LÄNSSTYRELSEN
VÄSTRA GÖTALANDS LÄN
Rapport 2006:04

Characterization of GULLMARN according to the WFD

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Interreg North Sea Region

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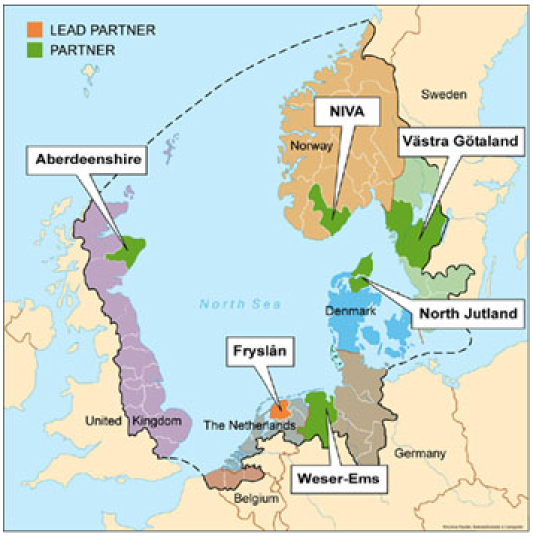
Foreword

The characterization of Gullmarn is made as two honour theses in Environmental Science at Göteborg University. The work has been done for an EU-project (Interreg III B) where the County Administrative Board of Västra Götaland is the project leader of the Swedish part. The project includes 6 countries around the North Sea in a fore study of the EC Water Framework Directive. The name NOLIMP-WFD stands for **NO**rth Sea Regional and **L**ocal **IMP**lementation of the **W**ater **F**ramework **D**irective, which partly reveals the aim of the project. A pilot area in each country has implemented the WFD as an attempt to improve the water quality by working according to the directive. Often the problems with a new way of working are not realised until the work begins. Many solutions can be found while working. The participating countries can communicate in a natural way through the project and experiences can be exchanged. There are several problems and threats against the water quality that all countries in the project have in common. Eutrophication due to emissions from sewerage systems and agricultural activities is an example of this. How to involve the local parties in the work is another. The work according to the WFD is supposed to give an improved water quality step-by-step by describing the water bodies and classify them according to their ecological status. A set of measures to meet the objectives set for the water area and a management plan for the area is also part of the work to be done. Read more about the NOLIMP-WFD at www.nolimp.org.



The Swedish pilot area is Gullmarn and its catchment area in the south west of Sweden. In this report Gullmarn is characterized and classified according to its ecological status.

Göteborg 2005-12-08

The County Administrative Board of Västra Götaland

Summary
Gullmarn, a sill fjord in Bohuslän, with its catchment area is the Swedish pilot area within the Interreg III B-project NOLIMP-WFD (North Sea Regional and Local Implementation of the Water Framework Directive). The project involves the countries around the North Sea and aims to ameliorate the water quality in pilot areas in each country by working according to the EC Water Framework Directive (WFD).

The WFD, in force since year 2000, has the objective that all the water within the EU will achieve *good ecological and chemical status* by 2015 at the latest. This will be the base for a sustainable water management in Europe and entails a new working procedure for water. The first step is to make an analysis of all the water bodies, which includes a characterization of the ecological status. To be able to do this a reference condition for the area needs to be established, corresponding to the expected conditions if undisturbed by human activity.

The aim of this report is to make a characterization of Gullmarn, testing several methods according to the WFD. The characterization of Gullmarn was made as two honour theses in environmental science for the County Administrative Board of Västra Götaland, which is responsible for the Swedish part of the NOLIMP-WFD-project.

A great effort has been made to establish reference conditions by different methods, and to compare and evaluate these. The methods that have been used are comparisons with historical data, modelling of nutrients and comparisons with reference conditions according to the new environmental quality criteria for coast and seas by the Swedish Environmental Protection Agency, which are not yet in force. Deviations from the reference conditions concerning predefined biological, physico-chemical and hydro-morphological quality elements decide the ecological status.

The apparent effects that are shown in the results are a decrease in depth extension of macrophytes and an increase in biomass of benthic invertebrates since early 1900. The decrease in depth extension of macrophytes is depending on the Secchi depth, which also diminished in the Fjord during the 20th century. This is due to an increased turbidity, which is caused by more particles in the water body. These particles are for example primary producers (algae and bacteria) and organic matter. The primary production has also increased since 1950, probably due to increased loading of nutrients. This is also the most probable cause of the increased biomass of benthic invertebrates.

To establish reference conditions, and to make an assessment of the deviations from this condition, is difficult and is affected by the person who makes the assessment. The supply of historical data from Gullmarn has been rather good. However there are great difficulties in making comparisons with data from today. Historical data often consists of just a single measurement and no statistically reliable comparisons can be made. Status classification according to the WFD should be based on the biological elements, and the element with the lowest ecological status will decide the total ecological status. The total status of Gullmarn is classified as moderate status.

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1. Introduction

The water situation in the world is increasingly one of the most important environmental issues to approach. Clean water is scarce in many regions and the biodiversity of lakes and seas is decreasing. This may cause dramatic effects and lead to conflicts between countries. Flooding and long periods of drought are also problems that are more and more common. Since pollution of water often is a trans-boundary issue, cooperation between countries is necessary to solve these problems. In the year 2000 the European Commission introduced a water framework directive (WFD) aiming to get a holistic water policy, thus replacing a number of different directives and decisions in the area. The implementation of the WFD involves a new approach to work with water issues in Sweden. Catchment areas, the natural borders of water bodies, instead of ”political” borders like municipalities, constitute the base of this new working procedure. The overall aim of the WFD is to achieve good ecological and chemical status in all water bodies by 2015 at the latest. This will be the base for a sustainable use of water in Europe (WFD, 2000).

NOLIMP-WFD (North Sea Regional and Local Implementation of the Water Framework Directive) is a collaborative project involving Sweden, Norway, Denmark, the Netherlands, Germany and Scotland aiming to improve the ecological status in pilot areas in each country, by working according to the WFD. The pilot projects focus on different measures to improve the ecological status, mostly to reduce eutrophication. During the project, and by its ending 2006, the expectations are that the countries exchange experiences which contribute to a more efficient work in the future (NOLIMP, 2004).

The project is an Interreg III B-project aiming to promote cooperation between the North Sea countries. The participating countries contribute with half the project funding and the EU contributes with the remaining part. The County Administrative Board of Västra Götaland together with the Forestry Board of Västra Götaland and the municipalities of Dals Ed, Färgelanda, Munkedal, Lysekil and Uddevalla run a pilot project in the catchment area of Gullmarn/Örekilsälven aiming to improve the water quality in the area. This is done by different measures, for example improved sewerage systems, daywater systems and information to forest owners about forestry management that will reduce the supply of nutrients into surrounding surface water (NOLIMP, 2004).

1.2 Water Framework Directive

The Water Framework Directive states that all the member countries shall take action to meet the objective of good surface water status, good ecological potential (heavily modified water) and good groundwater status (WFD, 2000). The aim is that all water resources should obtain good status by 2015 at the latest. If it is not possible to obtain good status, measures should be made to obtain the best ecological status possible. A summary of the definition of *Good ecological status* in surface waters is shown in Fact Box 1 (Naturvårdsverket, 2003).

FACT BOX 1

Good ecological status

The flora and fauna in the surface waters, the movement and torrent of the water, the structure of shores and beds of watercourses and the physico-chemical conditions in the water do not show more than minor deviations of what is said to be natural conditions (the reference condition) for that type of water in the specific area.

1.2.1 New working procedure

The working procedure according to the WFD can be divided into five main parts, see Figure 1:

1. Make a background analysis of the water bodies in the river basin district. This includes a characterization and an economic analysis.
2. Set environmental objectives for the water bodies.
3. On the basis of the background analysis and the classification establish a programme of measures to obtain the environmental objectives in the catchment area.
4. Monitor the environmental conditions in the various water bodies and follow the development and effects of the measures to see whether additional measures are needed in order to meet the objectives.
5. Summarize knowledge and obtained results in a management plan which should be updated every sixth year. This shall be an easily accessible report to be used as a planning tool for the public authorities and a tool for communication to the citizens and to the European Commission (Naturvårdsverket, 2003).

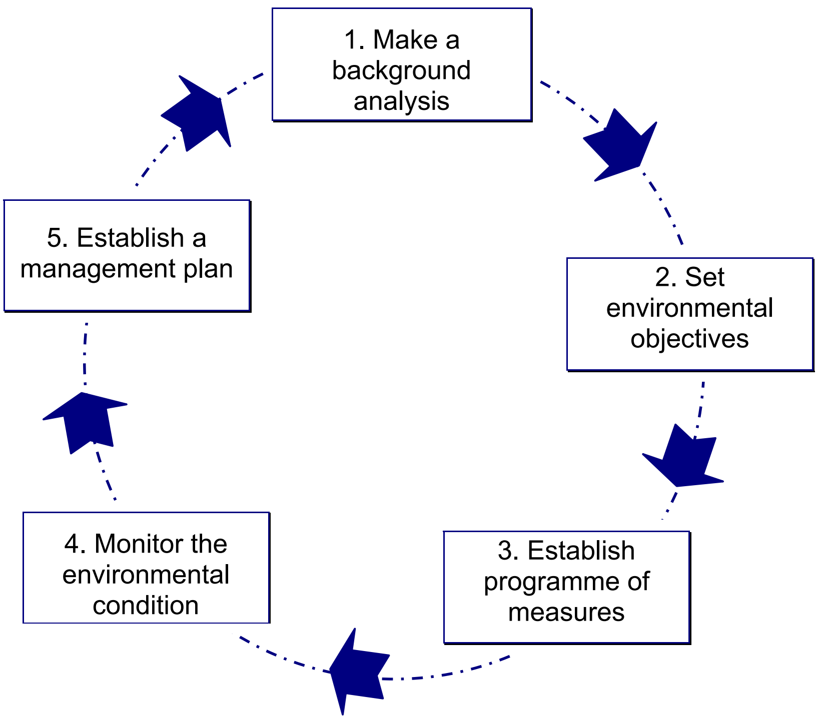

Figure 1.Description of the working procedure according to the WFD (modified picture from Naturvårdsverket, 2003).

1.2.2 Characterization

According to Article 5 in the WFD every member state should make an analysis of the characteristics of all the water bodies in the country. The content of this analysis is defined in Annex II of the WFD. The characterization aims to describe and assess the status of the water bodies in order to see which measures are needed, and is a process consisting of several parts, see Fact Box 2.

FACT BOX 2

Characterization

1. **Water category**
   – Lakes, rivers, groundwater, transitional or coastal water, heavily modified or artificial waters
2. **Differentiation according to type**
   – Altitude, size, mean water depth, geology etc.
3. **Reference condition**
   – Biology, chemistry, hydrology
4. **Impact**
   – Nutrients, acidification, hazardous substances, morphological changes etc.
5. **Classification of ecological status**
   – High, good, moderate, poor or bad

The Swedish Environmental Protection Agency has made a first characterization, which was reported to the EU in march 2005. A total assessment of the biological elements is made for the some aggregated areas that can be judged as similar. This characterization only identifies the water bodies at risk of failing the objective of good status by 2015, and it is not be specific enough to be the base for establishment of programmes of measures (Gunnarsson, pers. comm., 2004).

Differentiation according to type will group waters with resembling reference conditions. The Swedish Meteorological and Hydrological Institute has divided the coast of Sweden into 23 type areas. Gullmarn belongs to type area 2, *Fjords of the west coast* (Håkansson and Hansson, unpubl., 2003).

When the differentiation into types is made, a characterization of the ecological status should be done, according to the status classes defined in Annex V of the WFD; *high, good, moderate, poor or bad status*. Deviations from the reference condition are the base of the classification of ecological status. Predefined biological, physico-chemical and hydro morphological quality elements decide the ecological status.

Reference condition

When making an assessment of the ecological status, it is necessary to establish a reference condition for the water type that corresponds to the term *high ecological status*, with only minor ecological effects due to human activities. Establishing of reference conditions is an important but difficult part of the characterization, since there are very few water bodies that are not greatly impacted of human activities today. According to guidance document (CIS 2.4, 2002) there are several ways for establishing reference conditions, where a combination of methods is preferred, see Fact Box 3.

FACT BOX 3

Establishing reference condition

1. Find waters within the same water type with minor impact of human activities.
2. Historical data, including palaeological investigations
3. Modelling
4. Expert judgement

For most water types it will be impossible to find waters not affected by human activities. According to the guidance on classification of coastal and transitional waters (CIS 2.4, 2002) there are no undisturbed water bodies in these categories in Europe today. Regarding lakes and watercourses in the catchment area of Gullmarn it is expected that all waters, to some degree, be affected either by acidification or by high loads of nutrients.

It exists a rather large historical material concerning Gullmarn, because several marine biological research stations have been located there since the late 1800's. For a few of the lakes in the catchment area there are some data from the early 1900's. These data can be used together with expert judgements as historical references. The watercourses and the other lakes in the area have no known historical data. However there are data for bottom fauna for the last 20 years collected in the liming control programs. The sampling points with the longest series have been chosen. The other watercourses may be assessed based on modelling.

Good indicators of a reference condition should respond to anthropogenic influence, be generally present in the water type, be measurable with high accuracy and precision, have well-defined reference values, and be cost-effective and easy to communicate to the public. Examples on such indicators in coastal waters are depth extension of eelgrass, biomass of benthic filtrators and concentration of chlorophyll a. Concentration of nutrients, Secchi depth, frequency of oxygen concentrations below 2 ml/l and concentration of xenobiotics in sediment and biota are other examples of good indicators (Nielsen et al., 2003).

Classification of status

The established reference condition for the water type, and the deviation from this, is the basis for the status classification. The elements that should be assessed for lakes, watercourses and coastal waters are shown in Table 1. The biological element with greatest deviation from its reference condition decides the status class. The physico-chemical and hydro-morphological element should be supportive to the biological elements. The definitions for *High, good and moderate status* are found in the WFD (Annex V) for the various water categories concerning each quality element.

The biological quality elements shall be expressed with an Ecological Quality Ratio (EQR), where values from current measurements are divided with reference values. The calculated value can then be placed in a status class defined by a normative scale. No calculations of EQR of physico-chemical quality elements are made. The status classes are then defined by intervals of actual data.

Since the member states themselves will decide the limit values of the status classes, an intercalibration will be done between different countries. This will ensure that what is said to be a reference condition of a water type agrees within the member states. Before this intercalibration, a national intercalibration in Sweden will be done (Pettersson, pers. comm., 2004).

Table 1. Quality elements to be assessed according to the WFD.

QUALITY ELEMENTS		LAKES	RIVERS	COASTAL WATERS
Biological	Phytoplankton	Composition Abundance Biomass		Composition Abundance Biomass
	Macro vegetation	Composition Abundance	Composition Abundance	Composition Abundance
	Benthic invertebrates	Composition Abundance	Composition Abundance	Composition Abundance
	Fish	Composition Abundance Age structure	Composition Abundance Age structure	
Physico-chemical	Secchi depth	x		x
	Thermal conditions	x	x	x
	Oxygenation conditions	x	x	x
	Salinity	x	x	x
	Nutrient conditions	x	x	x
	Acidification	x	x	
	Specific pollutants	x	x	x
Hydro-morphological	Morphological conditions	Depth variation Quantity, structure & substrate of lake bed Structure of the lake shore	Depth and width variation Structure & substrate of river bed Structure of the riparian shore.	Depth variation. Structure and substrate of coastal bed. Structure of tidal zone
	Hydrological regime	Water flow Connection to groundwater bodies Residence time	Water flow Connection to groundwater bodies	
	River continuity		x	
	Tidal regime			Dominant currents Wave exposure

2. River basin

2.1 Localisation

The catchment area of Gullmarn is situated in Västra Götaland, a county in South-western Sweden, see Figure 2. The area actually consists of two main catchment areas; the catchment area of Örekilsälven and the catchment area of the outer Gullmarn. The area includes 1720 km^2. Örekilsälven and Valboån are the two largest watercourses in the area, where Örekilsälven has a catchment area of 1340 km^2. There are 297 lakes in the area (Harlén, unpubl.). 24 of those are bigger than 0,5 km^2 and need to be reported to EU according to the WFD. Örekilsälven has its mouth in Gullmarn, which is the largest fjord in Bohuslän.
Gullmarn is the only sill fjord in Sweden and the area is classified a Natura 2000-area. The fjord is situated between the borders of the southwest Swedish gneiss area and the granite area of Bohuslän. Gullmarn has a rich and partly unique marine fauna because of a complicated exchange of deep water that only takes place at some specific weather conditions. The sill level is 45 metres and the greatest depth in the fjord measures 118 metres (Norling & Sköld, 2002). Between the exchanges, which normally take place once a year, oxygen deficiency often occurs in the deeper parts.

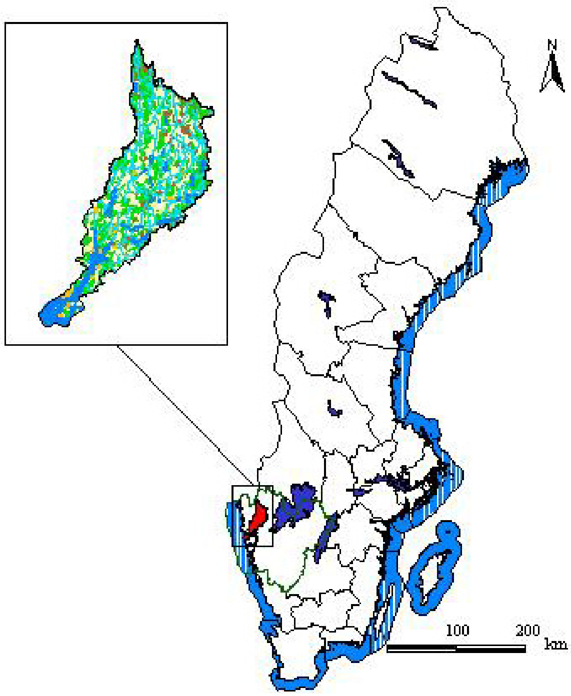

Figure 2. The river basin of Gullmarn in South-West of Sweden.

A great nutrient load causes algae blooms, bad oxygen conditions and bottom death. Investigations show that the bottom environment has deteriorated since the measurements started during the 1960's (Arctic Paper, 2004). Örekilsälven contributes with over 90 % of the freshwater coming to Gullmarn and is thereby a large source of nutrients.

2.2 Landscape

The area is mainly productive forestland with valleys along the watercourses. Agricultural land is situated in the valleys. In the northern parts bogs and swamp forests also are frequent.

Despite the large quantity of lakes, these only take up 3 % of the area. The lakes are situated mainly in the higher areas. The lakes and watercourses in the lower parts mostly are nutrient enriched, while the waters close to the valleys and agricultural areas are more mesotrophic. Lakes higher up are oligotrophic. The land use is shown in Figure 3.

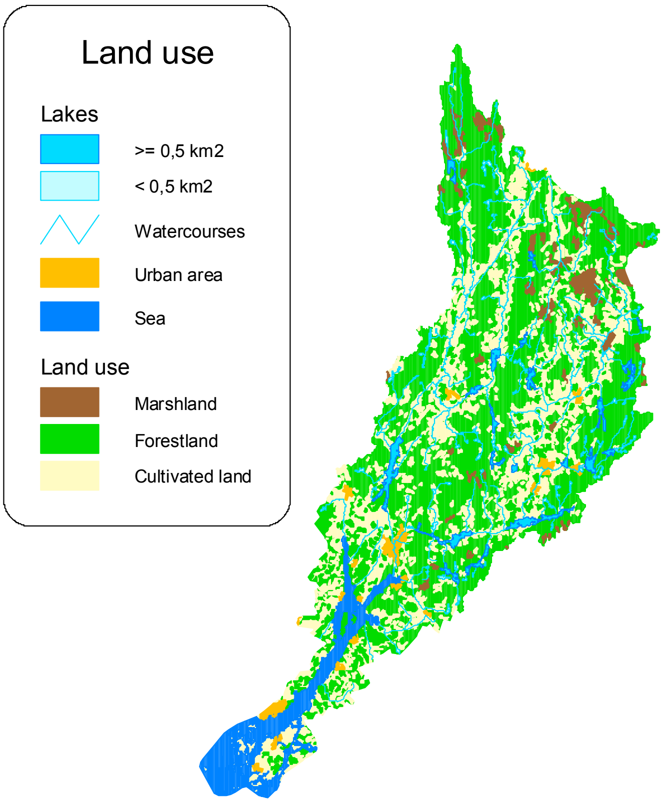

Figure 3. Land use in the catchment area of Gullmarn (ArcView).

The soil layers are thin and uncovered rock is frequently seen in the area. Large parts of the catchment area are situated below the highest coastline, which means that clay and coarse silt are widely distributed in the valleys.

3. Impact of human activities

Almost the entire water system of Örekilsälven is exposed to antropogenic impacts. Diffuse discharges of pollutants, acidification, diking and regulations of watercourses are examples of human impacts. Regulated dams impact the surface waters and often make it impossible for salmon and salmon trout to move upstream. The urban area is small and the industrial activity in the area is moderate. The discharges are therefore mainly nutrients leaking from the rural areas, the farmland and households in the sparsely populated areas. These discharges act over-fertilizing on the lakes and watercourses (Länsstyrelsen Älvsborgs Län, 1989). The area is also impacted of a tenfold increase of the population during summer, which increases the amount of boats on Gullmarn. This because it is an important recreation area (Lindahl et al. 1998).

The catchment area of Gullmarn suffers from two base problems:

1) Acidification
2) Eutrophication

3.1 Wetlands

Historical impacts have affected the area and increased the eutrophication of the waters. Several centuries ago man started to drain the wetlands to use them as agricultural land. After the inland-ice had left the area large parts of the catchment area was under the highest coastline, meaning under water. This was generally the case in Sweden and during the 1700 and 1800's the landowners were obliged by the authorities to drain these areas.

Drainage, lowering of the lakes and straightening of watercourses have been done to make the agriculture more effective but this has unfortunately given results in form of eutrophicated inland- and coastal waters.

3.2 Acidification

The lakes and watercourses in the higher areas are sensitive of acidification, making them vulnerable to acid rain. This has caused fish death before measures have been done. The bedrock and soil in the area are of great importance, since easily weathered soil and bedrock may neutralize acid precipitation. The bedrock consists, however, mainly of granite and gneiss, making the buffer capacity very low. The watercourses are also sensitive to acidification, partly because there are relatively few lakes and the retention time is short. The situation is ameliorating slowly and liming activities have increased the pH-value to a normal one in many cases. Continued liming is necessary to keep the status of these waters.

3.3 Eutrophication

In most parts of the drainage area of Örekilsälven agriculture plays a central role in local discharges of phosphorous, nitrogen, oxygen demanding organic matter and suspended matter. The agricultural land is the dominating source of both phosphorous and nitrogen in the area. The most important point sources in the area are the industry Arctic Paper Munkedals AB and the Munkedal municipal wastewater treatment plant. The past 25 years the discharges of phosphorous from point sources has diminished by more than 50 percent. With more than half of the population living in sparsely populated areas the impact from single properties outside the sewerage system is as important as the municipal treatment plants. The larger communities, Lysekil, Uddevalla and Stenungsund, have wastewater treatment plants since the beginning of the 1970's. Petrochemical industries are located in Stenungsund and a refinery is situated up north. None of these industries are supposed to affect the oxygen demand in Gullmarn (Rosenberg, 1990). The source distribution of nitrogen and phosphorous to Gullmarn from the drainage area of Örekilsälven is shown in Figure 4. The cultivated land is the clearly dominating source of nutrients to Gullmarn. The supply of nutrients varies with the torrent of the rivers (ALcontrol Laboratories 2001). The population in the area increases ten times during the summer months, which also includes a great number of boats on Gullmarn since the area is an important recreation area (Lindahl et al. 1998).

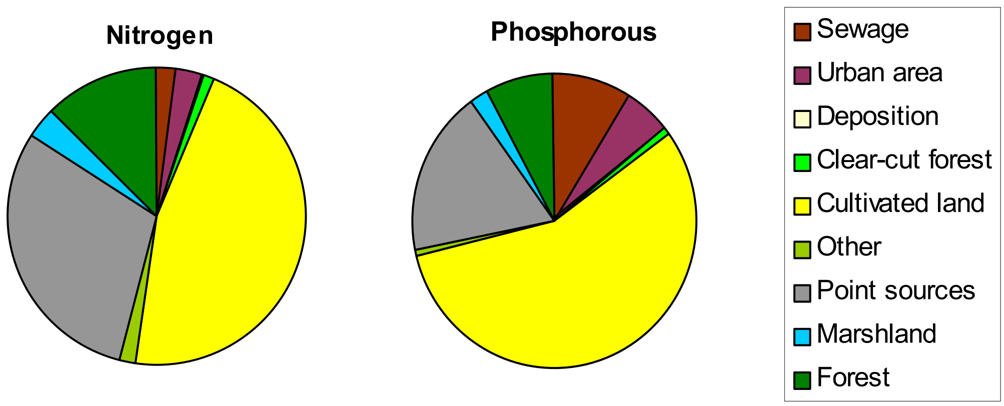

Figure 4. Source distribution of nitrogen and phosphorous modelled for 2001–2003 with a model called Watshman.

Large amounts of nutrients are brought in to the fjord from the sea. Import and export of nutrients have not been measured but calculations have been made for year 1994 through a model described later (section. During 1994 about 3900 tonnes nitrogen was brought in from the sea, according to the calculations. This can be compared with a supply from the rivers of 530 tonnes during the same time. This transport of nitrogen consists of plankton, detritus, ammonia and nitrate, where nitrate dominates. According to the same model, the nitrogen export to the sea was 4300 tonnes (Svensson, pers. comm., 2004).

4. Characterization of Gullmarn

4.1 Gullmarn

Gullmarn is the only sill fjord in Sweden. A sill fjord means that it is long, deep and narrow and has a sill at the mouth. The fjord is about 25 kilometres long and reaches into the country with a northeasterly direction (see Figure 5). In the inner parts the fjord is divided into two branches, Färlevfjord and Saltkällefjord. Somewhat south of the branching the two largest islands, Stora and Lilla Bornö, are located. Except for these, there are only a few islands in the fjord. Gullmarn was formed by a fault hollowed out by watercourses and inland ice, creating a basin with a sill at the mouth (Molander, 1964).

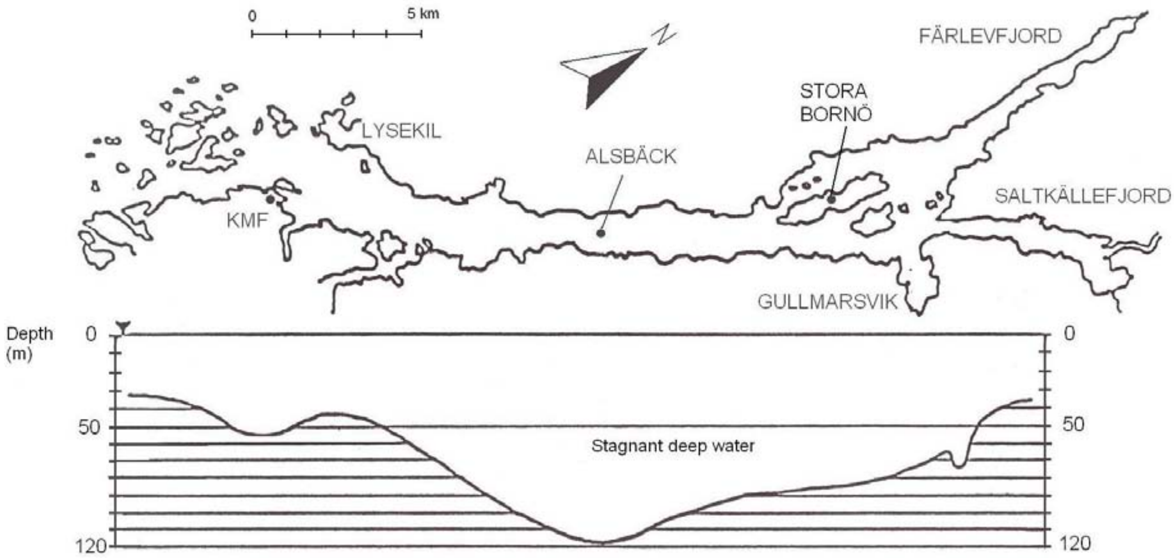

Figure 5. Gullmarn with its deep profile (Modified after Svansson, 1984).

The largest depth of the fjord is situated at Alsbäck. Marin Mätteknik AB has measured the depth to 118.5 metres. The maximum depth at the sill is 52 metres but due to another sill outside the mouth, the effective sill depth is only 42 metres (Bekkby and Rosenberg, 2004). The sill creates a unique biology in the fjord but causes at the same time a greater vulnerability to pollutants.

The sill and the salinity stratification complicate the water exchange and leads to stagnant deep water. This water normally is exchanged once a year. The nutrient load that causes algae blooms often leads to oxygen deficiency in the bottom water between the water exchanges. The hypoxia harms the bottom fauna and may in more extreme cases lead to bottom death. In 1997 there was no water exchange and this caused total bottom death at depth greater than 105 metres (Rosenberg et al., 2002).

The main part of Gullmarn lays on the massive granite of Bohuslän, while the southeast side and the entire northwest side consists of gneiss. The northwest side is flatter than the southeast side, which is dominated by irregular mountains with steep slopes (Molander, 1964).

In 2004 a mapping survey of the bottom of Gullmarn was made with sonar equipment consisting of Multi Beam Sonar, Side Scan Sonar and penetrating sonar. The results of this mapping are presented as maps of the bottom, concerning for example depth and substrate in the fjord. Objects on the bottom have been identified; among other things a wreck of an old aeroplane and several small boats were observed at the bottom of Gullmarn. The plane is most likely the English plane Hudson III Loch Leven, which was lowered in Gullmarn in 1942 after an emergency landing. Hardness data give rough information of the sediment according to the strength in reflection from the sonar. Profile maps show the top sediment layers and the distance to solid rock. Traces from trawling activities have also been mapped (Marin Mätteknik AB, unpubl., 2004).

A modelling of marine habitats (Natura 2000-habitats) has been made based on this mapping survey, where substrate, slope, reef structures and wind exposure are some of the background data. This has resulted in maps of possible distribution for eelgrass, macro algae, blue-shell and epifauna (Bekkby and Rosenberg, 2004). A 3 D-map of the depth in the fjord from the mapping survey is shown in Figure 6. In Figure 7the substrates of the bottom is described. The bottom consists mainly of clay and loose sediment (Bekkby and Rosenberg, 2004). Results from the modelling of wind exposure are shown as a map in Figure 8.

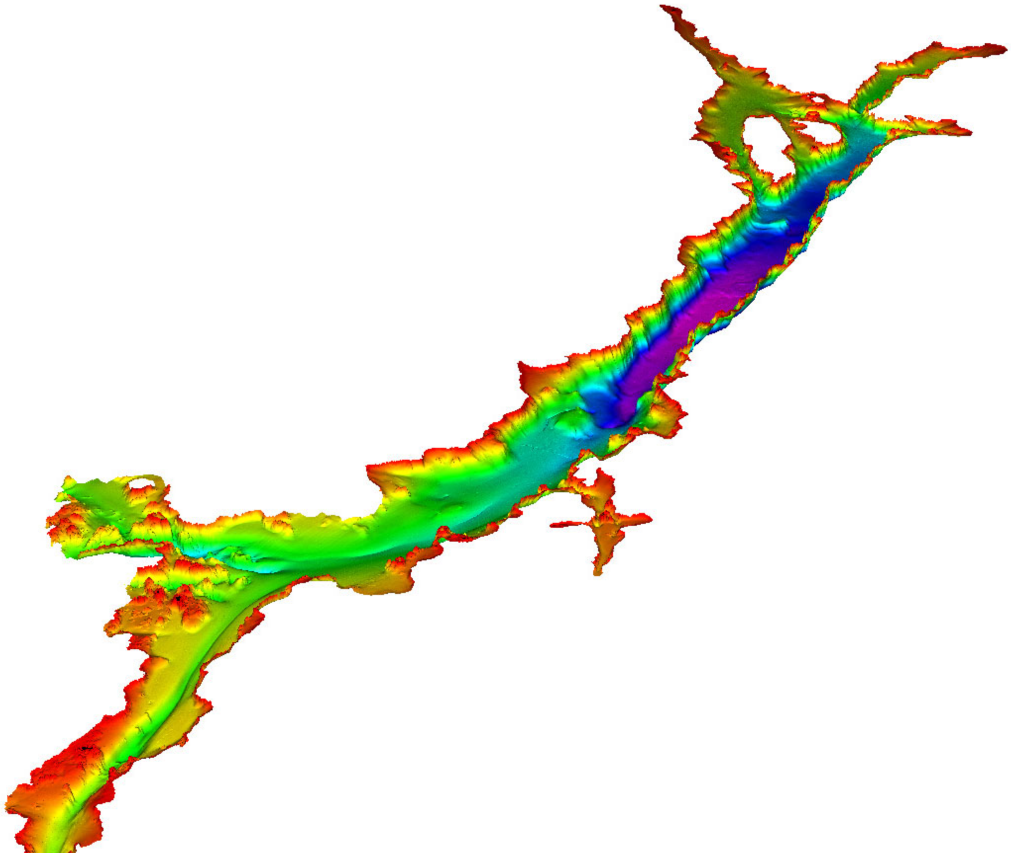

Figure 6. A 3D-map showing the depth in the fjord (Marin Mätteknik AB, unpubl., 2004).

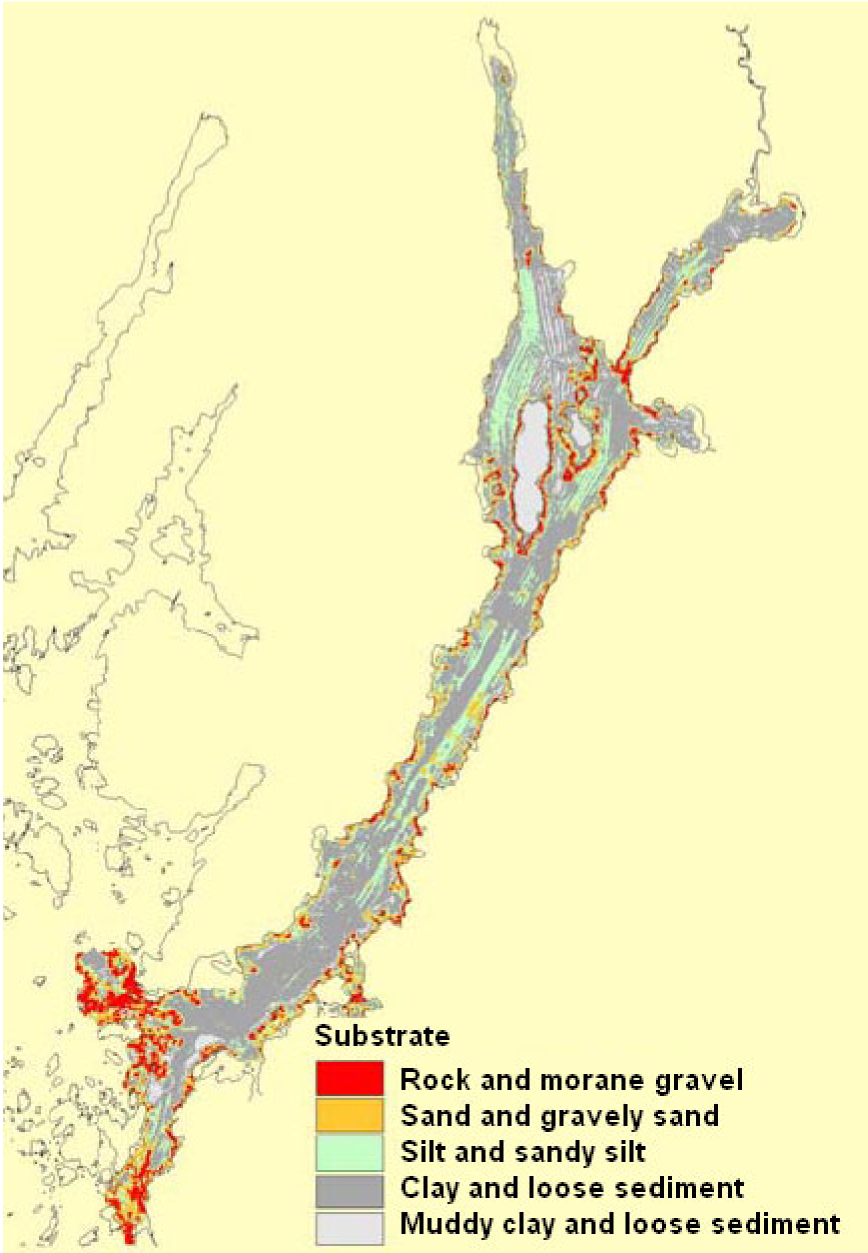

Figure 7. Bottom substrate registered by Marin Mätteknik AB (Bekkby and Rosenberg, 2004).

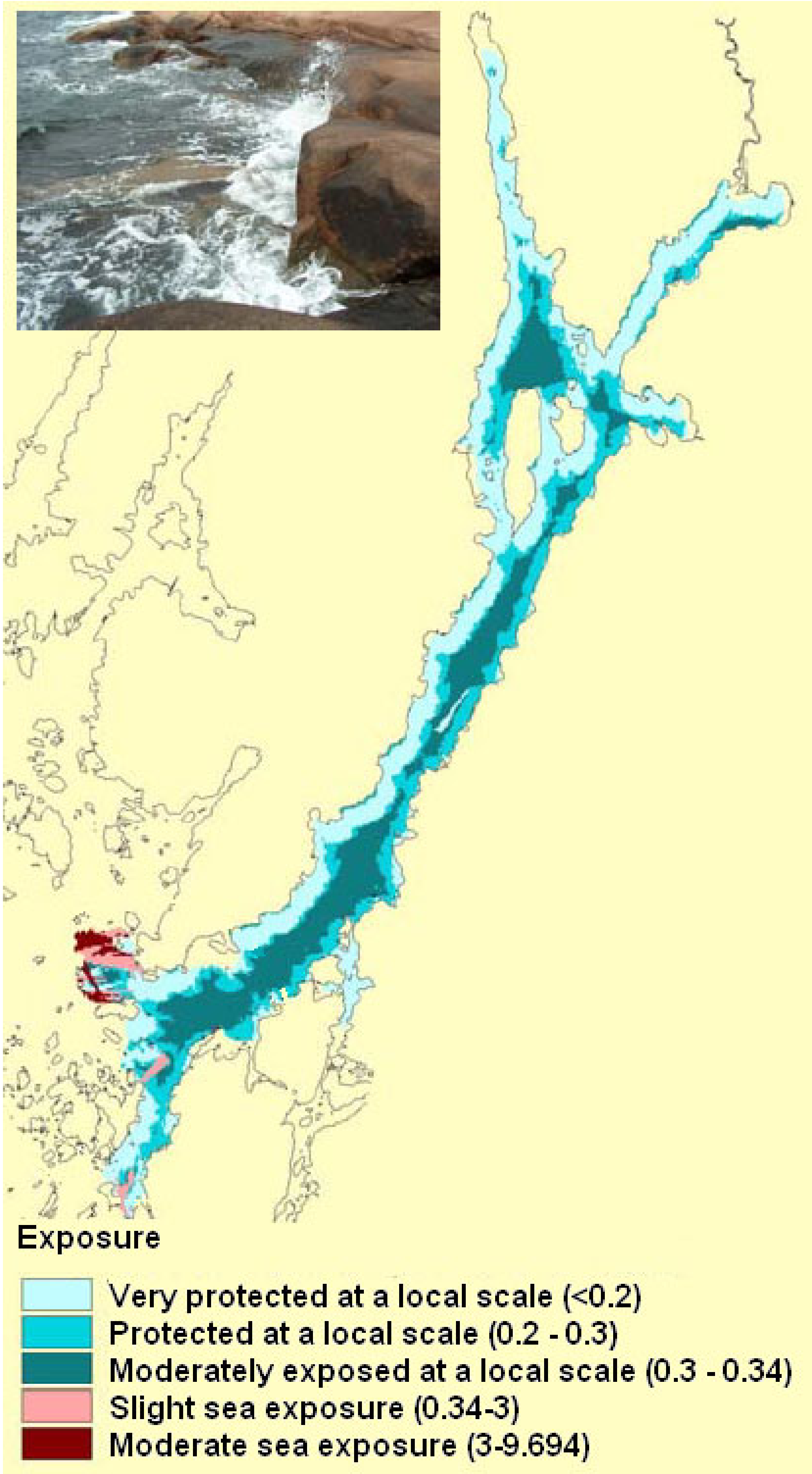

Figure 8. Modelling of the wind exposure based on data with a resolution of 50×50 m. The model includes the fetch, the strength, frequency and direction of the wind (Bekkby and Rosenberg, 2004).

4.1.1 Hydrography

Two major currents affect the Swedish west coast and thereby Gullmarn, see Figure 9 . The water with low salinity that flows upwards along the coast consists of a mixture of water from the Baltic Sea and the Kattegat/Skagerrak (the Baltic current). The other current (the Jutland current) brings high salinity water from the North sea/Atlantic towards the coast (Lindahl et al., 1998). The salinity difference between the different water masses creates four water layers in the fjord. Freshwater mainly from the Örekilsälven, constitutes the top layer. The Baltic water is the layer underneath the freshwater. Below this there is a layer of surface water from the Skagerrak/Kattegat. This water has lost its high content of nutrients due to primary production. Below the sill depth the stagnant deep water is situated (Svansson, 1984). The difference in salinity gives a clear stratification with one halocline at 10–20 metres and one at 50–60 metres. The water above the upper halocline has a salinity of less than 30 PSU, the water between the haloclines 30–33 PSU and the deep water more than 33 PSU. The tide amplitude is about 20 cm and therefore rather insignificant (Lindahl et al., 1998).

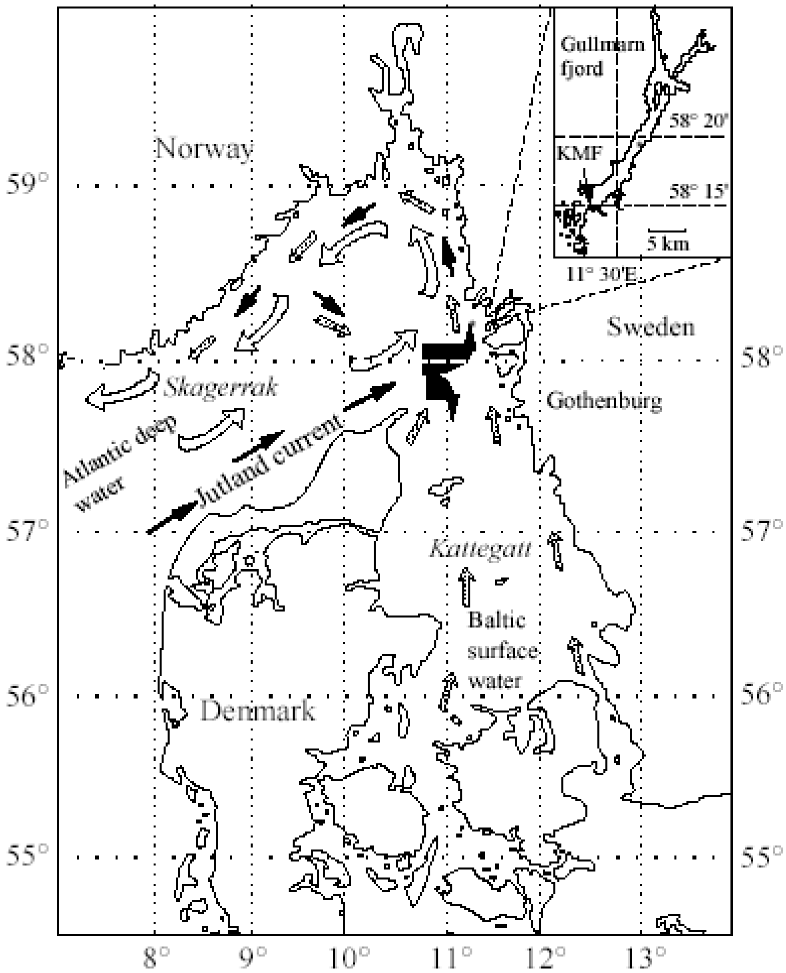

Figure 9. Currents that affect the hydrography of Gullmarn (Belgrano et al., 1999).

The exchange of water above the sill is caused by internal waves, baroclines, in the intermediate water mass. This water is exchanged constantly because of the halocline movements outside the fjord that acts like a pump, pushing water above the sill level in and out of the fjord; see Figure 10 (Arneborg, 2004). The deep-water exchange however, is not frequent, and dependent of climatological effects described later. (Kristinebergs Marina Forskningsstation, 2004).

The process of water exchange above the sill depth caused by vertical movements of the haloclines is described in the following two steps.

1) Rising
   a) The intercept rises when relatively warm water flows in below the upper halocline, leading to an outflow of surface water.

    b) The front of incoming water collapses and the density decides the new placement of the water, often between the upper halocline and 25 metres.
    c) A weak return flow under the new front brings colder and denser water towards the mouth.
2) Descending
    a) The intercept descends and the water below the halocline is pushed out of the fjord.
    b) New water flows in above the upper halocline.

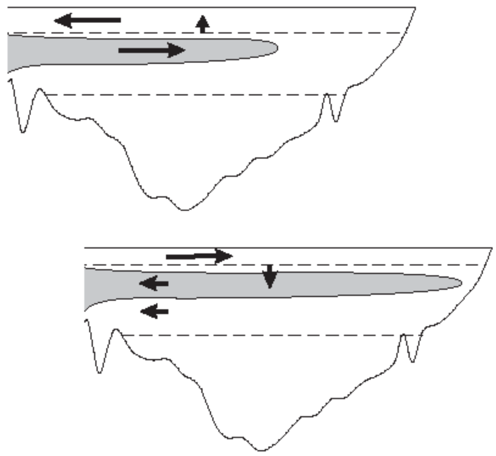

Figure 10. The water exchange process for the water above sill depth. The water from Örekilsälven cannot be distinguished from the Baltic water in the sketch. Upper picture: The interface rises and water flows in below the halocline, the surface water flows out above. The new position of inflowing water (shaded) is determined by its density. Lower picture: The interface descends pushing out some of the new and old water below the halocline (Arneborg, 2004).

The mean turnover time for the top water layer has been calculated to be 16–26 days and for the water above sill level 40 days (Arneborg, 2004). The water below the sill, the deep water, is colder, more saline and denser than the upper layers. This means that the deep water generally is exchanged only once a year, normally during springtime. The water can be exchanged in a couple of days or by a number of minor exchanges during several months. Between the exchanges the water remains stagnant. This may cause periods of six to ten months when no new water is brought in, leading to a continuously decreasing oxygen level (KMF, 1999). Exchange of the deep water demands a high pressure with steady north-easterly winds that push the coastal water towards the North Sea. A bottom current of water with high oxygen level is then drawn in over the sill and sinks down to the bottom due to its high salinity and low temperature (Kristinebergs Marina Forskningsstation, 2004).
The water temperature and the salinity in the surface water and bottom water at Alsbäck over the years 1980–2004 is presented in Figure 11.

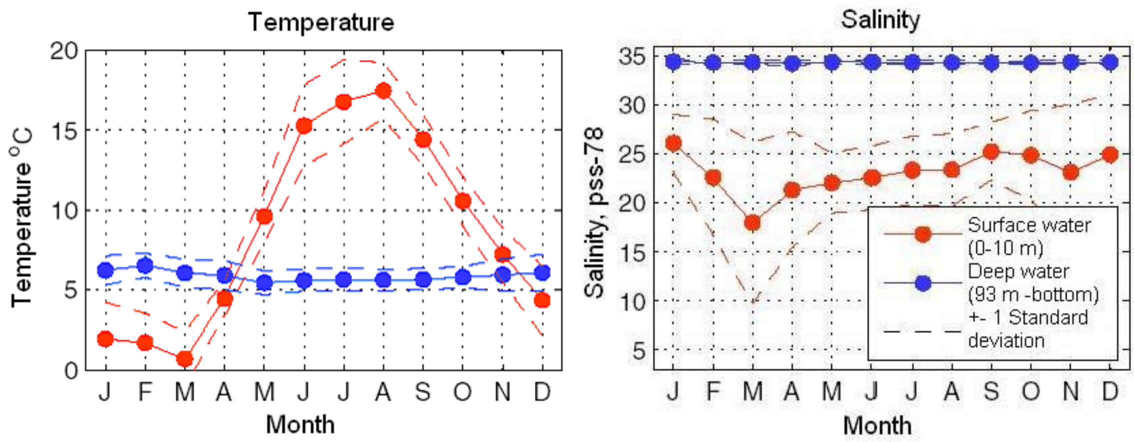

Figure 11. Variations of temperature and salinity in the surface water (0–5 m) (red line) and in the bottom water (blue line) at Alsbäck during the years 1980–2004. The red continuous lines show the mean temperature and the broken lines show mean ± 1 standard deviation (Bohuskustens vattenvårdsförbund, 2004).

4.1.2 Ecological values

Gullmarn has been well known for a long time because of its rich, partly unique, flora and fauna. There are descriptions from as early as 1835 about the great diversity of animals in the fjord. Ever since then many observations and examinations have taken place in the fjord. Both the flora and fauna are very species-rich, but the fauna in particular consists of many deep-sea species, usually rare at the Swedish west coast. Larvae might follow inflowing deep-water, and because of the stable condition in the deepest part with a temperature of 5–7 degrees and a salinity of 34–35 PSU, the species are able to settle. This phenomenon is known as “the fjord effect”. The environmental conditions in the deepest part, Alsbäck, correspond to conditions at depths of 200 – 300 metres in the actual Skagerrak (Kristinebergs Marina Forskningsstation, 2004).

Among the fish species in the fjord there are several species of *Cottidae* and *Sebastes* spp. Other species of fish in the fjord are cod, haddock, vitling, salmon, mackerel, and herring. Also catfish, ray, *Lophius piscatorus* and *Squalus acanthias* can be seen in the fjord (Länsstyrelsen, unpubl., 1986). *Somniosus microcephalus* is a big (<8 m) arctic deep sea-shark, which earlier could be catched in the fjord. Thus catch of this species are very rare since early 1980´s (Sportfiskarna, 2005). Marine mammals to be seen in the fjord are for example *Phocoena phocoena* and *Phoca vitulina*, the latter rather common in the archipelago of Lysekil, in the mouth area of the fjord. *Cyclostomata* spp. is common in soft bottoms of greater depth than 40 metres (Länsstyrelsen, unpubl., 1986).

There are about 1700 species of benthic animals (>1 mm) in the fjord. In bottoms of the deeper parts species like *Lithodes maja*, *Galathea squamifera*, bay scallop, *Patella vulgata*, several species of *Annelida*, for example *Sagitta arctica*, *Sabella pavonina* and *Melinna cristata* are found. Several species of *Echinodermata* spp. are common, for example starfish and *Amphilepis norvegica*. There are as well several cold water-species of *Porifera* spp. Examples of corals in the fjord are *Caryophyllia smithii*. Among solitaire soft corals the white *Prothantea simplex* is very dominating in large parts of Gullmarn at depths of 15–40 m, it is therefore called the “Gullmar anemone” and is a character species of the fjord (Lawett, pers. comm., 2005).

North sea shrimp (*Pandalus borealis*) is one of the most well known cold water species in Gullmarn (SNV, 1978). It was found in large shoals as early as in the 1840´s, and trawling for the shrimp was widespread in the deeper parts of the fjord from early 20th century until 1990 when it was forbidden. Since 1997 trawling for "Gullmar shrimp" is allowed, but strongly restricted (Lawett, pers. comm., 2005).

The fauna in the more shallow parts of the fjord is relatively similar to other parts of the Swedish west coast, with small fish and *Carcinus*, *Amphipoda*, *Polychaeta*, *Bivalvia* and *Gastropoda.* These animals are important as fish food and Gullmarn is essential as an area for reproduction and growth of many fish species along the west coast.

The flora in the fjord is very species-rich as well, with hundreds of algae species, but not very different from similar areas along the Swedish west coast. Since the vertical distribution is decided by the supply of light, the unique deep area of Gullmarn is not of such great importance for the flora. The more exposed areas in the outer part of the fjord are remarkably species-rich in comparison with Swedish environments generally. The algae vegetation in this area has been the base for the Swedish algae floras (SNV, 1978).

4.2 Methods of status classification of Gullmarn

The assessment of Gullmarn has mainly been done by two different methods; use of historical data and by using the Swedish Environmental Protection Agency's (SEPA´s) environmental quality criteria. No specific time-period is set as a "natural condition". When using historical data, more or less the earliest data available have been used, as long as the measurement methods are not too different. In the nutrient model, calculations for 1985 respective 1960 have been made. The reference conditions according to the proposed environmental quality criteria are set by different methods as well, for example historical data and expert knowledge.

Comparisons made in this characterization are relatively rough, and can only be used to indicate possible trends. No statistical comparisons of data have been made.

The coastal water in the pilot area consists of three water bodies; the actual Gullmarn, Färlevfjord and Saltkällefjord. In this characterization all these water bodies are assessed as one. In cases where a specific assessment is made for "Inner Gullmarn", this could be said to correspond to Färlevfjord and Saltkällefjord.

Gullmarn is a relatively well-examined area since three of the first founded marine scientific research stations in Sweden have been situated in the Gullmar area since late 19th century or early 20th century. However, documentation of investigations and observations are relatively sparse, and differences in data format have sometimes made comparisons with current data difficult. No statistical analyses are made on historical data.

The SEPA have developed environmental quality criteria for coast and sea respective lakes and watercourses. These criteria are currently being up-dated and adapted to the WFD, and different expert groups have proposed classifications for the various factors. When referring to the environmental quality criteria in this report, these proposals are the ones in mind. However, it is important to notice that they are still proposals, and that for example borders between different status classes might come to change.

The environmental quality criteria for coast and sea are set for each type area, in this case all the fjords of the Swedish west coast, and not Gullmarn specifically. Proposals are made for benthic fauna (Blomqvist et al., unpubl., 2004), macro vegetation (Kautsky et al., unpubl., 2004), phytoplankton (Samuelson et al., unpubl., 2004) and physico-chemical factors (Sahlsten och Hansson, unpubl., 2004), all shortly described in the following text. For all biological quality factors an Ecological Quality Ratio has to be calculated, see Fact box 4. A proposal regarding pollutants is in progress, but has not been available for this assessment. This proposal will probably be based on the EU´s Quality Standards.

FACT BOX 4

EQR – Ecological Quality Ratio

EQR is calculated for all biological quality factors in the classification of the status. The ratio is given by dividing the value measured with the reference value for the factor.

$$EQR = \frac{\text{Measured value}}{\text{Reference value}}$$

The new environmental quality criteria for benthic fauna are proposing a new environmental quality index, BQI (Benthic quality index), for classification of status. This index is based on composition of species (both number of species and of individuals) in combination with the relative abundance of sensitive respective tolerant species. Regarding macro vegetation the proposed environmental quality criteria are based on vertical distribution of some easily identified species of macro algae as well as the plant *Zostera marina* (eelgrass). Phytoplankton is classified with the proposed environmental quality criteria for bio volume, chlorophyll and dominating species.

The physico-chemical factors considered in the proposed environmental quality criteria are nutrients, Secchi depth and oxygen in bottom water. Due to the seasonal variations of these factors, the time of the year when measurements should take place is set, and the reference values are decided for this period.

A colour code is used for expressing the ecological status, see Figure 12.

HIGH	GOOD	MODERATE	POOR	BAD

Figure 12. Colour code for classification of ecological status.

4.3 Biological investigations of biological quality elements

Concerning macro vegetation and benthic invertebrates some historical data have been available, which have been compared with current investigations. Regarding phytoplankton measurements of primary production and chlorophyll a have been done in Gullmarn since mid 1980´s. Biological elements are not investigated with the same regularity as the physico-chemical elements, why ”current data” is represented by data since 1995. In some cases comparisons with data from the early 1980´s have been made in order to discover trends over the last 20 years.

4.3.1 Macro vegetation

Macro algae

An inventory was made in 1998 at Stora Bornö as a reinvestigation of a study performed by Wærn 1941 (Eriksson et al., 2002). This follow-up discovered that the algal cover was thinner in 1998, except at the surface, and a relatively increased abundance of filamentous algae. An increase of species with a positive correlation to increased sediment load was also noticed.

Two diving profiles were examined in 1998, a steep rock wall on the west side of Stora Bornö with a depth of 12 m, and a gently sloping rock at the south of the island with a depth of 30 m. A considerable decrease in depth extension since 1941 was discovered.

In 1941 18 species were found at a depth of 16 m or below, in 1998 only 5 species were registered at this depth. Three species were not found at all, as the others were found at less depth. Changes in the maximum depth of the species listed in the SEPA´s environmental quality criteria are shown in Table 2. A decrease in the abundance of red- and brown algae was discovered, while the abundance of green algae was scarce at both investigations. The relative abundance between the taxonomic groups had not changed (Eriksson et al., 2002).

In the proposed environmental criteria for macro vegetation the investigation mentioned above is used to exemplify calculation of EQR. The mean value of EQR of the two diving profiles is 0.62, which results in a classification of good status in the area, however close to moderate status.

Table 2. Changes in depth extension at Stora Bornö 1941–1998 (Kautsky et al., unpubl., 2004). Colourcode, see Figure 12.

Species	**Max. depth 1941 (m)**	**Max. depth 1998 (m)** *Diving profile 1, 30 m*	**Max. depth 1998 (m)** *Diving profile 2, 12 m*
Chondrus crispus	12.5	15	4.5
Furcellaria lumbricalis	15	6.9	4.5
Halidrys siliquosa	12.5	5.4	not found
Laminaria saccharina	10	5.2	not found
Phyllophora pseudoceranoides	11	6.7	8
Rhodomela confervoides	15	15	1.5
EQR	1.0 (reference value)	0.77	0.47

Gislén described the flora and fauna on hard bottoms in Gullmarn 1926–1929 (Kristinebergs Zoologiska Station, 1930). A follow-up of this investigation was made in 1986–1987 (Svane & Gröndahl, 1988). Gislén dived at 43 stations in the fjord scraping off samples of epiflora and epifauna from the bottom at a certain area, while Svane and Gröndahl used underwater stereophotographs taken at 2 m interval from 30 m depth towards the surface. The difference in method and the fact that no exact positions of the stations were given by Gislén, results in some uncertainty in the comparison. The results did not show any significant structural differences in the communities of flora and fauna described in the 1920´s. However a decrease in depth extension of macro algae was discovered, especially in the inner parts of the fjord where growth of macro algae were described at depths of 6 m in the 1920´s but not even at 4 m depth in the 1980´s. In the exposed outer parts of the fjord the vertical distribution had diminished from 15 m depth to 12 m, and in the central parts from 8 m to 5 m depth. Dominating macro algae species described in the 1920´s were found at all stations in the 1980´s except in the inner parts, were several species were not found (Svane & Gröndahl, 1988).

Zostera marina

Eelgrass, *Zostera marina*, grows in sandy or muddy bottoms in low to moderately exposed coastal areas and form ”meadows”, which are important areas of reproduction of fish and crustaceans (Bekkby & Rosenberg, unpubl., 2004). Its wide tolerance of salinity (5 – 35 PSU) makes it one of the most widely distributed sea grasses along the Swedish west coast, and a suitable indicator for assessment of macro vegetation according to the WFD. Eelgrass occurs from 0.5 to 1 m depth down to a depth that often match the Secchi depth (Boström et al., 2003). In inner parts of estuaries, the maximum depth extension generally is about 3 m, in outer parts about 4 m and along open coasts about 5 m (Boström et al., 2003). The distribution pattern is bell-shaped along the depth gradient, with maximum abundance at intermediate depths.

In the description of Gullmarn by Gislén 1927, it is said that *eelgrass occurs everywhere at a suitable depth and on muddy bottom where the locality is moderately to rather much sheltered* (Kristinebergs Zoologiska Station, 1930, del IV, s.146). It is further described that eelgrass usually are smaller below 5 – 6 m depth, but continues to cover the bottom down to 8 m or more, especially in the outer parts of the fjord. Eelgrass is described at 8 of the stations visited by Gislén, with depths between 0.9 and 8.4 m. The mean depth of these stations was 4.3 m. Four stations had depths of 5 m or more (Kristinebergs Zoologiska Station, 1930).

Inventories of eelgrass were made in Gullmarn in the year 2000 and in 2003. 78 stations were visited during the most recent investigation, even though this included some stations outside the sill. Eelgrass was found mainly in the outer part of the fjord, on sandy bottoms in sheltered areas with no or minor slope. The depth distribution was 0.5 – 8.5 m, with a mean depth of 2.5 m (standard deviation: 1.6 m). Out of the 78 stations one station had a depth of 8.5 m, two stations at 7 m depth and three stations had depths between 5 and 6 m (Bekkby, pers. comm., 2004). No classification of status according to the SEPA´s environmental quality criteria has been made using this data, since data from each station not has been available, and therefore the maximum depth of the stations situated in the actual fjord have been unknown. The areas where eelgrass was observed at the two inventories are shown in Figure 13.

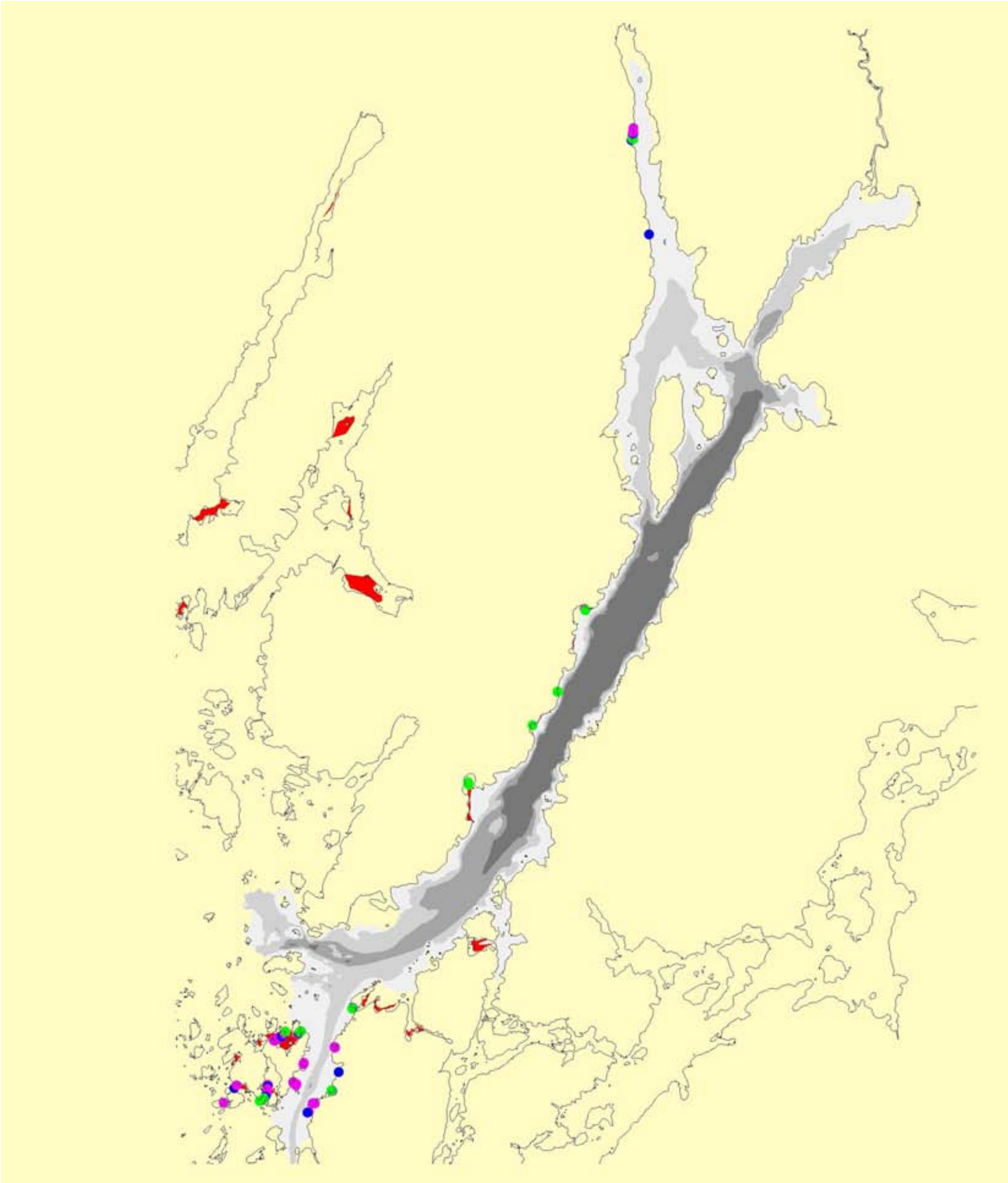

Figure 13. Eelgrass observed during investigations in chosen areas of Gullmarn. Red areas from the inventory in the year 2000, other from the inventory 2003. Green dots indicate sparse cover, blue dots indicate moderate cover and pink dots indicate total cover (Bekkby & Gullström, pers. comm., 2004).

The inventory in 2000 was a follow-up of an investigation of chosen areas along the Swedish west coast in 1980 (Gullström & Baden, unpubl., 2000). The coverage of eelgrass along the 200 km of coast that was investigated had diminished from 20 km^2 in 1980 to 8.4 km^2 in 2000, a reduction with 58 % (regional variations). In the municipality of Lysekil (Gullmarn included) the coverage of eelgrass had diminished in some areas and increased in others. The total covered area was unchanged (Gullström & Baden, unpubl., 2000). Eelgrass meadows in Gullmarn 1980 and 2000 are shown in Figure 14. This inventory investigated parts of Gullmarn. A more complete inventory has been made, but data have not been available for this characterization (Gullström, pers. comm., 2004).

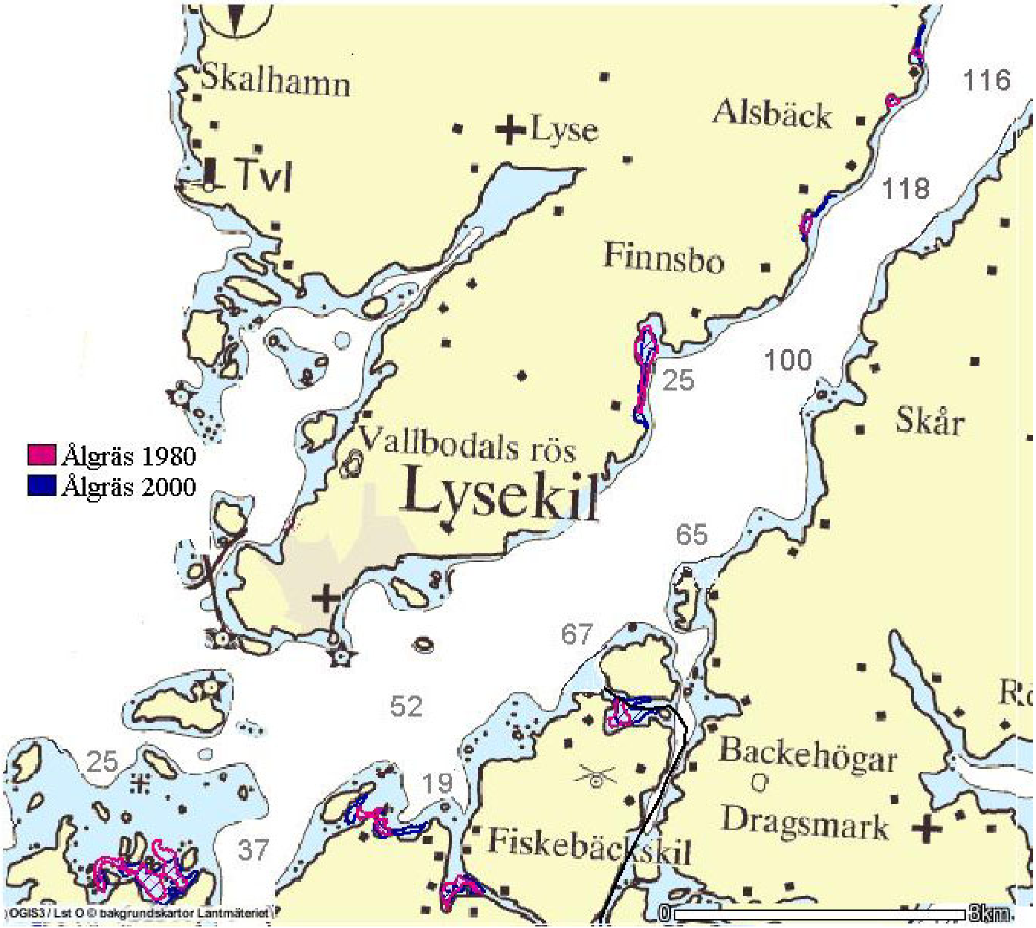

Figure 14. Distribution of eelgrass in Gullmarn 1980 and 2000 (Gullström & Baden, unpubl., 2000). (Modified map from OGIS/Lst O, background map from Lantmäteriet).

4.3.2 Assessment of macro vegetation

The historical data available for macro vegetation is based on occasional investigations. The distribution of macro vegetation is often patchy, and it is not clear how the testing areas have been selected in earlier investigations. A certain degree of subjectivity in the selection of testing areas may be expected, which increases the uncertainties of comparative investigations.

A considerable decrease in vertical distribution of macro vegetation in Gullmarn has been apparent during the late 20th century. This tendency can be seen for all species, and the cause may therefore be expected to be of such character that it affects all species similarly. Vertical distribution of vegetation is limited by the supply of light. A diminished supply of light is the consequence of more particles in the water, which is an effect of eutrophication.

An increase of small, filamentous algae was discovered at Stora Bornö between the periods of 1941–1943 and 1982–1994 (Eriksson et al., 2002). Small, filamentous algae generally have higher nutrient use efficiency than larger, perennial species, which often results in a relative increase of such species when nutrient availability increases. Increased supply of nutrients leads to increased (enhanced) productivity, and consequently an increase in sediment load. The fact that species positive correlated to increased sediment load have increased, strengthens the assumption of increased supply of nutrients as the cause to changes in macro vegetation in Gullmarn.

The investigation in 1941 coincided with an extensive development of *Ectocarpus* spp. Blooms of this species is common in connection with short periods of high nutrient level, and it may be interesting to emphasize that this phenomena appeared as long ago as the beginning of the 1940´s. However the frequency of such blooms at the time is not known.

It is difficult to make comparisons concerning eelgrass based on the available historical data. However it is likely that eelgrass meadows were widely distributed during the 1920´s, even on bottoms at a depth of more than 5 m (Kristinebergs Zoologiska Station, 1930). Nowadays this seems to be more unusual, and the mean depth of bottoms with eelgrass growth is just over 2.5 m (Bekkby, pers. comm., 2004).

In the proposed environmental quality criteria, an EQR of 0.62 is calculated for the area surrounding Stora Bornö, indicating good status, although close to moderate status. The difference between the two diving profiles is rather large, where the deeper one (30 m) obtains a high EQR, while the value calculated for the more shallow profile is close to poor status. No calculations of EQR have been made based on other investigations in Gullmarn. On the basis of the changes during the 20th century, regarding species compositions as well as vertical distribution, it might appear (seem?) inappropriate to classify the element of macro vegetation as good status. Thus, according to the WFD definitions of good and moderate status, the classification as good status seems more suitable, since the majority of species associated with the reference condition are present, and since some signs of disturbance are allowed within the class. However, the changes are considerable enough to make the classification close to moderate status.

4.3.3 Benthic invertebrates

Benthic Quality Index

Rosenberg et al. has calculated BQI on several stations in Gullmarn based on data from 1977 and forward, as well as data from investigations by Molander in the 1920´s (Rosenberg, pers. comm., 2004). The amount of samples, and time of sampling, differs greatly between the various stations. Difference in methods and taxonomic development make the comparison of data from the 1920´s with recent measurements difficult, since it is likely that more, especially small, species can be identified today. BQI has been transformed into EQR according to the proposed environmental quality criteria (Section 3.3.1.2).

For the period 1923–1926 only one calculated BQI is available from each station, where as during the period 1981–1983 five replicates of each sample were taken, enabling five calculated values of BQI from each sampling occasion. During the period 1996–2002 four BQI values were calculated for each sampling occasion. The majority of the values used in this comparison are calculated on samples taken in May each year, occasional samples from the end of April or beginning of June have also been used.

BQI from the 1920´s falls into the same interval as BQI for 1996–2002 (see Table 3). The mean values from the most recent measurements are higher than the value from the 1920´s, see Table 4. EQR were calculated using the mean values in Table 4 and it might appear as EQR is higher now than in the 1920´s, see Table 5. Still it is important to remember that the value for 1923–1926 is based on one single sample, leading to great uncertainties.

Classification of the mean values of BQI for the period 1996–2002, according to the proposed environmental quality criteria, gives the station between Lilla Bornö and Gullmarsvik good status, while the remaining stations are classified as moderate. Data from Hagar are close to the border of good status (Table 5).

Table 3. BQI-values in Gullmarn in the 1920´s, the 1980´s and the three most recent measurements from each station, 1996–2002. Min. and max. values from each period of time. Number of values for each station and time period in parenthesis. (Data from Blomqvist and Rosenberg, pers. comm., 2004).

	Station	**Depth (m)**	**1923–1926**	**1981–1983**	**1996–2002**
Inner Gullmarn	Färlevfjord	20 – 25	12.9 (1)		12.4 – 14.5 (12)
	L.Bornö/ Gullmarsvik	70	14.7 (1)		13.9 – 17.0 (12)
Central Gullmarn	Alsbäck	118	11.8 (1)	8.5 – 14.6 (15)	9.1 – 14.4 (12)
Outer Gullmarn	Hagar	30 – 35	13.1 (1)	13.9 – 16.5 (15)	11.5 – 15.4 (12)

Table 4. BQI, mean values for the periods 1981–1983 and 1996–2002, based on values in Table 3.

	Station	**Depth (m)**	**1923–1926**	**1981–1983**	**1996–2002**
Inner Gullmarn	Färlevfjord	20 – 25	12.9		13.3
	L.Bornö/ Gullmarsvik	70	14.7		15.8
Central Gullmarn	Alsbäck	118	11.8	11.6	11.7
Outer Gullmarn	Hagar	30 – 35	13.1	15.1	14.0

Table 5. EQR-values for benthic invertebrates in Gullmarn 1923–1926, 1981–1983 and 1996–2002, based on BQI-values in Table 4.

	Station	**Djup (m)**	**1923–1926**	**1981–1983**	**1996–2002**
Inner Gullmarn	Färlevfjord	20 – 25	0.59		0.60
	L.Bornö/ Gullmarsvik	70	0.67		0.72
Central Gullmarn	Alsbäck	118	0.54	0.53	0.53
Outer Gullmarn	Hagar	30 – 35	0.60	0.69	0.64

The tendency the latest 20 years shows that BQI varies greatly in the Alsbäck deep (Figure 15 between good and bad status. The other stations vary between moderate and good status (good status: BQI >14), with a weak descending tendency at the stations Lysekilen, Hagar and Färlevfjorden. The station Lysekilen is situated right outside the mouth of Gullmarn and shows BQI-values of good status. BQI calculated from single measurements on other stations in the fjord indicates on good or moderate status.

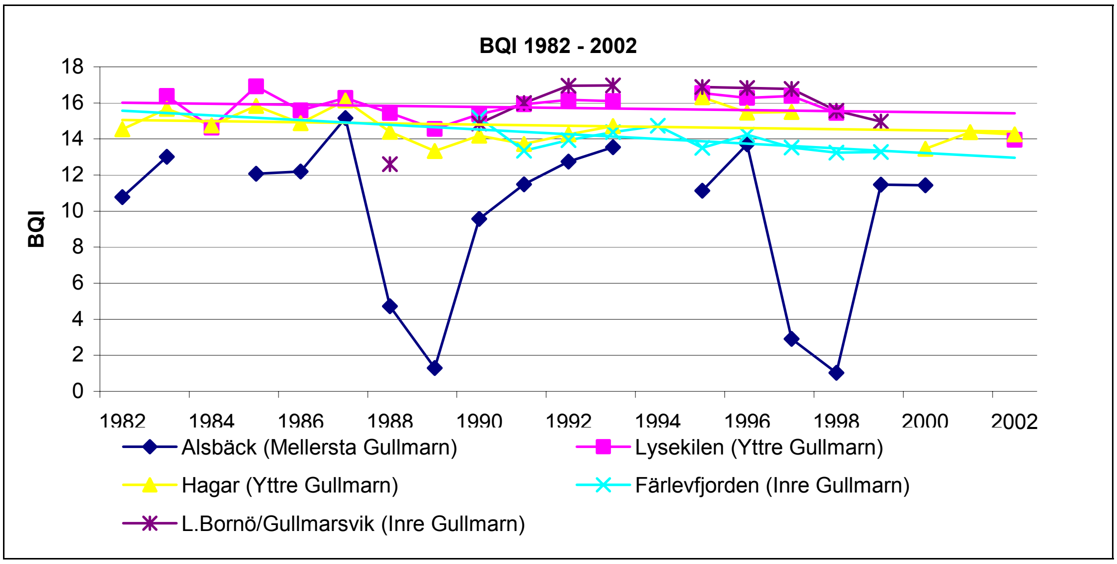

Figure 15. BQI-values for Gullmarn 1982–2002 based on measurements in May. Trends for Lysekilen, Hagar and Färlevfjorden. (Data from Blomqvist and Rosenberg, pers. comm., 2004).

After the hypoxia in 1997, when there was no renewal of the stagnant bottom water, re-colonisation and impact on benthic fauna was studied (Rosenberg et al., 2002). A significant decline of benthic fauna was apparent at oxygen saturation <10 % (85–95 m). At greater depths than 105 m the benthic faunal communities were eliminated. Two years after the hypoxia the benthic quality was restored according to analysis of Benthic Habitat Quality (BHQ), where sediment profile images are analysed (Rosenberg et al., 2002). The recovery was generally more rapid in shallow waters than in deeper waters. Earlier investigations have indicated longer recovery times. As a result of discharges from the sulphite pulp mill at Munkedals Bruk, the benthic fauna was eliminated in the inner parts of the fjord, due to oxygen deficiency and presence of hydrogen sulphide. When the sulphite pulp mill was closed in 1966, re-colonization of the bottom did not start until 1969. After 5–8 years, depending on the size of the area, the benthic fauna was considered as having returned to undisturbed conditions, and was then similar to the description by Molander 1928 (Rosenberg et al., 2002).

Biomass

Changes of benthic fauna can also be made by comparing recent and historical data of biomass of the benthic fauna at a certain area. This may give a more reliable picture of changes than a comparison of BQI, which is affected by the taxonomic development during the last century.

Molander determined biomass at several stations in Gullmarn during the 1920´s (Kristinebergs Zoologiska Station, 1930). The total weight of the individuals' collected in three replicates of a 0.1 m^2 sampling area at each station, was put together to one value of the biomass in gram per 0.3 m^2. At the majority of the stations samples were collected at one single occasion, usually during the summer. From time to time, since late 1970´s, the biomass of 0.1 m^2 –samples from a few stations in Gullmarn have been determined. The size of the sieve was 1 mm, which is the same used by Molander, making a comparison of data from closely situated stations possible (Agrenius, pers. comm., 2004).

The biomass has been compared in two different ways. First at five different stations for the periods 1923–1926, 1981–1983 and the three most recent measurements at each station, done between 1995–2000 (Table 6–Table 8). Secondly a comparison is made between several stations within the inner, central and outer part of Gullmarn in the periods of 1923–1926 and 1995–2002, (Table 9–Table 10). The comparisons below show an apparent increase of biomass of the benthic fauna during the 20th century. The smallest increase is in the Alsbäck deep, and the greatest in the inner parts of Gullmarn. The first comparison show five of the stations where recent measurements have been made, related to the most closely situated stations examined by Molander. In the cases where measurements were made in the early 1980´s, the biomass from this time is shown as well. The measurements during this period consist of five replicates of each sample. In the 1990´s there were only four replicates of each sample. One value has therefore randomly been excluded, in order to increase the comparability of the two most recent groups.

Table 6. Biomass of benthic fauna, min. – max. values of samples taken in May. Number of measurements in parenthesis. Values from the 1920´s are the total weight of 3 replicates at the same sampling date. Notice the units of measurements. (Data from Blomqvist and Rosenberg, pers. comm., 2004).

Station	Depth (m)	1923–1926 (g/0.3 m^2)	1981–1983 (g/0.1 m^2)	1995–2002 (g/0.1 m^2)
Färlevfjord	20 – 25	7.3 – 11.3 (6)		15.7 – 105.6 (12)
Saltkällefjord	45	5.7 (3)	17.2 – 34.8 (12)	13.0 – 39.6 (12)
L.Bornö/ Gullmarsvik	70	8.5 (3)		15.9 – 46.8 (12)
Alsbäck	118	6.2 (3)	2.0 – 15.2 (12)	1.0–10.8 (12)
Hagar	30 – 35	13.6 (3)	8.6 – 42.7 (12)	2.0 – 61.5 (12)

Table 7. Biomass of benthic fauna, mean value for observations in May. Values from the period 1923–1926 represent one single observation, except Färlevfjord which shows a mean value of two measurements. Notice the units of measurements. *Mean value when highest value is excluded (deviant value). (Data from M. Blomqvist and R. Rosenberg, pers. comm, 2004).

Station	Depth (m)	1923–1926 (g/0.3 m^2)	1981–1983 (g/0.1 m^2)	1995–2002 (g/0.1 m^2)
Färlevfjord	20 – 25	9.3		31.9 (25.2*)
Saltkällefjord	45	5.7	23.7	21.5
L.Bornö/Gullmarsvik	70	8.5		26.2
Alsbäck	118	6.2	5.5	5.1
Hagar	30 – 35	13.6	20.7	14.7

Table 8. Biomass of benthic fauna, g/0.3 m^2. Mean values from 1981–1983 and from the three most recent measurements (1995–2002) multiplied by three in order to make a comparison possible. *Mean value when highest value is excluded (deviant value). (Data from Blomqvist and Rosenberg, pers. comm., 2004).

Station	Depth (m)	1923–1926	1981–1983	1995–2002
Färlevfjord	20 – 25	9.3		95.7 (75.6*)
Saltkällefjord	45	5.7	71.1	64.5
L.Bornö/Gullmarsvik	70	8.5		78.6
Alsbäck	118	6.2	16.5	15.3
Hagar	30 – 35	13.6	62.1	44.1

The stations examined by Molander have been divided into groups of the outer, central and inner Gullmarn. These are compared with the biomass at the current stations within the same areas (Table 9–Table 10). In the inner part the stations have been divided with respect to depth as well. In the other areas most of the stations are situated within the same depth interval (less than 40 m in the outer part of Gullmarn and more than 70 m in the central part of Gullmarn). Molander visited many stations, mostly only at one occasion (3 replicates). Today fewer stations are visited, but several replicates have been taken continuously during several years at each station. Table 10 is based on all measurements since 1995. The bottom row in Table 10 shows the median of the values of biomass multiplied with three, in order to make a comparison possible with data from Molander, who expressed biomass in gram per 0.3 m^2.

Table 9. Biomass of benthic fauna in different parts of Gullmarn (g/0.3 m^2) in the period of 1923–1926. Number of stations and number of replicates within parenthesis. (Data from Molander, Kristinebergs Zoologiska Station, 1930).

	Outer Gullmarn	Central Gullmarn	Inner Gullmarn	
Depth	<40m	>70m	<40m	>40m
Min–max	12.1–39 (6/21)	2.5–31.9 (9/36)	4.4–25.3 (12/54)	4.9–10.2 (5/15)
Median	27.7	9.2	10	7.3

Table 10. Biomass of benthic fauna in different parts of Gullmarn (g/0.1 m^2) in the period of 1995–2002. Number of stations and number of replicates within parenthesis. (Data from Blomqvist and Rosenberg, pers. comm. 2004).

	Outer Gullmarn	Central Gullmarn	Inner Gullmarn	
Depth	<40m	>70m	<40m	>40m
Min–max	2.0–61.5 (1/24)	0.2–51.8 (4/89)	16.3–126.8 (1/19)	1.2–57.0 (2/40)
Median	13.4	3.4	26.8	19
Median×3	40.2	10.2	80.4	57

Josefson (1981) compared the benthic fauna at Hällebäck, Stora Bornö and Alsbäck during the period 1977–1980 with the data by Molander 1923–1926. An increase of both individuals per m^2 and biomass were noticed. Josefson also described a change in the structure of the benthic faunal community, with an increase of deposition feeders and the species *Thyasira* spp., as well as a decrease of deep burrowing species.

Sediment Profile Images

The benthic environment in Gullmarn have also been analysed by sediment profile images, SPI´s. A camera penetrates into the sediment taking a photo that shows the activity of benthic fauna, through structure of burrows, tubes and voids. Also the depth of the redox potential discontinuity is analysed digitally. This technique has been used in the United States for 20 years, for example by the Environmental Protection Agency (EPA), and is recommended by the Swedish Environmental Protection Agency (SEPA) for assessment of benthic quality.

The great advantage of SPI-technique is that many pictures can be taken covering a large area, as well as a rapid digital analyse. This enhances the possibility of getting information about any changes in larger areas than only at one station. Also the analysis is made *in situ* and is non-destructive.

By valuation of different structures on the surface of the sediment (such as tubes and faeces), subsurface-structures (burrows and voids) and the depth of the shift between oxidized brown sediment and reduced black sediment, an environmental quality index, BHQ (Benthic Habitat Quality) can be calculated. The index varies between 0 – 15, where numbers >11 indicates high benthic quality. Analyse by SPI give no information of species diversity, it is therefore recommended with analyse of benthic fauna at some stations as a complement. Gullmarn has been analysed with SPI´s during 2004 with the result of high to good status at all stations. Some SPI´s shows traces of trawling (Rosenberg & Nilsson, 2005).

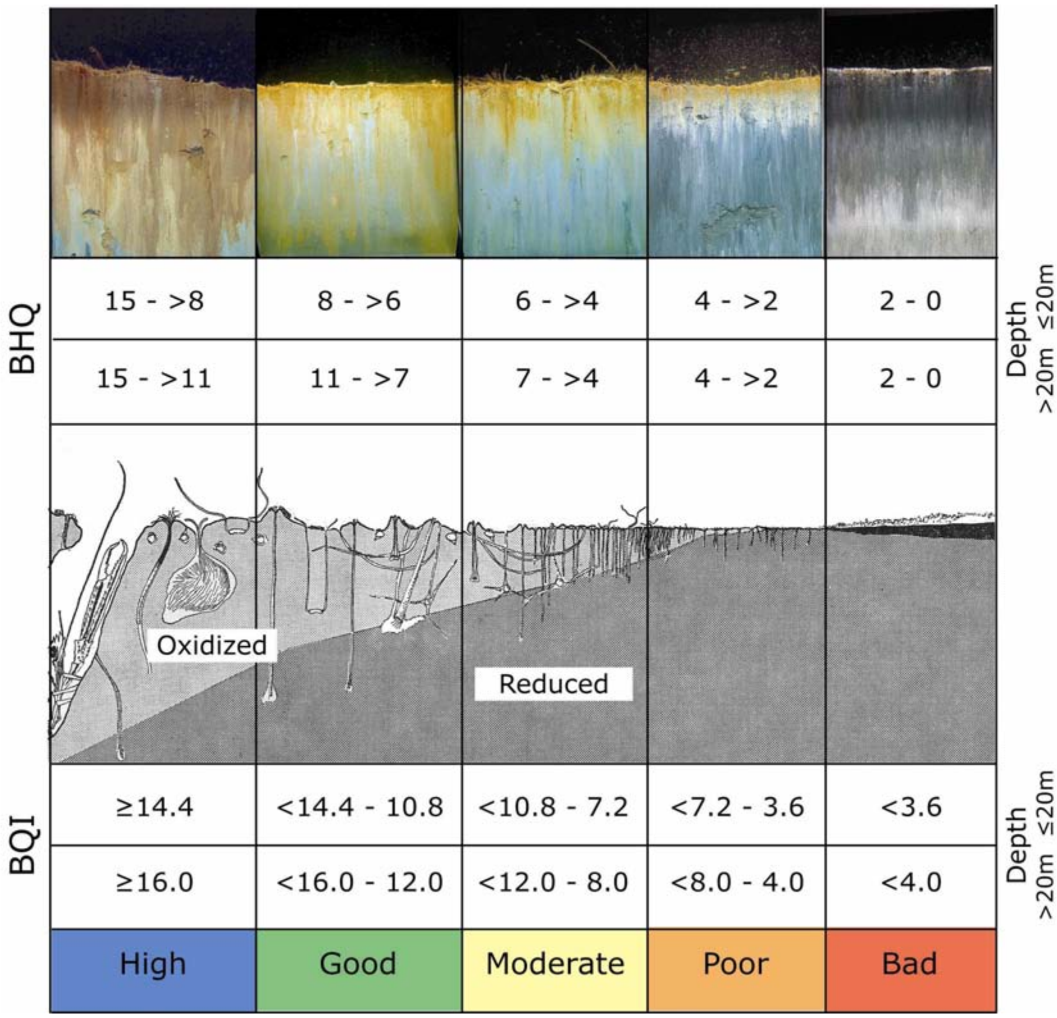

Figure 16. Sediment Profile Images are shown on the top. Brownish colour indicate oxidised conditions and black reduced conditions (colours enhanced). BHQ indices and corresponding BQI indices are presented for depths >20 m and ≤ 20 m (Rosenberg & Nilsson, 2005).

4.3.4 Assessment of benthic invertebrates

According to the proposed environmental quality criteria for benthic invertebrates, assessment of this element will be assessed by calculation of BQI, an index based on species tolerance, diversity and abundance at a station. Even though BQI based on older data is not considered reliable, a comparison has been made since calculations from single measurements in the 1920´s have been available. BQI from the 1920´s falls into the same interval as BQI based on measurements during 1996–2002, which could indicate that there is no deviation from the reference condition (1920´s). Considering the observation on structural changes in the benthic faunal community made by Josefson, this statement is not very probable (further discussion later on). Assessment of the status of benthic invertebrates in Gullmarn by calculation of BQI should only be based on the values from the period 1996–2002.

With the exception of the Alsbäck deep, the BQI-values are higher at stations of greater depth. The station between Lilla Bornö and Gullmarsvik has BQI-values relatively stable in the class *good status*. This station has a depth of 70 m, making it less exposed to oxygen deficiency than other parts of the fjord. In addition, temperature and salinity are more stable than in more shallow parts. This would make the benthic fauna less exposed to environmental variations, leading to a greater diversity and more sensitive species present in the community.

In the Alsbäck deep, BQI varies within a relatively large interval during the last 20 years. This variation is probably correlated to the oxygen level in the bottom water. The benthic fauna is strongly dependent of oxygen supply, and years with poor exchange of water seem to have a negative effect on the benthic fauna the following year as well. Figure 15 shows a very low BQI in 1998, following the absence of water exchange in 1997. There are observations indicating times of very low oxygen level in the beginning of the 20th century as well, which makes it difficult to state that temporary reduction of benthic fauna in the deepest part is a deviation from the natural condition. However the higher frequency of oxygen deficiency in Alsbäck will probably lead to worse conditions for benthic fauna.

Changes in biomass of benthic fauna are probably due to increased levels of nutrients. There is a possibility that more species are included in samples today. However this would not affect the comparison that much, since the larger species, which have the biggest effect on the weight, most likely were included in the measurements by Molander. A higher proportion of large, heavy species could also be a cause to the increase of total biomass on a certain area. More detailed studies of this have not been done. However heavier individuals of for example the echinoderms *Brissopsis lyrifera* and *Echinocardium cordatum* are present in data from the 1920´s. There are no data indicating a change of benthic fauna regarding size.

The increase of biomass of benthic fauna is smallest in Alsbäck. In the more shallow parts of the fjord the benthic fauna is less exposed to oxygen stress than the deeper parts, which could allow a greater growth of the individuals in the faunal community.

The biomass on a certain area does not give any information about the species diversity in the area. It is possible that species favoured by high nutrient levels have increased in the more shallow parts, the lower BQI´s in these areas could be a sign of this. These opportunistic species have a higher nutrient efficiency and often shorter generation times, leading to more individuals, thus affecting the biomass. The diversity of species has been increased to a certain degree with increased supply of nutrients, probably since the competition of nutrients decreases and therefore more species are able to settle. However, at a certain degree of increased nutrient supply it is likely that species favoured by high nutrient availability will have an advantage and other species therefore will diminish.

Josefson (1981) explained his observation of the structural change in benthic faunal communities with increased sedimentation during the 20th century, leading to more loose sediment containing more nutrients. Signs of this were for example an increase of deposition feeders and *Thyasira* spp, which usually exists in environments with high supply of organic matter. There were also increases of other species positively correlated with eutrophication. Deep-burrowing species, characteristic for more firm sediment, had decreased. Josefson points out other, from his point of view, signs of early eutrophication following either increased supply of organic matter to the fjord or lasting effects of discharges from the sulphite mill in Munkedal.

No increase of biomass is shown since early 1980´s until the period 1996–2002, which might indicate that the increase of biomass of benthic fauna has ceased.

There are no environmental quality criteria regarding biomass of benthic fauna. An apparent deviation since the 1920´s is obvious, with increased biomass at all stations used in this comparison. Based on this the ecological status is classified as moderate in this characterization. The increase is most significant in the inner and shallower parts of the fjord.

Analysis of SPI results in high or good status in Gullmarn. This analysis technique has been shown to correlate well with analysis of benthic fauna, which would indicate on good status of benthic fauna in Gullmarn as well.

The classification of status is supposed to be based on deviation from reference condition, and could therefore be assessed as moderate because of the evident deviation of biomass since early 20th century. However, several observations, without comparison with earlier data, indicate good status for benthic fauna. The classification is therefore not obvious but our assessment is made based on the increased bio mass.

4.3.5 Phytoplankton

Regarding phytoplankton assessments have been made of chlorophyll, bio volume, dominating species and primary production.

Chlorophyll a

Table 11 shows EQR based on results from measurements of chlorophyll in surface water (0–10 m) from June to August 2001–2003.

Table 11. Classification of status, according to the environmental quality criteria on chlorophyll, at the stations Björkholmen and Släggö. Mean values of the chlorophyll content in surface water 0–10 m June–Aug are shown, as well as a mean value over a three-year period (2001–2003). The colour shows the status. Colour code, see Figure 12.

CHLOROPHYLL, EQR				
STATION	**2001**	**2002**	**2003**	**Mean 2001–3003**
Björkholmen	0.53	0.32	0.29	0.35
Släggö	0.50	0.50	0.76	0.57

Comparisons over time can only be done from the 1990´s, since no earlier measurements have been done. These results are shown in Table 12 regarding Björkholmen and Table 13 regarding Släggö. The maximum values indicate a significant deterioration. The mean and median values show an increasing content of chlorophyll as well.

Table 12. Comparison of chlorophyll 1990–2003 (June–Aug) at Björkholmen. Colour code, see Figure 12.

CHLOROPHYLL (µg/l)			
Björkholmen	**1990–1994**	**1995–1999**	**2000–2003**
Mean	2.21	4.12	4.63
Median	1.60	3.55	3.55
Max	8.80	18.00	30.20

Table 13. Comparison of chlorophyll 1990–2003 (June–Aug) at Släggö. Colour code, see Figure 12.

CHLOROPHYLL (µg/l)				
Släggö	**1986–1989**	**1990–1994**	**1995–1996**	**2000–2003**
Mean	2.21	1.70	2.31	3.05
Median	1.88	1.30	2.40	2.50
Max	5.89	6.40	5.00	13.60

Bio volume

Table 14 shows bio volume of phytoplankton at Släggö 2000–2003. The value is calculated by the Swedish Meteorological and Hydrological Institute (Hansson et al., unpubl., 2004). The mean value indicates a good status, close to moderate.

Table 14. Bio volume at Släggö (June–Aug) 2000–2003 (Hansson et al., unpubl., 2004). Colour code, Figure 12.

BIO VOLUME (mm^3/l)	
Släggö	**2000–2003**
Mean	1.97

Dominating species

The water quality association of the Bohus Coast has sampled phytoplankton at Kristineberg in Gullmarn April–June 2003 (9 occasions) and April and May 2004 (4 occasions). Most of the species that indicate good status, according to the environmental quality criteria, are present during the observations in May and June. The species most frequently described as common are *Dactyliosolen fragilissimus, Guinardia flaccida* and *Proboscia alata*. Species observed only a few times are *Ebria tripartita* and *Prorocentrum micans.* All data can be found at www.bvvf.com.

Blooms of certain phytoplankton species may lead to production of different toxic substances in *Mytilus edulis*. These substances do not cause effects in blue-shell, but might be harmful for humans eating them. Species which might cause this are for example *Dinophysis* spp., *Alexandrium* spp. and *Pseudo-nitzschia* spp. Observations at Släggö in the mouth of Gullmarn 1986–2002 show regular occurrence of these species. *Dinophysis* spp. may occur in large amounts, while the other species occur in smaller amounts. No trends are seen over time of the occurrence of certain species (Karlson, 2002). However *Dinophysis norvegica* is normally present in the phytoplankton community in Gullmarn, and is thus one of the species indicating good status according to the environmental quality criteria (Edler, pers. comm., 2004).

In May 1998 there was a large toxic bloom of *Chrysochromulina polylepis* in the West sea, covering an area of 75 000 km^2. During the observations at Kristineberg *Chrysochromulina* spp. was present at all occasions in 2004 and a few times in 2003, but never described as common or dominating.

Primary production

Primary production in the mouth of Gullmarn has been measured since 1985. An increase over time has been observed. The mean value of the annual primary production 1985–1986 was approximately 230 grams of carbon per m^2, and around year 2000 a little less than 250 grams of carbon per m^2. The mean value of the annual increase was 3 grams of carbon per m^2 and year. The primary production during the period May – September represents around 80 % of the total production of the year (Lindahl, 2002).

A longer time-serie has been made starting at 1950, presumed as a time of no significant human impact. An assumption was made that the development in Gullmarn has been the same as in Kattegat. Calculations of the primary production in Kattegat from the late 1950´s have been used. The starting value for the time serie was decided by Lindahl (2002) to 100 grams of carbon per m^2 and year. This value is somewhat higher than the calculated value from the late 1950´s. A higher value is assumed more likely due to differences of measuring methods and stations (Lindahl, 2002).

4.3.6 Assessment of phytoplankton

Concentration of chlorophyll has been measured since the 1990´s showing a trend of deterioration since then. However, bio volume is a better measure of biomass than chlorophyll. Classification of bio volume and concentration of chlorophyll result in good to moderate status. The values from Björkholmen are considered more relevant in the assessment of Gullmarn than Släggö, and these values are slightly worse. Most of the species indicating good status are present at Kristineberg. However, also potential toxic species occur. Composition of species should be used as a complement to bio volume, but are of minor importance in the assessment. The significant increase of primary production in grams of carbon per m^2 contribute to the classification of moderate status regarding phytoplankton

4.4 Physico-chemical observations

The physico-chemical quality factors are assessed using comparisons with historical data and by using the environmental quality criteria proposed by the Swedish Meteorological and Hydrological Institute, SMHI. When no other source is given the data come from the Swedish ocean archive, SHARK. SMHI, KMF, and the Water Quality Association of the Bohus Coast within the Swedish coordinated environmental monitoring have produced this data. The data are quality checked until year 2003 (Hansson, pers. comm., 2004). Therefore no later data are used.

An assessment of the status has to include some natural variations and here a tree-year period has been used to represent the present status of the water body. Three years are the standard period according to the old guidelines.

The assessment based on the historical data is made with data from Gullmarn, while the guidelines are more general and are valid for the type *Fjords of the west coast*.

4.4.1 Oxygen in the bottom water

The deepest part of the fjord, Alsbäck deep, is a critical area in the fjord, where oxygen deficiency and damage of the biota often occur. At this station observed changes of the oxygen status clearly indicate amelioration or a deterioration of the situation. This is why Alsbäck is chosen for assessment of the status. Analyses of data from the other stations in the fjord have also been made but there are no problems with hypoxia at those stations.

The assessment is based on oxygen saturation level because of its connection with ecological effects due to oxygen deficiency. The oxygen dissolves easier in cold water and making the oxygen level more or less harmful with the temperature of the water. The salinity is another important factor for the solubility.

The minimum oxygen level of the three years and a mean value of the minima are shown in Table 15. The mean represents poor status. The data are monthly measurements at depth greater than 110 metres. Measurements at several stations have been done at different times, with varying frequency and depth.

Table 15. Assessment of the status according to the environmental quality criteria for oxygen in the bottom water in the Alsbäck deep (Sahlsten och Hansson, unpubl., 2004). Data from SHARK. The minimum oxygen level of the year for the bottom water (≥110 m) is shown as well as a mean value of the tree year period (2001–2003). The colours represent the status. Colour code, see Figure 12.

OXYGEN SATURATION IN THE BOTTOM WATER (%) (min)				
STATION	**2001**	**2002**	**2003**	**Mean 2001–2003**
Alsbäck deep	10	18	14	14

Comparison with historical data

Table 16 shows the development of the oxygen level since the late 1800's until 2003. A decreasing oxygen saturation level is clear, even though the last three years show an increase of the minima.

Table 16. A comparing analysis of the data from 1890 until 2003. The figures indicate the oxygen saturation level in percent in the Alsbäck deep (≥110 m). Median and minima of the year is reported. Data from 1890–1893 are taken from the material gathered by Gislén (Kristinebergs Zoologiska Station, 1930), the other data come from SHARK.

OXYGEN SATURATION IN THE BOTTOM WATER (%) 1890–2003							
Alsbäck deep	**1890–1893**	**1902–1906**	**1959–1969**	**1970–1979**	**1980–1989**	**1990–1999**	**2000–2003**
Median	58*	45**	43	46	39	32	34
Min	22*	12**	14	12	3	2	10

* Only 4 measurements ** 15 measurements.

Figure 17 shows a diagram of the frequency of oxygen deficiency at Alsbäck from 1960 until now. Since the 1980's the acute oxygen deficiency (0–2 ml/l) has become more frequent.

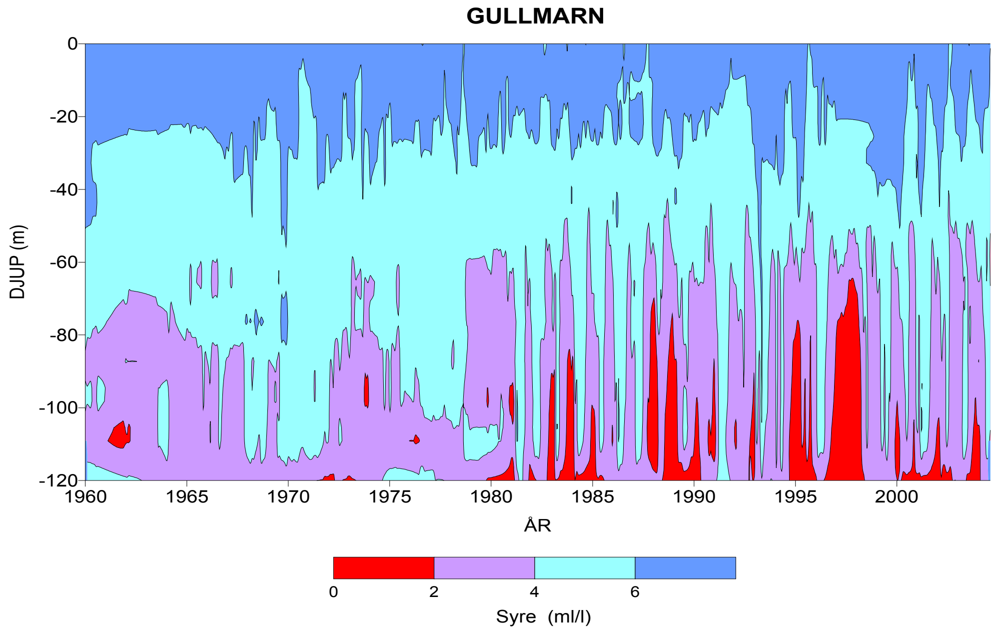

Figure 17. Oxygen levels in the Albäck depth 1960–2004 (Andersson, pers. comm., 2005)

4.4.2 Assessment of oxygen in the bottom water

There exists oxygen data from the late 1800's and the methods have not changed a lot since then. The measurement of depth was not as exact and depths of 130 metres have been measured in the fjord. To get a larger material 110 metres is made the upper limit of the bottom water. In the historical data there are only some single values and the minimum of the year may have been missed. This gives great uncertainties when comparing to the measurements today, which are done monthly.

The trend of the oxygen saturation from 1890 until the 2000's is declining. The minima of the year and the median values decrease, meaning that the oxygen deficiency gets worse and the most frequent oxygen levels lower. This was expected and several researchers, Lindahl and Rosenberg among others, have also shown that the situation deteriorates. Data from the 1890's exist only as one or two measurements a year. These are made in February till August, after an eventual exchange of bottom water, but at different times. Hypoxia has occurred historically, a minimum of 0.85 ml/l, 12 % saturation is observed in August 1906. If this value is reliable is hard to say. It could be an error in the measurement, but could as well be correct. It is natural that the sill fjord suffers from hypoxia caused by a lack of water exchange. The increased frequency of hypoxia can have two reasons. A complicated water exchange that leads to less oxygen enriched water that is brought to the bottom and/or an increased eutrophication. The latter is the most probable according to most research. From 2000 till 2003 it seems to be an ameliorated oxygen situation. No conclusions can be drawn from this because of the short period of time. There may have been better water exchanges these years. The last 10 years the situation also seems to get better.

The status classes set in the new environmental quality criteria can be discussed. A definition of acute hypoxia is <2 ml O_2/l and in the environmental quality criteria this is classed as moderate status. According to OSPAR oxygen levels up to 6 ml/l is defined as oxygen deficiency. Maybe moderate status should not include oxygen concentrations that clearly represent hypoxia. In the proposed environmental quality criteria the classification of oxygen is assumed not be dependent on type because the oxygen deficiency affects the bottom fauna to the same extent. This is correct but we think the environmental quality criteria should be decided according to the deviation from a reference condition. In Gullmarn the hypoxia is partly natural, which should give a minor deviation than for areas where hypoxia is not natural. The past three years the status has been poor, nearly moderate. The total valuation gives Gullmarn a moderate status for the oxygen level in bottom water at Alsbäck. This is based on the increased frequency of hypoxia but historical data show that hypoxia is partly natural in the depth. Alsbäck is the station with the lowest status; at the other stations the status is good or high.

4.4.3 Nutrients

The environmental quality criteria for nutrients are based on winter values (Jan–Feb) in the surface water, 0–10 metre. Data from SHARK are available for Björkholmen and Släggö. The mean values for nutrients in surface water during Jan–Feb 2001 till 2003 are presented in Table 17 to Table 21 together with the colours of the status classes. The environmental quality criteria demand a salinity of >22 PSU and a oxygen saturation level of >100 % to avoid data of algal blooms. The data is analysed based on these conditions.

Table 17. Status assessment according to the environmental quality criteria for phosphate at Björkholmen and Släggö. Mean values from winter values (Jan-Feb) for a three-year period (2001–2003). Data from SHARK for surface water 0–10 m. The colours represent the status. Colour code, see Figure 12.

PHOSPHATE (µmol/l)				
STATION	2001	2002	2003	Mean 2001–2003
Björkholmen	0.75	0.55	0.68	0.66
Släggö	0.68	0.52	0.55	0.59

Table 18. Status assessment according to the environmental quality criteria for ammonia at Björkholmen and Släggö. Mean values from winter values (Jan–Feb) for a three-year period (2001–2003). Data from SHARK for surface water 0–10 m. The colours represent the status. Colour code, see Figure 12.

AMMONIA (µmol/l)				
STATION	2001	2002	2003	Mean 2001–2003
Björkholmen	0.78	0.69	1.30	0.92
Släggö	0.76	0.68	0.85	0.77

Table 19. Status assessment according to the environmental quality criteria for nitrite and nitrate at Björkholmen and Släggö. Mean values from winter values (Jan–Feb) for a three-year period (2001–2003). Data from SHARK for surface water 0–10 m. The colours represent the status. Colour code, see Figure 12.

NITRIT + NITRAT (µmol/l)				
STATION	2001	2002	2003	Mean 2001–2003
Björkholmen	10.01	9.10	10.77	9.96
Släggö	9.81	9.18	8.35	9.11

Table 20. Status assessment according to the environmental quality criteria for total P at Björkholmen and Släggö. Mean values from winter values (Jan–Feb) for a three-year period (2001–2003). Data from SHARK for surface water 0–10 m. The colours represent the status. Colour code, see Figure 12.

TOTAL P (µmol/l)				
STATION	2001	2002	2003	Mean 2001–2003
Björkholmen	0.92	0.71	0.61	0.75
Släggö	0.85	0.69	0.64	0.73

Table 21. Status assessment according to the environmental quality criteria for ammonia at Björkholmen and Släggö. Mean values from winter values (Jan–Feb) for a three-year period (2001–2003). Data from SHARK for surface water 0–10 m. The colours represent the status. Colour code, see Figure 12.

TOTAL N (µmol/l)				
STATION	2001	2002	2003	Mean 2001–2003
Björkholmen	22.37	22.98	24.17	23.17
Släggö	22.76	23.21	18.76	21.57

Comparison with historical data

Data from the 1970's until the 1980's are used to represent historical data. There are some data from the 1960's but these are too unsure to use (Pettersson, pers. comm., 2004). Due to different frequency of measurement and changes of stations in the monitoring programs it is hard to compare data from different years. However when this is done no trends or clear differences are seen. For Släggö, where data exists for almost the entire period, a slightly increasing nitrogen load, mainly inorganic nitrogen, is noticed.

The nutrient model

A model for nutrient modelling has been developed for Gullmarn to simulate changes in nutrient loading and the effect on sedimentation of organic matter (Svensson, unpubl., 2004). The relation between primary production and sedimentation from the photic zone has been analysed by Wassman (Lindahl, 2002). This relation is used in the nutrient model for calculation of the *export production*, that is, the material that falls out of the photic zone through sedimentation. The export production is smaller than the primary production since the primary production is partly decomposed in the photic zone and the nutrients are reused directly for new production. The export production demands oxygen when decomposed in the bottom water and therefore it is an interesting variable in the eutrophication process. The model is based on both biological factors and physical factors. By simulating scenarios with a changed nutrient loading from each source; atmosphere, freshwater and sea, the export production can be predicted.

The model has been used for calculating how large decrease of nutrient load is necessary in order to reach the levels of export production of 1985 and 1960 in Gullmarn. Measurements of primary production in Gullmarn exist from 1985, while the primary production 1960 is calculated from measurements in Skagerrak.

Four scenarios where the nutrient input from the different sources has been decreased are simulated. Table 22 show the reduction of nitrogen and phosphorous in the scenarios.

Table 22. Scenarios to model reductions of nutrients. The target of Scenario 1–3 is a reduction to levels of 1985, while Scenario 4 represents the status 1960 (Data från Svensson, unpubl., 2004 and pers. comm., 2004).

REDUCTION OF NUTRIENTS (%)								
SOURCE	**Scenario 1**		**Scenario 2**		**Scenario 3**		**Scenario 4**	
	P	**N**	**P**	**N**	**P**	**N**	**P**	**N**
Air	–	50 %	–	50 %	–	50 %	–	50 %
Sea	3 %	10 %	0 %	0 %	15 %	30 %	50 %	50 %
Freshwater	3 %	30 %	100 %	100 %	15 %	30 %	75 %	50 %

In year 2000 the export production on the west coast of Sweden was 150 g C/m^2 (Lindahl, 2002). To attain the levels of 1985 the export production needs to decrease by 30 g C/m^2 and to reach the levels of 1960 the decrease has to be 120 g C/m^2. Decreasing the nutrient input can only do this. The results of the simulations are presented in Table 23. More simulations will be done to study the effects that fish and zooplankton have on the sedimentation of detritus.

Table 23. The decrease in export production with the year 1994 as a starting point after simulation of the four scenarios. The reductions of nutrients is modelled according to Table 22. A reduction by 30 g C/m^2 is desired to reach the levels of 1985. Scenario 4 has the target levels of 1960 and the export production needs to decrease by 120 g C/m^2 (Svensson, unpubl., 2004).

DECREASED EXPORT PRODUCTION (g C/m^2 year)				
STATION	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**
Saltkällefjord	14	35	35	156
Färlevfjord	18	41	42	148
Bredungen	17	41	42	161
Skredsvik	17	39	39	176
Kristineberg	12	20	32	121

4.4.4 Assessment of nutrients

When comparing nutrient data from the 1970's, 1980's, 1990's and 2000's no clear trends or differences were found. The concentrations vary a lot both within and between the periods. The lack of conformity of the data also complicates the analysis. Often the winter values, which normally are used for assessment, are missed. There are some problems with analysis of nutrients because of the algal blooms that happens at different times a year. A spring bloom can be early, sometimes already in February, or sometimes later than usual. Correction of the data is made to avoid blooms but this means fewer data to analyse and sometimes all results are missing.

Classification of the status according to the environmental quality criteria is done for Släggö and Björkholmen. Släggö is right at the mouth of the fjord and gets great influence of the sea. The nutrient status is good or high for most of the nutrients except phosphate. Phosphate gives a moderate status and even close to poor at Björkholmen 2001. The mean value of the three years is however nearly good status. The environmental quality criteria for nutrients are not yet set and there are changes of class limits to be expected.

Another aspect that could be interesting for further assessments is the length and frequency of the blooms, which are important questions.

The nutrient model has simulated scenarios with different reductions in nutrient loading at each source. The Scenarios 1–3 strive to attain the export production of 1985 and the Scenario 4 tries to go back to levels of 1960. The reductions in Scenario 1 are not enough to reach the target. Scenario 2 shows a situation without any nutrient input from the rivers and a halved deposition from the atmosphere. This is sufficient at all stations except Kristineberg. Almost the same results are given in Scenario 3 where the nitrogen input is decreased by 30 percent from rivers and sea and the atmospheric deposition is reduced with 50 percent. Scenario 4 reduces the export production by more than 120 g C/m^2 when the nutrient input is greatly reduced.

The Scenario 4 is probably very hard to attain and it is doubted if the runoff of nutrients ever have been so small. This indicates that the model underestimates the effects of a reduced nutrient input. It is maybe possible to reach the nutrient status of 1960 without reducing the input quite as much. Discharges of nutrients to the sea are made from all the countries with run off to the Baltic Sea, Skagerrak and Kattegat. Most likely a reduction of nutrient input has to be done in several countries to ameliorate the water quality.

The nutrient model contains one phytoplankton species and one zooplankton species. Modelling of grazing show that the amount of zooplankton in the water matters in the sedimentation. More zooplankton decreases the sedimentation of detritus, which means that nutrients are transported to the sea as dissolved inorganic nutrients during the winter. An out fishing of herring in the 1960's may have caused high levels of zooplankton and thereby a decreased export production. This suggests that there can be other reasons of changed sedimentation than the eutrophication. Modelling with different grazing pressures will be done to decide how predation affects the export production. In the scenarios already simulated a death rate of 0.1/day is used.

The total assessment of the nutrient status gives Gullmarn a moderate status because of the clear signs of eutrophication, even though the environmental quality criteria give good status.

4.4.5 Secchi depth

Secci depth data has been analysed at Björkholmen, Alsbäck and Släggö for 2001 till 2003. Summer values (Aug–Sep) from SHARK are used to avoid periods with blooms. In this analysis the Secci depth at salinities below 22 PSU have not been corrected, since the low salinities only affect the most upper layer.

Table 24. Classification of the status according to the environmental quality criteria for Secci depth at Björkholmen, Alsbäck and Släggö. Data from SHARK. Mean values from summer data (Aug–Sep) for the three years (2001–2003). The colour represents the status class. Colour code, see Figure 12.

SECCI DEPTH (m)				
STATION	**2001**	**2002**	**2003**	**Mean 2001–2003**
Björkholmen	5.8	3.9	6.5	5.4
Alsbäck	7.8	3.5	6.9	6.0
Släggö	8.9	6.2	9.4	8.2

Comparison with historical data

Secci depth from July and August 1928 are found for some stations in Gullmarn (Kristinebergs Zoologiska Station, 1930). Secci depth has been measured with a gray and a white disc, here the white disc data have been used to correspond to current data. An aquascope is used both historically and today. The stations are not the same as today but comparisons have been made for stations in the same area. Data from July and August 1928, 1970–1979 and 2001–2003 are compared. Table 25 show the results.

Table 25. Comparison of Secci depth from 1928 and 1970's with data of today. The intervals refer to minimum and maximum values for the period. The values of 1928 are from the studies of Gislén (Kristinebergs Zoologiska Station, 1930), the other data are from SHARK.

SECCI DEPTH (m) 1928–2003				
	1928	**1970–1979**	**2001–2003**	**2001–2003 Median**
Inner Gullmarn	11.3*	7.0–14.5	3.0–10.0	6.8
Central Gullmarn	11.5*	5.0–13	2.8–8.9	5.5
Outer Gullmarn	10.3–14.0**	6.7–10	4.7–6.0	6.0

* Only one value measured. ** Only two values measured. (The others are based on 15–30 measurements.)

Figure 18 shows mean Secci values at Alsbäck, Björkholmen and Släggö during August and September 1969, when the measurements began, till 2003.

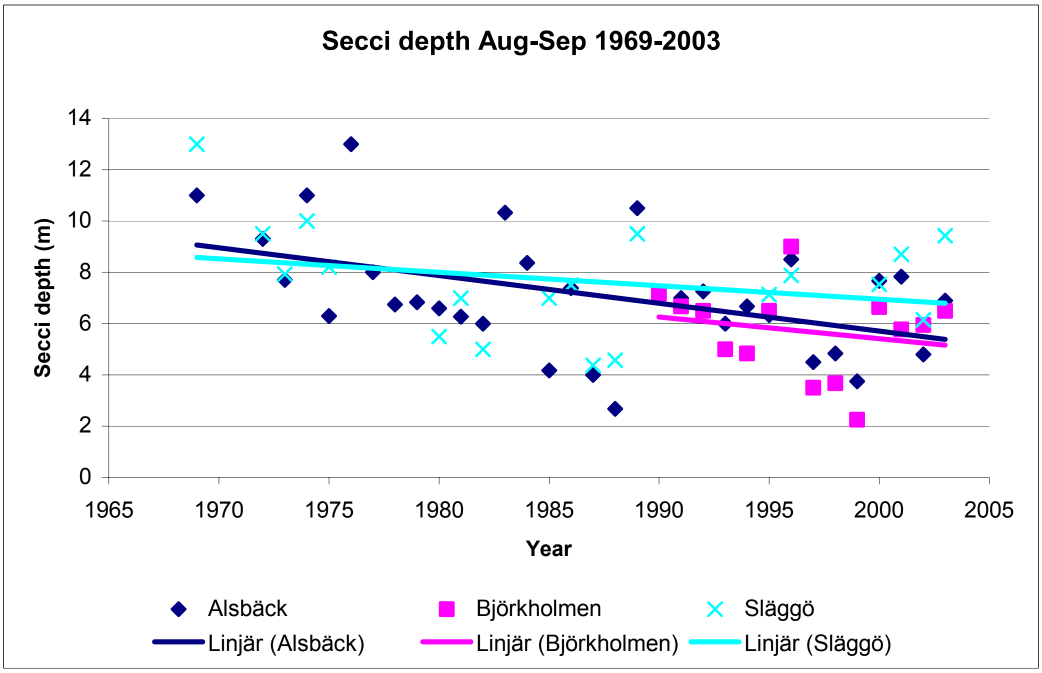

Figure 18. Secci depth trends from the beginning of the measurements in Gullmarn. The points represent mean values of Aug–Sep (1–6 measurements per station and summer). Data from SHARK.

4.4.6 Assessment of Secci depth

The results of the historical comparison of Secci depth from 1928, 1970's and 2000's, show a decreasing trend. Since the primary production has increased and therefore the transparency of the water is decreased, this is not surprising. There are only one or two data from 1928 and this is to be considered. The inner, the central and the outer Gullmarn represent stations in these parts of the fjord, but the exact locations change from year to year. To be able to compare, the stations are aggregated to represent a larger area.

To make an assessment of the status Alsbäck, Björkholmen and Släggö are used. In 2002 the status was poor, close to moderate at Alsbäck and Björkholmen, while good or nearly good the other years. The greatest variations are in the inner parts, which could be caused by an irregular input of organic matter and nutrients from the Örekilsälven. The total assessment of Secci depth for Gullmarn is moderate status.

4.4.7 Pollutants

The Water quality association of the Bohus Coast monitor the pollution situation in Gullmarn and investigations are done every five years (Schelander, pers. comm., 2005). In 2001 investigation of pollutants in blue shell, bladder wrack and sediment. The biological samples were taken at Flatholmen in outer Gullmarn (station 12 a) and at Saltkällefjord (station 12). Since there were not enough blue shells at station 12 they were collected at Gårvik, a station between the Saltkällefjord and the Färlevfjord. Sediment was sampled at Alsbäck (GK2) and these results are analysed according to the old environmental quality criteria by Ingemar Cato at the Geological Survey of Sweden. Some of the results are shown later. The report will also contain the biological investigations of pollutants but this part is not yet finished (Cato, pers. comm., 2005).

Blue shell and bladder wrack were sampled manually. At least 50 blue shells with a shell length of 40–60 mm were sampled at each station. Five to ten sprouts (50–60 mm) of bladder wrack, were sampled from five to ten individual plants.

There are substances other than the prioritised analysed within the monitoring program. These are chosen especially for the Bohus Coast and Gullmarn. Substances known to have been discharged earlier are followed-up to see the development, others are analysed to discover leakage or find substances not supposed to be released. Dioxines (PCDD och PCDF) and PCBs are examples of these.

For the next investigation of the pollution situation (in 2006), it is suggested that more substances should be analysed. The prioritised substances according to the EU are going to be screened for along the Bohus Coast (Schelander, pers. comm., 2005). A presentation in Swedish of all the pollutants in the monitoring program of the Bohus Coast (Miljöföroreningar i havet, 2004) is found on the website of the Water quality association of the Bohus Coast, www.bvvf.com.

Since no new environmental quality criteria regarding pollutants are made, the old ones are used in the assessments. The criteria for pollutants in sediment are not considered to be changed a lot, while the criteria regarding pollutants in biota probably will change more (Pettersson, pers. comm., 2005). The old criteria contain reference values for organic pollutants in fish liver but not for blue shell or bladder wrack. Only the heavy metals have been assessed, see Table 26. The lack of criteria and historical data have made it impossible to assess the organic pollutants.

Table 26. Assessment of the prioritised substances according to the WFD, for which there are environmental quality criteria for blue shell (soft parts), bladder wrack (new sprouts) and sediment (Naturvårdsverket, 1999). The figures give the content in mg or µg/kg dry weight (DW). The colours correspond to the status classes according to Figure 12, grey indicates that criteria is missing. Data from the Water quality association of the Bohus Coast, 2002.

	BLUE SHELL (2001)		BLADDER WRACK (2001)		SEDIMENT (2000)	
PRIORITISED SUBSTANCE	**Outer Gullmarn**	**Inner Gullmarn**	**Outer Gullmarn**	**Inner Gullmarn**	**Alsbäck**	**UoM DW**
Naphthalene	<0.01	0.011	0.032	0.037	0.038	mg/kg
Anthracene	<0.002	<0.002	<0.002	<0.002	0.012	mg/kg
Fluoranthene	0.0031	0.0076	<0.002	<0.002	0.13	mg/kg
Benzo[b]fluoranthene	<0.002	<0.002	<0.002	<0.002	0.335 (b+k)	mg/kg
Benzo[k]fluoranthene	<0.002	<0.002	<0.002	<0.002		mg/kg
3,4-benz[a]pyrene	<0.002	<0.002	<0.002	<0.002	0.076	mg/kg
Indeno[1,2,3-cd]pyrene	<0.002	<0.002	<0.002	<0.002	0.23	mg/kg
Benzo[ghi]perylene	<0.002	<0.002	<0.002	<0.002	0.15	mg/kg
PAH, sum 16 (sum 11 sediment)	<0.01	0.021	0.039	0.05	0.448 /TOC	mg/kg
2,2',4,4'-TeBDE, #47	0.55	0.48	0.21	0.18	0.14	µg/kg
2,2',4,4',6-PnBDE, #100	0.095	0.086	0.077	0.065	<0.1	µg/kg
2,2',4,4',5-PnBDE, #99	0.26	0.32	0.49	0.34	0.18	µg/kg
2,2',4,4',5,6'-HxBDE, #154	<0.05	<0.05	0.068	<0.05	<0.1	µg/kg
2,2',4,4',5,5'-HxBDE, #153	<0.05	<0.05	0.062	<0.05	<0.1	µg/kg
2,2',3,4,4',5'-HxBDE,#138	<0.05	<0.05	<0.05	<0.05	<0.1	µg/kg
DekaBDE, #209	0.16	<0.1	2.4	0.15	0.84	µg/kg
Tributyltin (TBT)	0.19	0.36	<0.05	<0.04	Not analysed	mg/kg
Mercury	0.031	0.035	<0.0092	<0.0098	0.056	mg/kg
Cadmium	0.81	0.74	1.4	0.88	0.13	mg/kg
Lead	0.61	5.2	1.5	1.9	29	mg/kg
Nickel	0.97	0.59	1.8	2.2	21	mg/kg
Zinc	69	55	46	54	70	mg/kg

Comparison with historical data

Figure 19 to Figure 22 show how the pollution situation has developed in Gullmarn regarding heavy metals and organic pollutants.

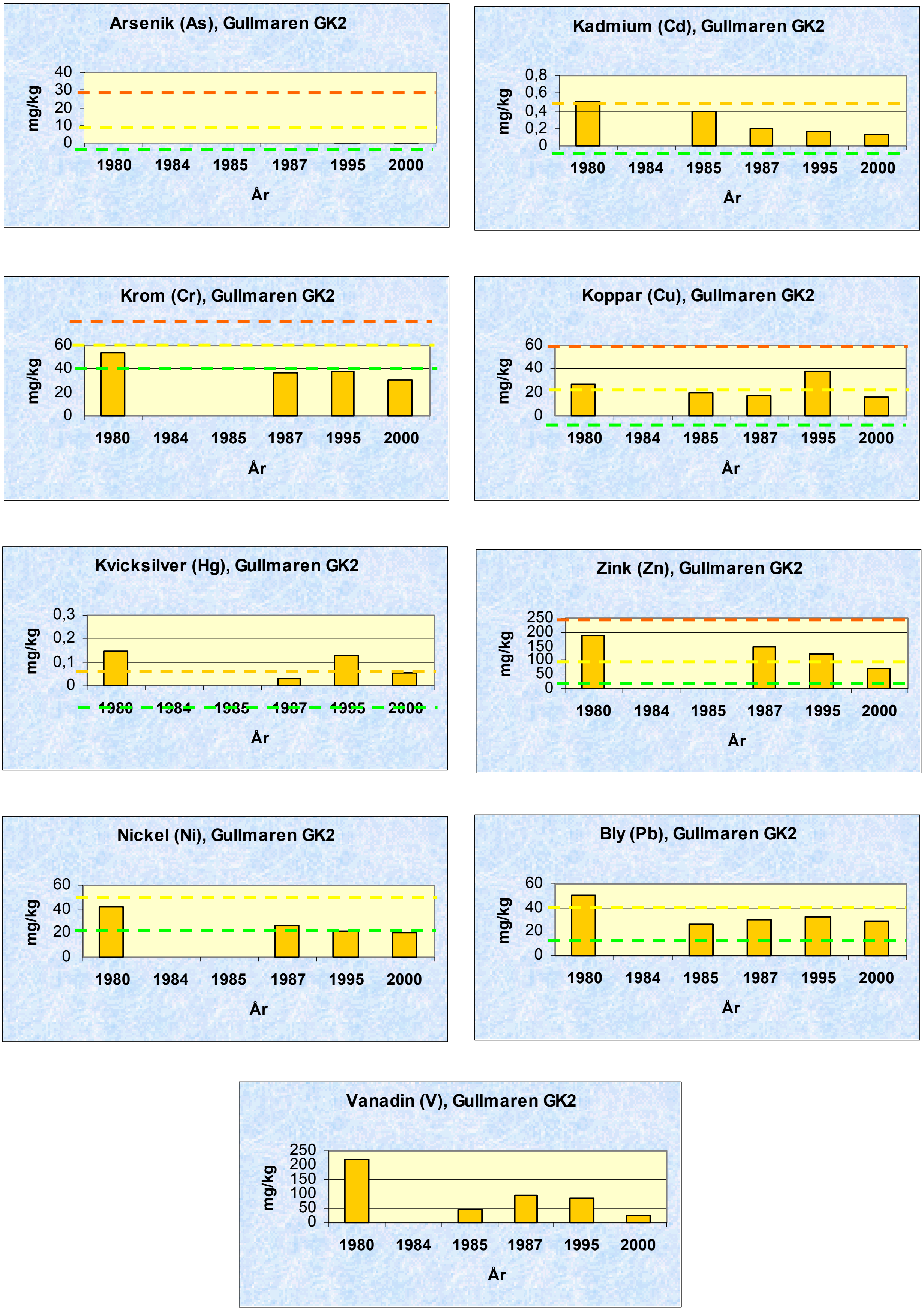

Figure 19. The change of heavy metals in surface sediments between 1980 and 2000 at Alsbäck (GK2) in Gullmarn. The hatched line corresponds to the upper limit of each class in the Swedish environmental quality criteria of sediments of the coast and sea (Naturvårdsverket, 1999) (Cato, unpubl., 2005).

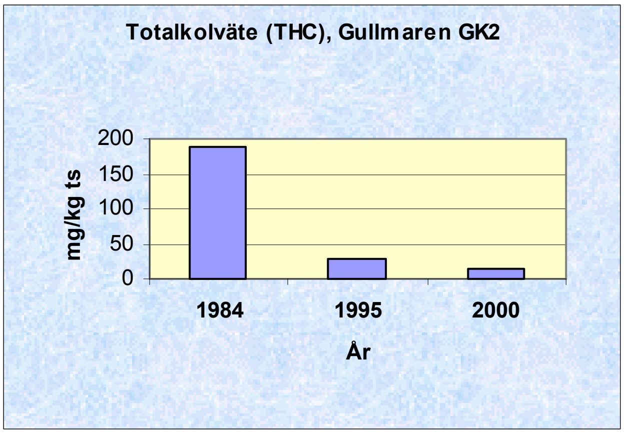

Figure 20. The change of total hydrocarbon in surface sediments between 1984 and 2000 at Alsbäck (GK2) in Gullmarn (Cato, unpubl., 2005).

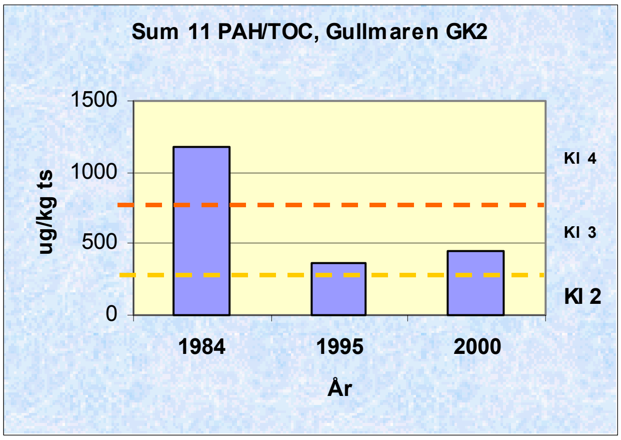

Figure 21. Environmental quality criteria with respect to polycyclic hydrocarbons (sum 11 PAH/TOC) in the surface sediments at Alsbäck (GK2) in Gullmarn. Classification according to the Swedish environmental quality criteria (Naturvårdsverket, 1999) (Cato, unpubl., 2005).

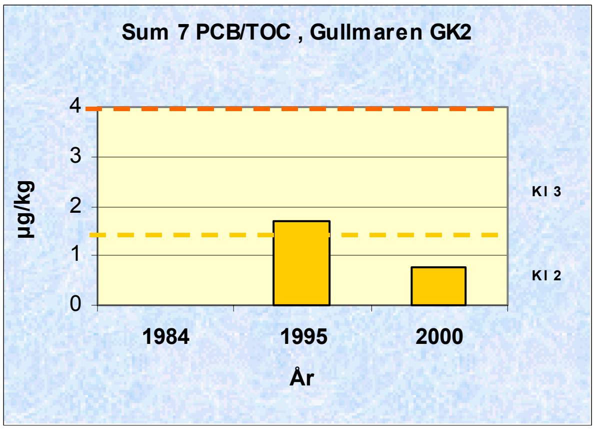

Figure 22. Environmental quality criteria with respect to polychlorinated biphenyls (sum 7 PCB/TOC) in the surface sediments at Alsbäck (GK2) in Gullmarn. Classification according to the Swedish environmental quality criteria (Naturvårdsverket, 1999) (Cato, unpubl., 2005).

Extract translated from the report of Cato (Cato, unpubl., 2005).
The investigation of year 2000 contains sampling of the upper sediment layer (0–1 cm) at the station of 1980, 1987 and 1995, GK2. Assumed that the upper sediment mostly consists of newly sedimented material, the development of the environmental quality in form of substances antropogenically spread to Gullmarn, can be analysed with a trend analysis. In the following summary of the trend analysis the trend is given for each of the factors, substance or compound at the station GK2. The conditions at the station probably show the effect of Lysekil and Fiskebäckskil on the sediment quality.

To decide the load of a chemical or a compound in a coast area or in recipient like Gullmarn, the effect of the natural variations of the substance due to the varying content of organic matter, has to be considered. This can be done by the so-called Gradient method, where the gradient is a measure of the load. This presupposes that the substance/compound show an acceptable and probable positive correlation to the total organic carbon content of the sediment. This has not been possible to decide, because a single station in Gullmarn is too poor as a statistical base.

The content of clay and silt, that is, the grain fractions of <63 µm, are decided with one of the aims of assessing the sedimentation environment at the stations. This together with optical and radiographic analysis and the water content of the sediment show that the station GK2 (the Alsbäck deep) is a potentially good sedimentation environment. The content organic carbon, inorganic carbon (OOC, mainly carbonate carbon) and total carbon (TC) in the sediments are normal for the Bohus Coast. After 1980 the content of organic carbon has been very stable and has only varied within a interval of 1.3 %.

The nitrogen in the sediments is mainly organically bound and show therefore a distribution like the one of organic carbon. The nitrogen content in the sediment at the station increased by 24 % while the C/N-ratio decreased by approximately 34 % between 1980 and 1995. Between 1995 and 2000 the nitrogen content has diminished by 10 % and the C/N-ratio has increased by 12 %. The change after 1995 may indicate that the earlier increase of the proportion sedimentated marine detritus (rich in nitrogen, poor in cellulose) in the area now is beginning to decrease. The reason of the changes of the C/N-ratio until 1995 in Gullmarn, was connected with an eutrophication of the fjord that favour/favoured the production of marine organic matter relative the input of organic matter from land. A correspondent change of the C/N-ratio was earlier stated in the archipelago of Gothenburg between 1966 and 1982, in Brofjorden between 1972 and 1995, and in the area of Stenungsund between 1975 and 1995 (see Cato 1997a). The trend between 1995 and 2000 is however indicating that the eutrophication of the area is diminishing. Observations like this one has during the same time period been done in Göta River and in other areas along the Bohus coast. The total phosphorous content (tot-P) in the fjord is in the upper limit of the interval measured in other recipients along the Bohus coast in 2000. The phosphorous content has increased by 60 % at the station GK2, that is the Alsbäck deep.

The results show that the station GK2 is not polluted regarding cadmium (Cd), chromium (Cr), nickel (Ni), lead (Pb), copper (Cu), mercury (Hg) and polychlorinated biphenyls, that is, the levels are low or at the same level as the background. Regarding arsenic (As) and polyaromatic hydrocarbons GK2 is moderately polluted, meaning that moderate levels are measured at the station.

The result of the trend analysis show a strong significant increase between 1995 and 2000 regarding As, Sn and a moderate increase of tot-N and PAH. The other heavy metals and PCB show a distinct decrease, while TOC and tot-P are unchanged during the same period. In the longer perspective of 1980 till 2000, all the heavy metals and PAH have decreased while tot-P has increased.

4.4.8 Assessment of pollutants

The results indicate an amelioration of the pollution situation in Gullmarn regarding most of the analysed heavy metals and organic compounds. However amelioration is not enough when it comes to organic pollutants because they are antropogenic and not supposed to exist in the environment at all. The assessment of the pollutants is focused on the prioritised substances even though there are many more analysed in Gullmarn.

Where the levels are below the limit of reporting, the status must be said to be good. Worth noting is the OSPAR threshold value of organic pollutants in tissues. The theoretical NOEC value (No Observed Effect Concentration) for TBT (TriButylTin) is 0.006 mg/kg dryweight in blue shells and in Gullmarn there are levels of 0,36 mg TBT/kg measured. This is a lot more even if the safety interval is disregarded. TBT is a antifouling agent used in boat bottom colours to prevent fouling. It is not surprising to find high levels in biota in Gullmarn since there are a lot of larger ships in the area. TBT with its bioaccumulating and persistent properties is a threat against the marine environment and is shown to harm different kinds of shells in very low concentrations.

Among the pesticides on the prioritised list the majority are prohibited to use in Sweden and not measured in Gullmarn.

4.5 Classification of the status for Gullmarn

The ecological status is decided by the biological factors, and the physico-chemical factors have a supportive role in the assessment. Still the groups are closely related. The biological condition is dependent of the water environment, but minor variations of the water environment do not necessarily result in biological effects. However stress due to fluctuations of the physico-chemical factors will lead to a higher sensitivity in the flora- and fauna communities, diminishing biological diversity.

The apparent effects shown in the results are a decreased vertical distribution of macro vegetation and an increased biomass of benthic fauna since early 20th century. The vertical distribution of macro vegetation is dependent of the Secchi depth, which also has diminished during the 20th century according to the results. This is caused by an increased turbidity due to more particles in the water mass. The particles consist of primary production and other organic matter. The primary production has increased in the fjord since the 1950´s (Lindahl, 2002), probably due to a greater supply of nutrients. A larger load of nutrients is most likely the cause of increased biomass of benthic fauna as well. Data regarding nutrients are available from the 1970´s and forward. The material is too incomplete in order to use for comparisons between nutrient load today and in the early 1970´s. A slight increase of inorganic nitrogen, mainly nitrate, is observed at one station, but it is difficult to draw any general conclusions.

The cause of the increased nutrient supply is not clear. Several contributing factors are likely. During the 20th century the nutrient load from agriculture has increased due to more intensive use of fertilizers. Larger field areas and a smaller amount of wetlands and agricultural protection zones have resulted in an increased leakage of nutrients and organic matter to surrounding watercourses. Thus, the agricultural areas surrounding Örekilsälven might be a part of the reason of increased supply of nutrients to Gullmarn. Nutrients might also be transported to the fjord by upwelling, when deeper, nutrient-rich water masses are mixed with more shallow waters. This has also been observed to relate to climatological effects by the North Atlantic Oscillation (NAO) (Björk & Nordberg, 2002, Lindahl, 1998 m.fl.). NAO give rise to more south-easterly and south-westerly winds which bring nutrient-rich water from Kattegat and the North Sea/Skagerrak towards the Swedish west coast. The increase of primary production in Gullmarn since 1985 has been shown to correlate with variations in NAO-index. This seems likely since the primary production has increased, even though the supply of phosphate to Skagerrak/Kattegat has diminished since 1985 and the supply of nitrogen has decreased or is unchanged (Lindahl, 2002).

The nutrient-model that has been developed for Gullmarn predicts the effects of decreasing nutrient supply from different sources. This gives valuable information about where measures are most effective, which might be very helpful when establishing measurement plans. The modelling of Gullmarn indicates that the biggest impact is from the sea. However a decrease of nutrient supply from local inflows will give great effect in inner and central parts of the fjord. The possibility to diminish the nutrient supply from different sources varies. A drastic decrease of the supply from the sea is not realistic, even though this would give the greatest effect. In order to do so cooperation between all countries with outflows to the surrounding sea is needed, with extensive measures from all countries.

The exchange of water in Gullmarn is dependent of dominating winds. The exchange coincides with north-easterly winds. South-westerly winds are becoming more common, due to NAO, resulting in a poorer water exchange in the fjord (Nordberg et al., 2000). The worsened oxygen condition in the fjord might thus be caused by climatological changes. The significant increase of primary production, leading to an increased demand of oxygen due to increased decomposition, makes eutrophication a likely contributing factor to the more frequent hypoxia as well. There are contradicting opinions of whether there the exchange correlates with the climatological effects. Arneborg (2004) states that no correlation with NAO can be seen, based on modelling of water exchange mechanisms in Gullmarn.

A more frequent deficiency of oxygen, with low oxygen levels higher up in the water column as well as longer periods of hypoxia, is to be seen as an important factor in the assessment of the ecological status in Gullmarn. The benthic fauna is apparently affected, and the decomposition of organic matter is deteriorated. The unique faunal community of Gullmarn, with several species otherwise only found at great depths in the sea, is threatened due to changes in the bottom environment.

To be able to assess the prioritised substances analyses of all substances have to be made. This will be done at the next investigation in Gullmarn 2006. Since no classifications are done there is hard to assess the pollution situation. Something to mention is that there exist organic pollutants in biota and sediment in Gullmarn and that is not satisfactory. If no biological effects are seen and the good status can be guaranteed Gullmarn could still have good status.

Classification according to the WFD should be based on the biological factors, following the principle of “One out, all out”, meaning that the biological factor indicating the lowest ecological status determines the final status. The final status of Gullmarn is thus decided as moderate since both benthic invertebrates and phytoplankton have been assessed to this status class. The results according to the SEPA´s environmental quality criteria give moderate status close to the border of good, or good status close to the border of moderate, regarding all the biological factors. When assessing historical data the definitions in the WFD regarding good and moderate status have been used. However it is not easy to interpret the results by these definitions, or decide for example the border between *slight disturbance* and *moderate disturbance*, without expert knowledge. The total classification of each factor is based on a subjective valuation of the material used for respective assessment. The SEPA´s environmental quality criteria are set for larger areas, while the historical comparisons that have been made are specific for the Gullmarn area. Oxygen in bottom water was classified as poor according to the environmental quality criteria, but considering the natural variations in

Gullmarn due to limited water exchange, the deviation from the reference condition is considered less significant. In addition, the assessment is based only on the deepest part, in shallower areas of the fjord the status of bottom water is classified as good or high. The physico-chemical factors are most important when the biological factors are decided as good or high and will not affect the final status in this case. The biological and physico-chemical factors mostly show the same status in the case of Gullmarn.

Table 27. Classification of status according to the WFD. Classification of each factor by different methods is assessed to a total status. The final status is set by the biological factor showing the lowest status. (+) and (–) signify that the factor are close to the border to a higher or lower status class. Colour code, see Figure 12.

	SEPA Environmental quality criteria	Historical data	Total status	Final status
Macro vegetation	EQR calculated for St. Bornö. (–)	Most species present. Vertical extension decreased. (–)		
Benthic invertebrates	In Alsbäck fluctuations following oxygen concentration. Highest status at station of medium depth. (+)	Significant increase of biomass since 1920´s, greatest in the inner parts.		
Phyto-plankton	Chlorophyll in outer part better. Species composition at KMF good status. (+)	Significant increase of primary production since 1985.		
Nutrients	Phosphate worse than other nutrients. Classification borders unsure.	Fivefold increase of export production since 1960´s.	Obvious eutrophication	
Oxygen	(+)	More frequent hypoxia in Alsbäck. Low levels of oxygen in early 20th century as well.		
Secchi depth	(–)	Decline since 1920´s.		
Pollutants				

5. Conclusions

- It is difficult to find a reference condition and assess the deviation from this condition in an objective way. Comparing with historical data is the best method for assessment. When old data are missing or are scarce additional methods is necessary. An intercalibration is important to make the assessment objective.

- An increased biomass of the benthic fauna, a decreased vertical distribution of macro vegetation and an increased oxygen deficiency in the deepest part indicates that Gullmarn is subject of eutrophication.

- The reasons of the eutrophication are probably mainly an increased nutrient load from the sea but the inner parts of Gullmarn are locally affected of the nutrient load from land.

- The ecological status of Gullmarn is assessed moderate status in this characterization.

- The work according to the WFD demands great resources and monitoring programs. The local Water Quality Associations will be useful assets in the future work.

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