/miljogifter/prioriterte-miljogifter/polyklorerte-bifenyler-pcb/

Mong, A., Sjøblom, M.A.N., & Storsveen, T.M.H. (2019). *Hydrographic change as recorded in Lake Hafslovatnet sediments, Western Norway, over the past 40 years* (Bachelor thesis). Department of Environmental Sciences, Western Norway University of Applied Sciences, Sogndal. Retrieved on 21 January 2020, from https://hvlopen.brage.unit.no/hvlopen-xmlui/bitstream/handle/11250/2630623/Sediment%C3%A6re%20signaler%20av%20hydrografiske%20endringer%20i%20Hafslovatnet%2C%20Vest-Norge%2C%20over%20de%20siste%2040%20%C3%A5r%20%281%29.pdf?sequence=1&isAllowed=y

Nesje, A., & Whillans, I.M. (1994). Erosion of Sognefjord, Norway. *Geomorphology*, *9*(1), 33-45.

Niemistö, L. (1974). A gravity corer for studies of soft sediments. Merentutkimuslait Julk./Havsforskingsinstituttets Skrifter. 238, 33-38.

Norge i bilder. (n.d.). Retrieved on 21 Januari 2020, from *https://www.norgeibilder.no*

Paetzel, M. & Dale, T. (2010). Climate proxies for recent fjord sediments in the inner Sognefjord region, western Norway. *Geological Society, London, Special Publications, 344*, 271-288. DOI: 10.1144/SP344.19

Paetzel, M., & Schrader, H. (1991). Heavy metal (Zn, Cu, Pb) accumulation in the Barsnesfjord: Western Norway. *Norsk Geologisk Tidskrift, 71,* 65-73.

Paetzel, M., & Schrader, H. (1992). Recent environmental changes recorded in anoxic Barsnesfjord sediment: Western Norway. *Marine Geology, 105,* 23-36.

Pedersen, A., Alve, E., Alvestad, T., Borgersen, G., Dolven, J.K., Gundersen, H., Hess, S., Kutti, T., Rygg, B., Velvin, R., & Vedal, J. (2016). *Bløtbunnsfauna som indikator for miljøtilstand i kystvann: Ekspertvurderinger og forslag til nye klassegrenser og metodikk.* Retrieved on 7 April 2020, from https://www.miljodirektoratet.no/globalassets/publikasjoner/m633/m633.pdf

Ramberg, I.B., Bryhni, I.,Nøttvedt, A., Rangnes, K., Binns, R., & Grogan, P. (2008). *The making of a land: geology of Norway.* Trondheim: The Norwegian Geological Association.

Recommended sampling & sorting methods. (n.d.). Retrieved on 31 March 2020, from http://www.iopan.gda.pl/projects/biodaff/EMBS-08.html

Rygg, B., & Norling, K. (2013). *Norwegian Sensitivity Index (NSI) for marine macro-invertebrates, and an update for Indicator Species Index (ISI): Report SNO 6475-2013*. Retrieved on 17 April 2020, from https://niva.brage.unit.no/niva-xmlui/bitstream/handle/11250/216238/6475-2013_200dpi.pdf?sequence=1&isAllowed=y

SAIV A/S Environmental Sensors & Systems. (n.d.). *STD/CTD - model SD204: With multi-parameter & auto range facilities*. Retrieved on 15 April 2020, from http://saiv.no/WordPress/wp-content/uploads/2017/07/SD204_091026.pdf

Scales, H. (16 July 2014). Tributyltin. Received on 25 May 2020, from https://www.chemistryworld.com/podcasts/tributyltin/7553.article.

Secchi Disk study. (n.d.). *Secchi Disk.* Retrieved 15 April 2020, from http://www.secchidisk.org/

Spellerberg, I., & Fedor, P. (2003). A tribute to Claude Shannon (1916–2001) and a plea for more rigorous use of species richness, species diversity and the 'Shannon–Wiener' Index. *Global Ecology and Biogeography, 12*(3), 177-179.

Syvitski, J.P.M., Burrell, D.C., Skei, J.M. (1987). *Fjords: Processes and Products*. New York: Springer Verlag.

Vann-Nett. (n.d.). *Barsnesfjorden*. Retrieved on 21 January 2020, from https://vann-nett.no/portal/#/waterbody/0280021303-C

Van Veen, J. (1933). Onderzoek naar het zandtransport van rivieren*. De Ingenieur (B. Bouw- en Waterbouwkunde 11),* 48(27), 151-168.

Working Group 2.4 – Coast. (2003). *Common implementation strategy for the water framework directive* Report 2000/60/EC*: Guidance Document No 5 Transitional and Coastal Waters – Typology, Reference Conditions and Classification Systems*. Retrieved on 15 April 2020, https://circabc.europa.eu/sd/a/85912f96-4dca-432e-84d6-a4dded785da5/Guidance%20No%205%20-%20characterisation%20of%20coastal%20waters%20-%20COAST%20(WG%202.4).pdf

World Wide Fund For Nature. (2019, 22 March). 375,000+ Citizens tell the European Commission "Hands off our Water Law!". Retrieved on 13 January 2020, from https://wwf.panda.org/_/search_wwf_news/?344893/375000-Citizens

Appendix A

Field data – Shore zone – Location data					
Location name and number			Date		dd:mm:yy
Water type			Time		hh:mm
Coordinate type (EU89, WGS84 etc.)			Water level above low tide		0,0 m
North			Time of low tide		hh:mm
East			Observer		
Description of shore zone – shore zone potential					
Turbid water? (not anthropogenic)	Yes = 0, No = 2	Answer			
Sand abration?	Yes = 0, No = 2	Answer			
Ice abration?	Yes = 0, No = 2	Answer			
Dominating shore type (habitat)					
Small crevasses/Strongly cracked rock/ Overhang/Rock platforms	Yes = 4	Answer			
Strongly cracked rock	Yes = 3	Answer			
Small, medium and large boulders	Yes = 3	Answer			
Steep/vertical rock	Yes = 2	Answer			
Unspecified hard substrate/Bare rock	Yes = 2	Answer			
Small and big stones	Yes = 1	Answer			
Gravel	Yes = 0	Answer		Points	
Other shore types (sub-habitat)					
Wide, shallow water pools on shore (Rock pools: >3 m wide and <50 cm deep)	Yes = 4	Answer			
Large water pools on shore (>6 m long)	Yes = 4	Answer			
Deep water pools on shore (50% >100cm)	Yes = 4	Answer			
Minor water pools on shore	Yes = 3	Answer			
Large holes	Yes = 3	Answer			
Large overhang and vertical rock	Yes = 2	Answer			
Other types of habitat (specify)	Yes = 2	Answer			
None	Yes = 0	Answer		Points	
Remarks			Adjustments norwegian conditions		3
			Sum points		
			SHORE POTENTIAL		

Appendix A. *Shore description form of Direktoratsgruppen vanndirektivet (2018b); translated into English*