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Collection and interpretation of Sediment Profile Images (SPI) using the Benthic Habitat Quality (BHQ) index and successional models

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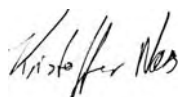| Collaborates | |
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Abstract

Sediment profile imaging (SPI) has a history back to the early 70's, however, it was during the 90's with the introduction of digital cameras and image analysis softwares that the use of the method expands. This could be tracked in the publication rate of scientific papers where SPI have been used.

The sediment profile camera work as an upside-down periscope penetrating the sediment surface and looking horizontally into the sediment. The image is about 17 cm wide and 26 cm high, with a typical penetration depth of 15 cm. Sediment profile image analysis according to the benthic habitat quality index (BHQ) is based on sediment surface structures, subsurface structures and the measurement of the apparent redox potential discontinuity (RPD).

This paper focuses on the interpretation of features observed in SPIs and the analysis of SPIs according to the BHQ-index. It also shows how the image analysis could be correlated to successional models and benthic classification according to European Union Water Framework Directive (WFD).

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# Collection and interpretation of Sediment Profile Images (SPI) using the Benthic Habitat Quality (BHQ) index and successional models

# Preface

This paper was promoted by the Sediment Profile Imaging Workshop U.S. EPA, Atlantic Ecology Division hold in December 6 - 8, 2005 Narragansett, Rhode Island, USA. Financial support was partly given by the NIVA internal research program O-25072.

Oslo, 15 Mars, 2006

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# Contents

# Summary

Sediment profile imaging (SPI) has a history back to the early 70's. However, it was during the 90's with the introduction of digital cameras and image analysis softwares that the use of this method expanded. This could be tracked in the publication rates of scientific papers where SPI have been used.

The sediment profile camera is working as an upside-down periscope penetrating the sediment surface and looking horizontally into the sediment. The image is about 17 cm wide and 26 cm high, with a typical penetration depth of 15 cm. Sediment profile image analysis according to the benthic habitat quality (BHQ) index is divided in sediment surface structures (fecal pellets, tubes, pits and mounds), subsurface structures (infaunal structures, burrows and oxic voids) and the measurement of the apparent redox potential discontinuity (RPD).

This paper focuses on the interpretation of features observed in SPIs and the analysis of SPIs according to the BHQ-index. It will also show how the image analysis could be correlated to successional models and benthic classification according to European Union Water Framework Directive (WFD). The statistical analyse of about 3000 images from Swedish waters and 1000 images from Norwegian waters indicate a shift in the distribution of the BHQ index at 20m water depth.

# Sammendrag

Sediment profils fotografering (SPI) har en historie som går tilbaks til 1970-talet, men teknikkens gjennombrudd kom på 90-talet etter introduksjonen av digital kamerat og programvara for bilde analyse. Dette kan likeså spores i publikasjonstakten av vitenskapelige arbeid med SPI.

SPI har blitt benyttet for å analysere og studere effekter på bløtbunn av oksygenmangel, oppmudring og dumping arbeid, fisk- og muslingoppdrettsanlegg, trålfiske, spredning av borekaks. Teknikken kan også med fordel anvendes for å kartere habitat og i mer generelle overvakningsprogram der en mer arealdekkende metode etterlyses.
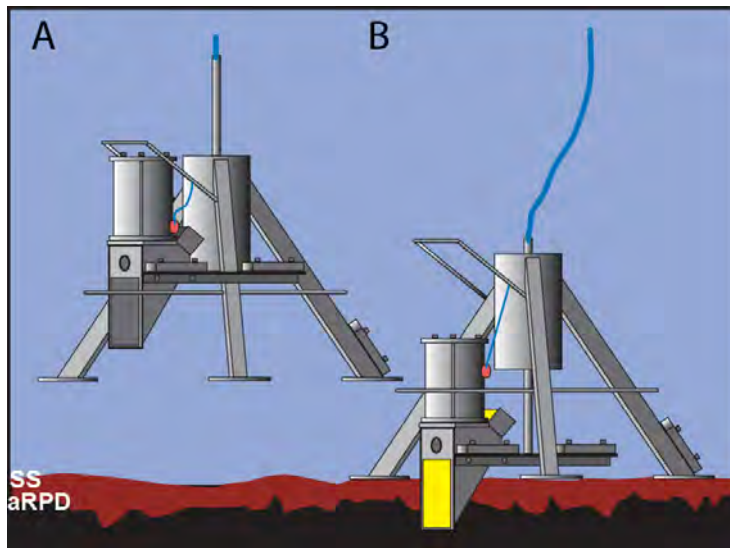


*Prinsippskisse på et sediment profile kamera. Til høyre syns hvordan prismat sunket ner i sedimentet for bildet blitt tatt.*

Teknikken kan sammenliknes med ett opp og nedvent periskop som ser horisontal inn i de øverste desimeterne av sedimentet. Bildene med fysisk størrelse på 17 cm bred og 26 cm høy tas *in situ* og ødelegger ikke sedimentet. Resultatet er digitale fotografier med detaljer både av strukturer i sedimentet og farger av overflatesedimentet. Fra bildene kan en miljøindeks beregnes utefra strukturer på sedimentoverflaten (børstemarkrør, fødegrop og fødehaug), strukturer under sedimentoverflaten (bløtbunnfauna, faunagang og oksidert tomrom i sedimentet) og redox betingelser i sedimentet (aRPD). Gjennom å summere verdier for disse strukturene beregnes en miljøkvalitetsindeks (Benthic Habitat Quality index; BHQ indeks), som varierer mellom 0 og 15. Dette indekset kan siden sammenliknes med faunas suksesjonsstadium etter Pearson & Rosenberg klassiske suksesjonsmodell.

Denne rapporten vil fokusere på tolkning av strukturer observert i bildene og analyser av SPI bildene i henhold til BHQ indeksen. Den vil også vise hvordan analysen kan korreleres til suksesjonsmodeller og klassifisering av bløtbunn i henhold til EUs vanndirektiv. Siden det meste av utviklingsarbeidet har blitt utført langs svenskekysten, har en sammenligning mellom ca. 3000 bilder fra svenske Kattegat og Skagerrakkysten og 1000 bilder fra norske Skagerrak og Nordsjøkysten blitt analysert. Den statistiske analysen viser en forandring i distribusjon av BHQ indeksen ved et vanndyp på ca. 20 meter, hvilket skyldes fysisk stress (salinitet, bølgeeksponering etc.), i de øvre vannlag.
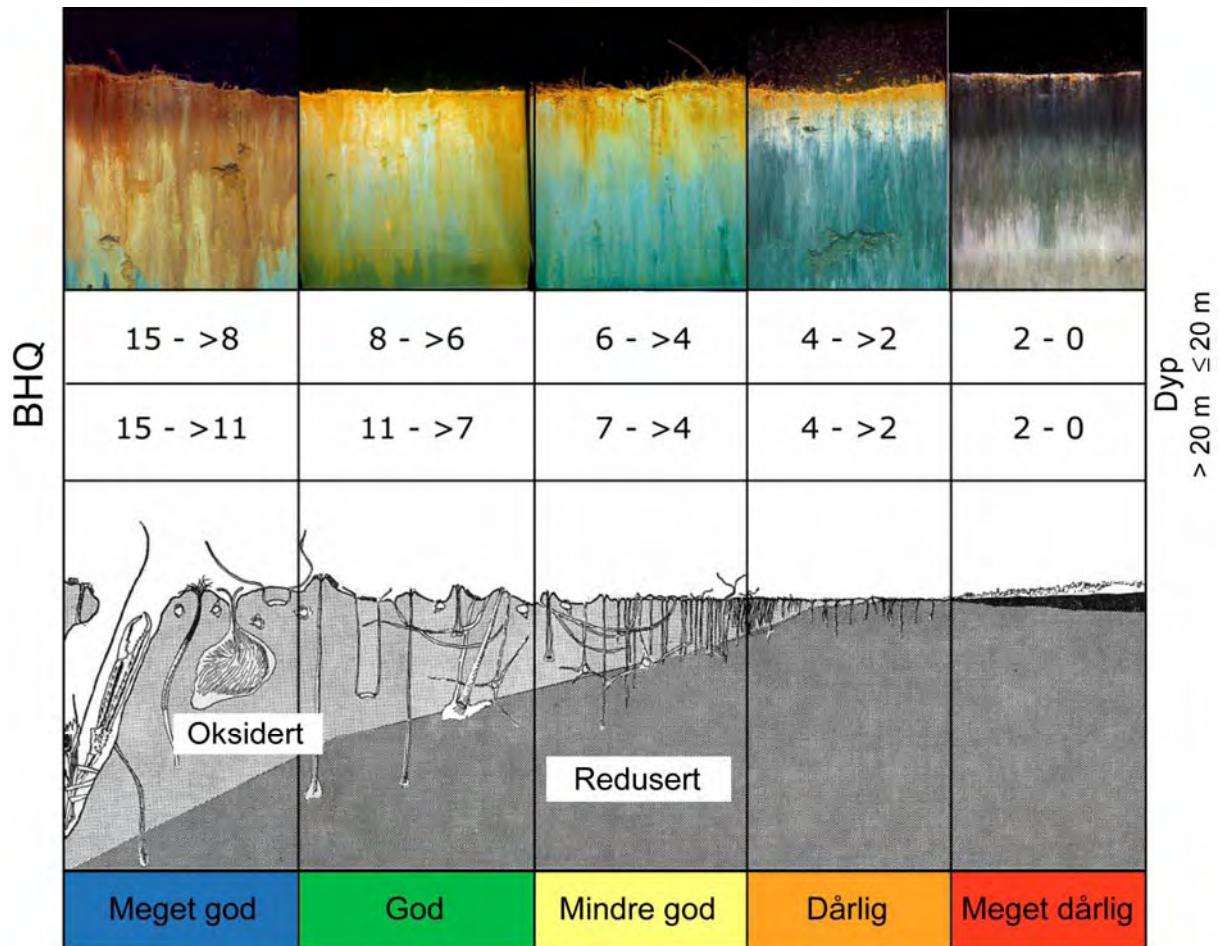


Figuren over viser en modell av endringer i faunatype fra upåvirkede bunnsedimenter med en rik, dyptgravende fauna til en gruntlevende, fattig fauna i påvirkede områder. Sedimentprofilebilde er vist i toppen av figuren, der brunt farget sediment indikerer oksidert bioturberte sediment og sorte reduserte forhold. BHQ-miljøkvalitet indeks for vanndyp ≤ 20 meter og > 20 m er i henhold til EUs vanndirektiv.

Introduction
Since the pioneering work by Rhoads and Cande (1971) sediment profile imaging (SPI) has proven to be useful to demonstrate benthic succession according to stress and disturbance gradients in marine benthic environments. Different approaches have been developed to assign sediment profile images to different successional stages. In this paper we focus on the interpretation of different features observed in sediment profile images and how these features could be used to assign a sediment profile image a successional stage by using the calculation of the benthic habitat quality index.

The benthic habitat quality (BHQ) index was developed in 1997 using sediment profile images collected in oxygen stressed fjords on the Swedish west coast (Nilsson and Rosenberg 1997). A majority of the use of the index have focused on areas well known to be temporally affected by low oxygen. However, BHQ have also been used in studies around mussel and fish farms, trawling experiments, dredging and dumping studies, habitat mapping, mapping drill cuttings around oil platforms, and benthic monitoring programs.

This paper is written to be a guideline in the interpretation of different features in sediment profile image and the calculation of the BHQ index. It will also show how the analysis of sediment profile images could be used to classify benthic habitats into different successional stages (Nilsson and Rosenberg 1997 and 2000, Rosenberg et al. 2004.

# 1. Sediment profile imaging (SPI)

After the first described sediment profile image camera by Rhoads and Cande (1971), most equipment have shown a similar design with a vertical mounted camera above a 45 degree prism penetrating the sediment surface. The prism is mounted and sliding on a frame standing on the sediment surface. However, there are some constructions with smaller angle prism and equipments with flat bed scanners designed to increase the penetration depth in coarser sediment. In this paper we focus on the analysis of images and briefly describe the principle of the 'standard' sediment profile camera. The largest step in the progress in sediment profile imaging and image analysis was the introduction of the digital camera and image software in the later part of the 90's.

The prism of the sediment profile camera work as an upside-down periscope penetrating the sediment surface and pushing the underlying sediment backwards (**Figure 1**). The front of the prism has then a vertical view of the top sediment layer to a depth down to 26 cm depending on the sediment conditions and equipment. The camera is trigged (often time delayed) by the sliding movement of the prism and camera against the frame standing on the sediment surface. After the image is taken the equipment can be retrieved to the ship or additional replicates can be taken by lifting the frame a couple of meters above the sediment and then lowered again.

Today with most digital camera equipments it is possible to download and store the images directly after retrieving the equipment on the ship.
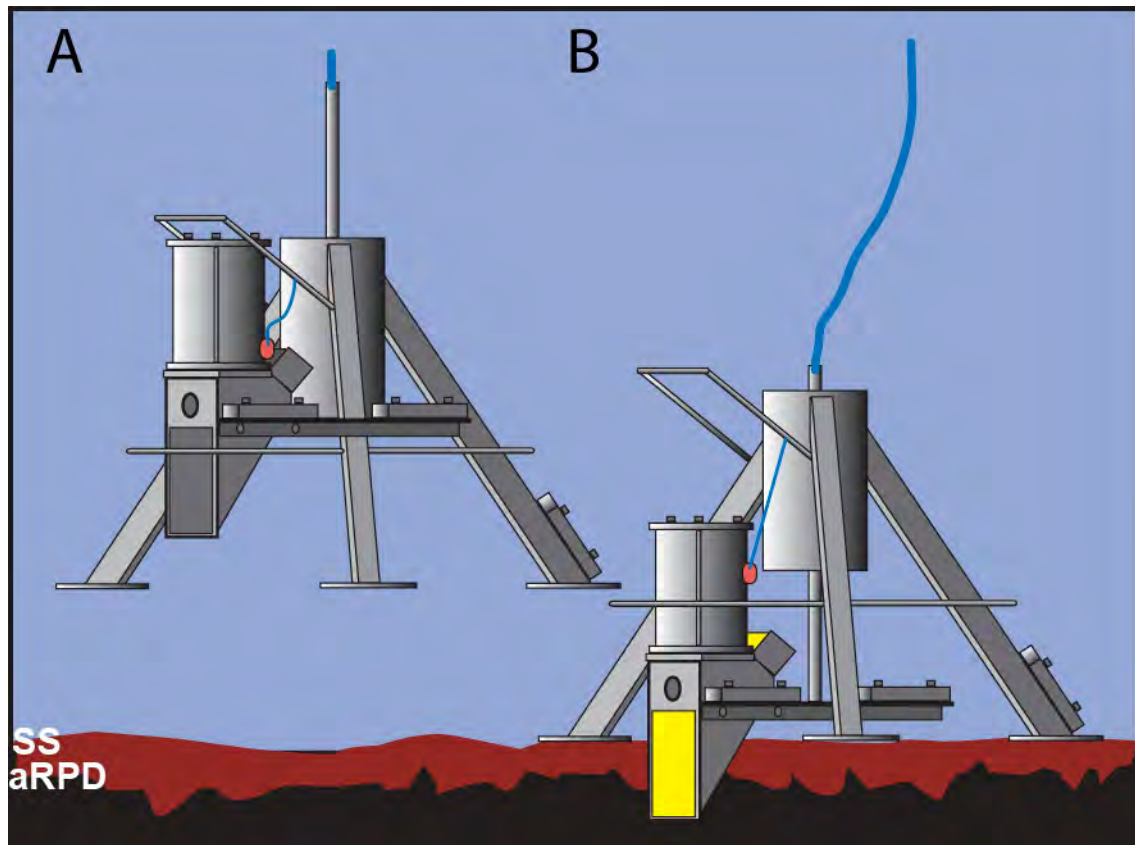


**Figure 1.** Diagram of a sediment profile camera in operation. (A) The sediment profile camera just above the sediment surface. (B) The prism has penetrated the sediment surface and the image is exposed. Sediment surface (SS) and the apparent redox potential discontinuity (aRPD) is marked in the line drawing.

# 2. Calculation of the Benthic Habitat Quality (BHQ) index

This chapter describes the calculation of the BHQ-index with a few more detailed explanations of the different features than in the original paper (Nilsson and Rosenberg 1997). However, we have also included some features that were not described in the original paper. The scoring of these features is included in the originally described features and do not affect the sum of the calculation or the interpretation of the successional model. Features with changes are marked with an * in the table, and with *italic* in the explanatory text below.

Calculation of the Benthic Habitat Quality (BHQ) index from the sediment profile images (**Table 1**). BHQ = Σ A + Σ B + C, where A is surface structures, B subsurface structures, and C mean sediment depth of the apparent redox potential discontinuity (RPD). The BHQ values vary between 0 and 15.

**Table 1**. Calculation of the Benthic Habitat Quality (BHQ) index from the sediment profile images. Numbers at right are point values assigned to features. For detailed description and example images of features see below.

| A: Surface structures | | | |
|---|---|---|---|
| | | Fecal pellets | 1 |
| | | Tubes ≤ 2 mm in diameter and ≤ 30 mm in length* | 1 |
| | Or | Tubes > 2 mm in diameter or > 30 mm in length or brittle star arm* | 2 |
| | | Pit or mound* | 2 |
| **B: Subsurface structures** | | | |
| | | Infauna* | 1 |
| | | Burrows # 1 - 3 | 1 |
| | Or | Burrows # > 3 | 2 |
| | | Oxic void at ≤ 5 cm depth | 1 |
| | Or | Oxic void at > 5 cm depth | 2 |
| **C: Mean depth of apparent RPD*** | | 0 cm | 0 |
| | | 0.1 - 1.0 cm | 1 |
| | | 1.1 - 2.0 cm | 2 |
| | | 2.1 - 3.5 cm | 3 |
| | | 3.6 - 5.0 cm | 4 |
| | | > 5 cm | 5 |

*Features with new definitions, see description below

**A: Surface structures**
**Fecal pellets.** A 'worked' surface with repackaged sediment grains. Pellets with distinct form and size on the sediment surface. Distinct casts or pellet mounds.

**Tubes ≤ 2 mm in diameter.** Small tubes at random or frequent (mat). Size - diameter less than 2 mm *or with a length less than 30 mm over the sediment surface*. Any tube like feature appearing alive of this size is included.

**Tubes > 2 mm in diameter.** Large tubes at random or frequent (normally not making a mat on the surface). Size - diameter larger than 2 mm at any point *or with a length greater than 30 mm over the*

*sediment surface.* Any tube like feature appearing alive of this size is included, *including brittle star arms protruding the sediment surface.*

**Pit.** Funnel shaped at the sediment surface, below it could continue as a water filled burrow that may end in an oxic void (> 1 cm wide at lest somewhere in the feature). If the pit is connected to a void – the feature scores only as a feeding pit.

**Mound.** A larger (> 2 cm wide) oxic mound often associated with fecal pellets and an increased aRPD underneath. If the mound is connected to a void – the feature scores only as a mound.

**B: Subsurface structures**

**Infauna.** A distinct structure (shape and/or colour difference) of macrofauna *larger than 1 mm in diameter in at least one direction. Other infaunal species than brittle stars (arms) or polychaetes and crustaceans (tubes) protruding the sediment surface (e.g. sea anemones or the top of sea urchins)*

**Burrow.** A distinct halo often vertical of 'more oxic' sediment then the surrounding. A lumen surrounded by oxic sediment. Only an infaunal structure without surrounding oxic sediment is not valid as a burrow.

**Oxic void.** A pore water filled area below the sediment surface surrounded by or with oxic sediment with no visual connection to the sediment surface.

**C: Mean depth of apparent RPD**

The mean depth (area/image width) of the reworked oxidized layer defined by the colour shift from brown/yellow to grey/black. Here it is important that the underlying sediment layer not is contrast to yellow. *Just an oxidized thin layer of a spring bloom and/or fecal pellets will just score for fecal (se above) not as measured RPD > 0.1 cm, independent of the thickness of such a layer.*

# 3. Figures and images of features

## 3.1 Line drawings

**Figure 2.** Outlined line drawings of the described features 'feeding pit ', 'mound', 'oxic void' and 'burrow' as used in the BHQ index.
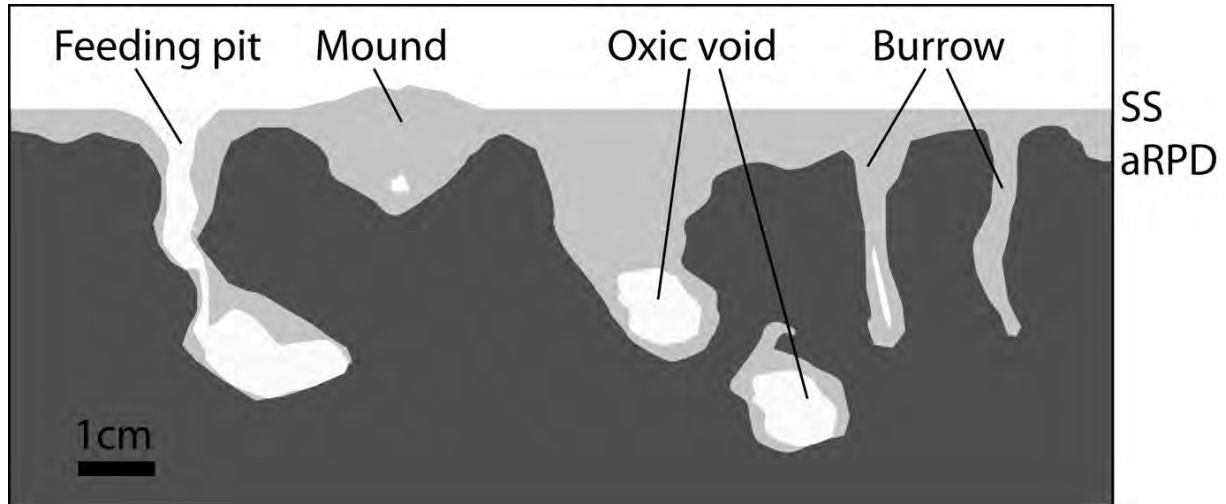


**Figure 2.** Line drawing of different features. White = water or pore water, light grey = oxic sediment and dark grey = anoxic sediment. Pits and mounds have often a void in connection to the feature – the total feature will just score 2 points for 'Mound' and not for oxic void in such cases.

The following SPI images should be used as examples of a guideline of 'images observed features'; different appearances and colours could be observed in different areas, depending on used camera equipment and how the colours are enhanced. All images shown below have been enhanced. In most of the images the features are pointed out with a line or as enclosed areas. The scoring assigned to each feature (BHQ; =) is done according to this papers updated table and explanations of described features.

## 3.2 Images – Fecal



No fecal pellets (sediment reduced). (BHQ; Fecal pellets = 0)



Fecal pellets (aRPD = 0 cm). (BHQ; Fecal pellets = 1)



A 'reworked' surface with repackaged sediment grains. (BHQ; Fecal pellets = 1)

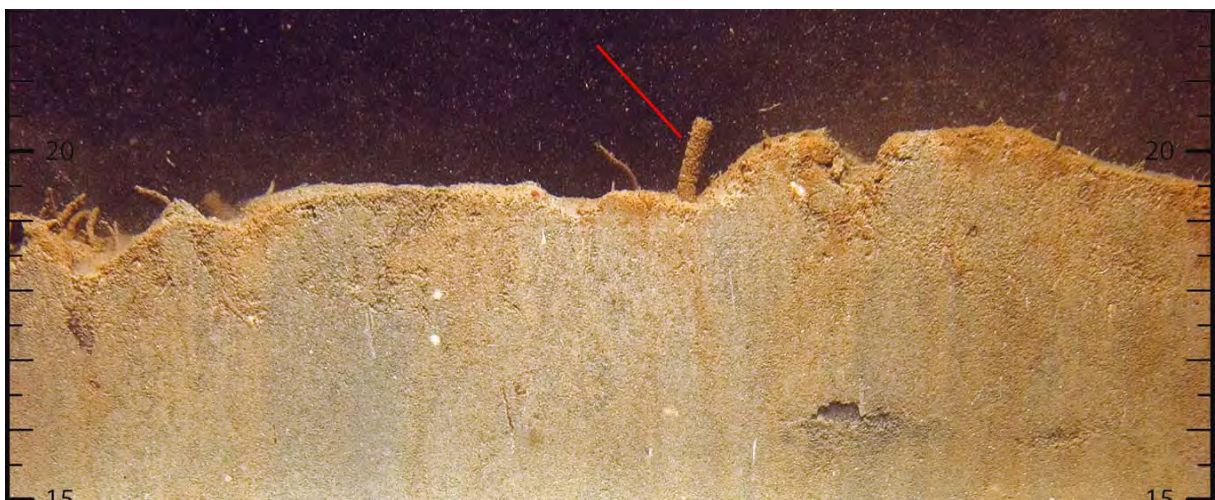## 3.3 Images – Tubes
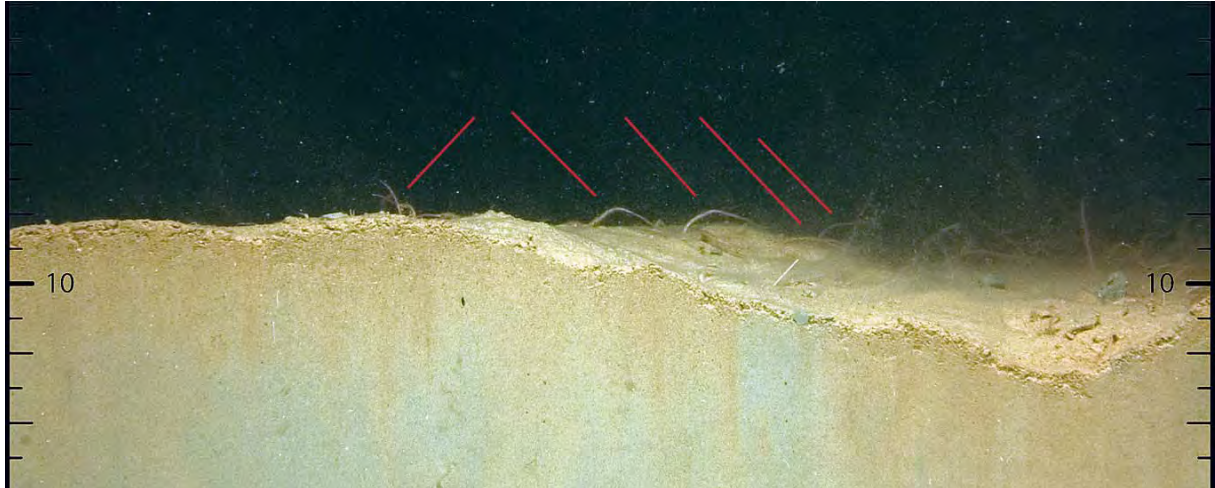


Tubes ≤ 2 mm in diameter or length < 30 mm over the sediment surface. (BHQ; Tubes = 1)



Tubes > 2 mm in diameter or length ≥ 30 mm over the sediment surface. (BHQ; Tubes = 2)



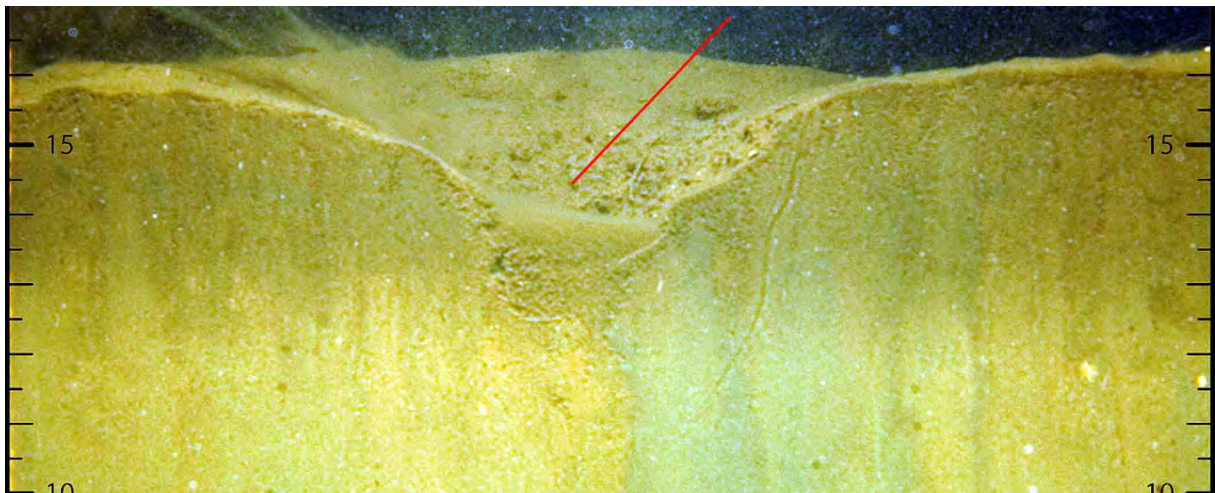Tubes ≥ 2 mm in diameter or length > 30 mm over the sediment surface. (BHQ; Tubes = 2)

Brittle star arms. (BHQ; Tubes = 2)

## 3.4 Images – Feeding pit or mound



Large (> 2 cm) oxic mound. (BHQ; Pit or mound = 2)



Typical large (> 2 cm) pit with 'large water filled burrow'. (BHQ; Pit or mound = 2)
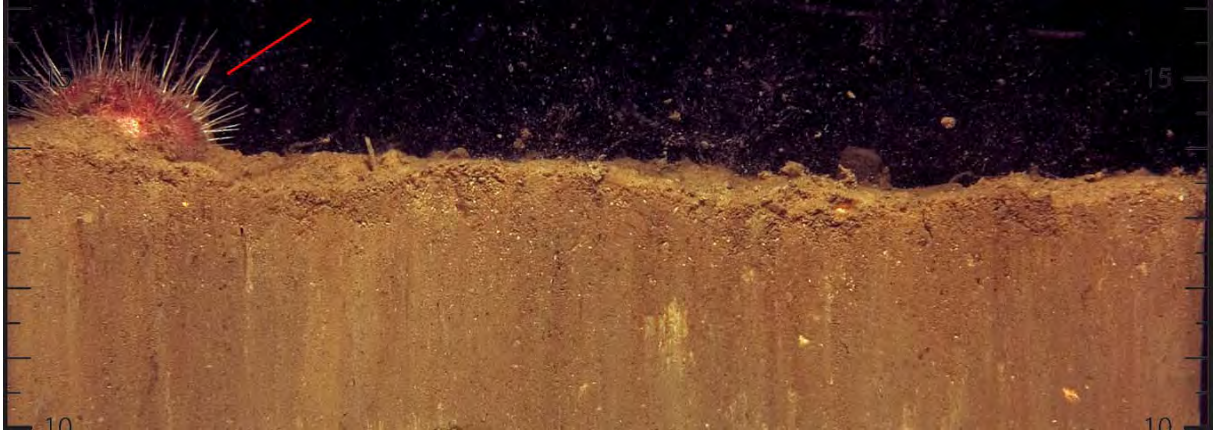
Pit with associated 'oxic void' connected to the sediment surface. Feature larger than 2 cm. The feature will not score for oxic void (BHQ; Pit or mound = 2)
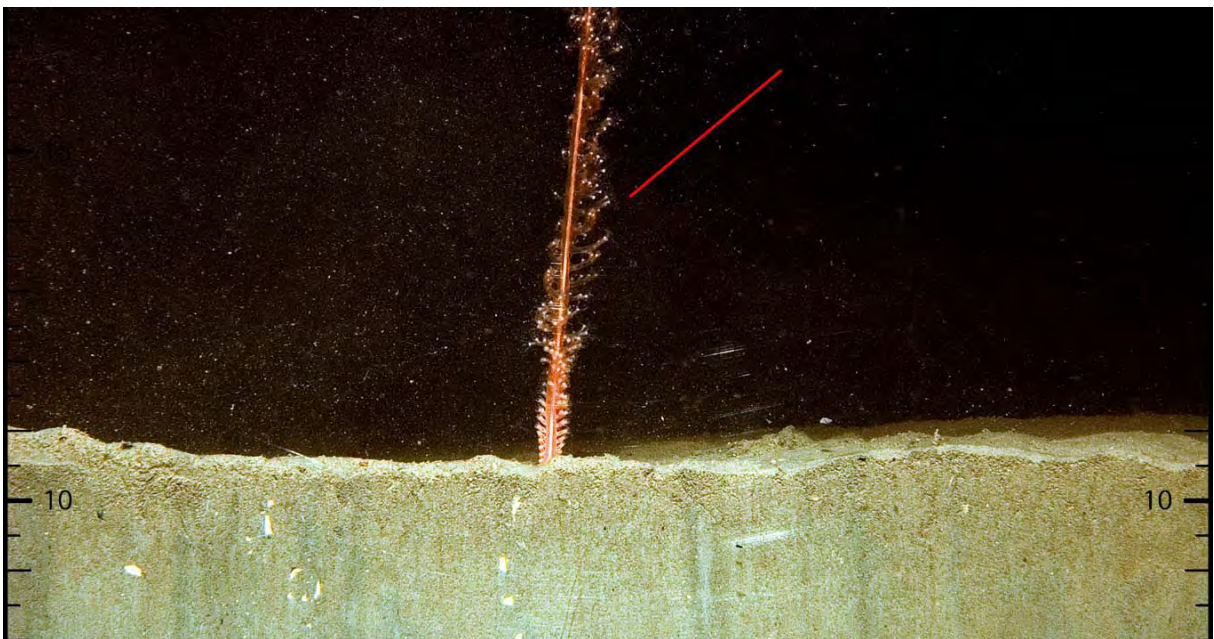
## 3.5 Images – Infauna



Infaunal structure (which not will be covered by a ø 1 mm 'brush tool'). Compare the size of the infauna structure with the red circle (ø 1 mm). (BHQ; Infauna = 1)

Normally infauna species (sea urchin) observed at the sediment surface. (BHQ; Infauna = 1)
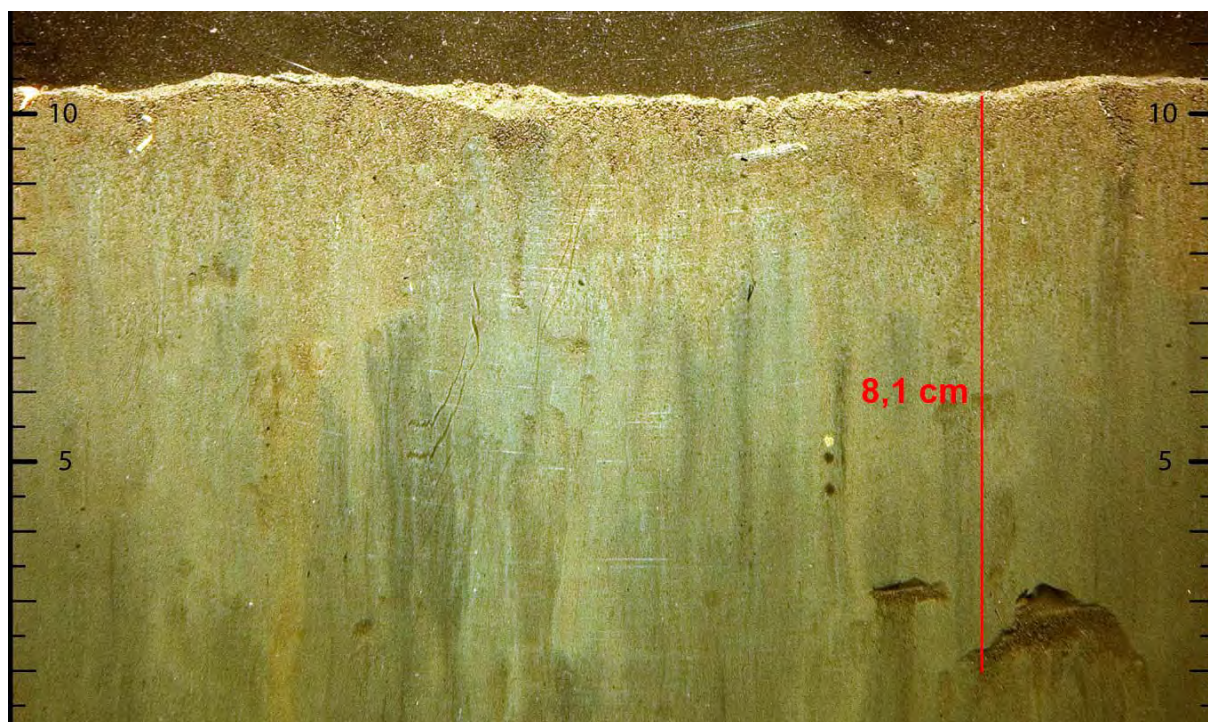


Sessile benthic fauna (sea pen) observed above the sediment surface. (BHQ; Infauna = 1)

## 3.6 Images – Burrow



Number of burrows counted to 10 (green arrows). However, it is easier and slightly more conservative to count the burrow after marking the aRPD (se below). (BHQ; Burrow = 2)
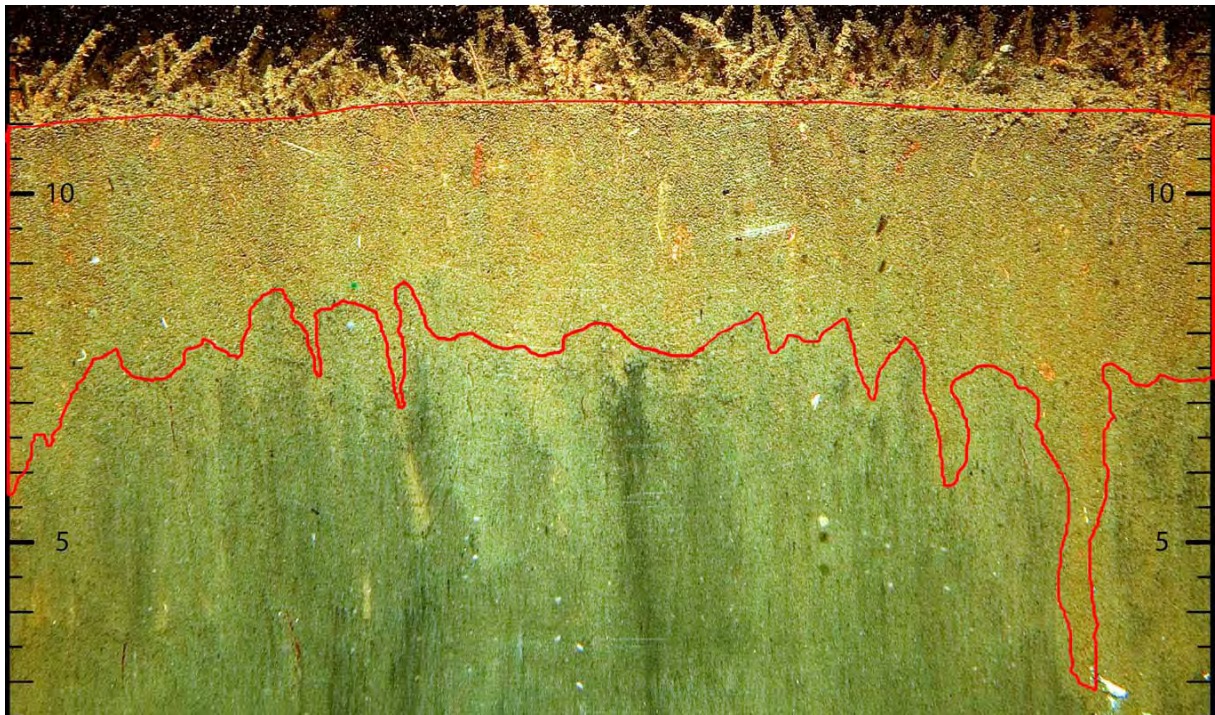
## 3.7 Images – Void



Maximal depth from the sediment surface to the lower part of an oxic void = 8.1 cm. (BHQ; Oxic void = 2)
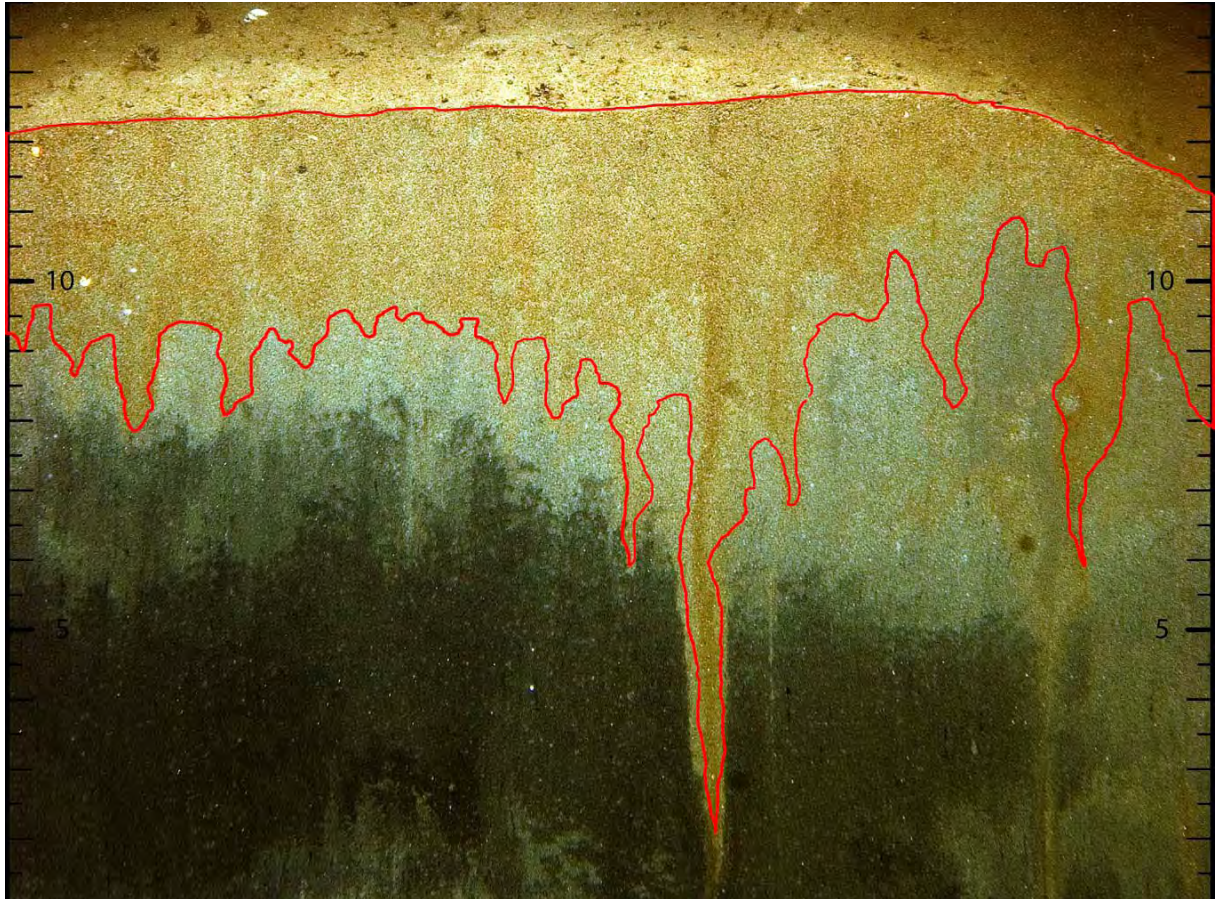
## 3.8 Images – aRPD



Measurement of aRPD. Enclosed aRPD (red area) is 77 cm$^2$ and mean depth of aRPD is 4.5 cm.
(BHQ; aRPD = 4)



Measurement of aRPD. Enclosed aRPD (red area) is 64 cm$^2$ and mean depth of aRPD is 3.7 cm.
(BHQ; aRPD = 4)

Measurement of aRPD. Enclosed aRPD (red area) is 63 cm$^2$ and mean depth of aRPD is 3.6 cm. (BHQ; aRPD = 4)

# 4. Successional stages

## 4.1 Successional stages according to Nilsson and Rosenberg (1997, 2000)

The obtained value of the BHQ index is assigned to one of the serial stages in a successional model in **Figure 3** (Nilsson and Rosenberg 1997). The scoring of the BHQ index was adjusted to fit the successional model of Pearson and Rosenberg (1976, 1978). As this model originally was partly developed from a Swedish fjord, images from that fjord gradient were used as a reference.
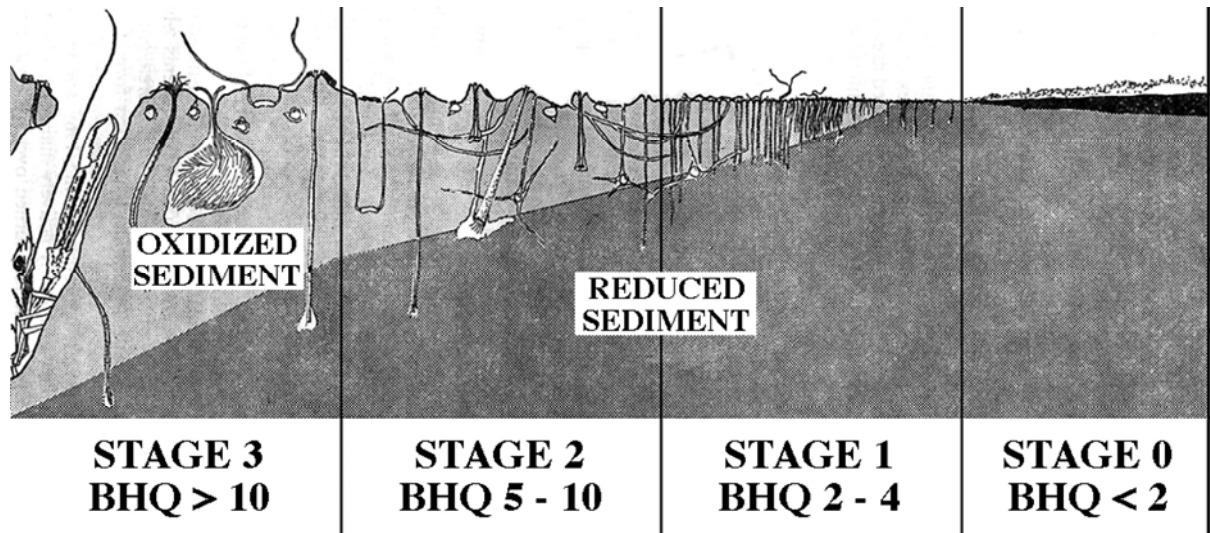


**Figure 3.** The distribution of benthic infaunal successional stages along a gradient of increased environmental disturbance from left to right (after Pearson and Rosenberg 1976, 1978) and the associated Benthic Habitat Quality (BHQ) index (described in **Table 1**). The successional stages are similar but not identical to those described by Rhoads and Germano (1986).

This method for assigning BHQ values to benthic habitat successional stages was later significantly correlated with Species-Abundance-Biomass (SAB) curves during periods of increasing hypoxia (Nilsson and Rosenberg 2000, **Figure 4**) and during re-colonisation following re-oxygenation of the bottom water (Rosenberg et al. 2002).
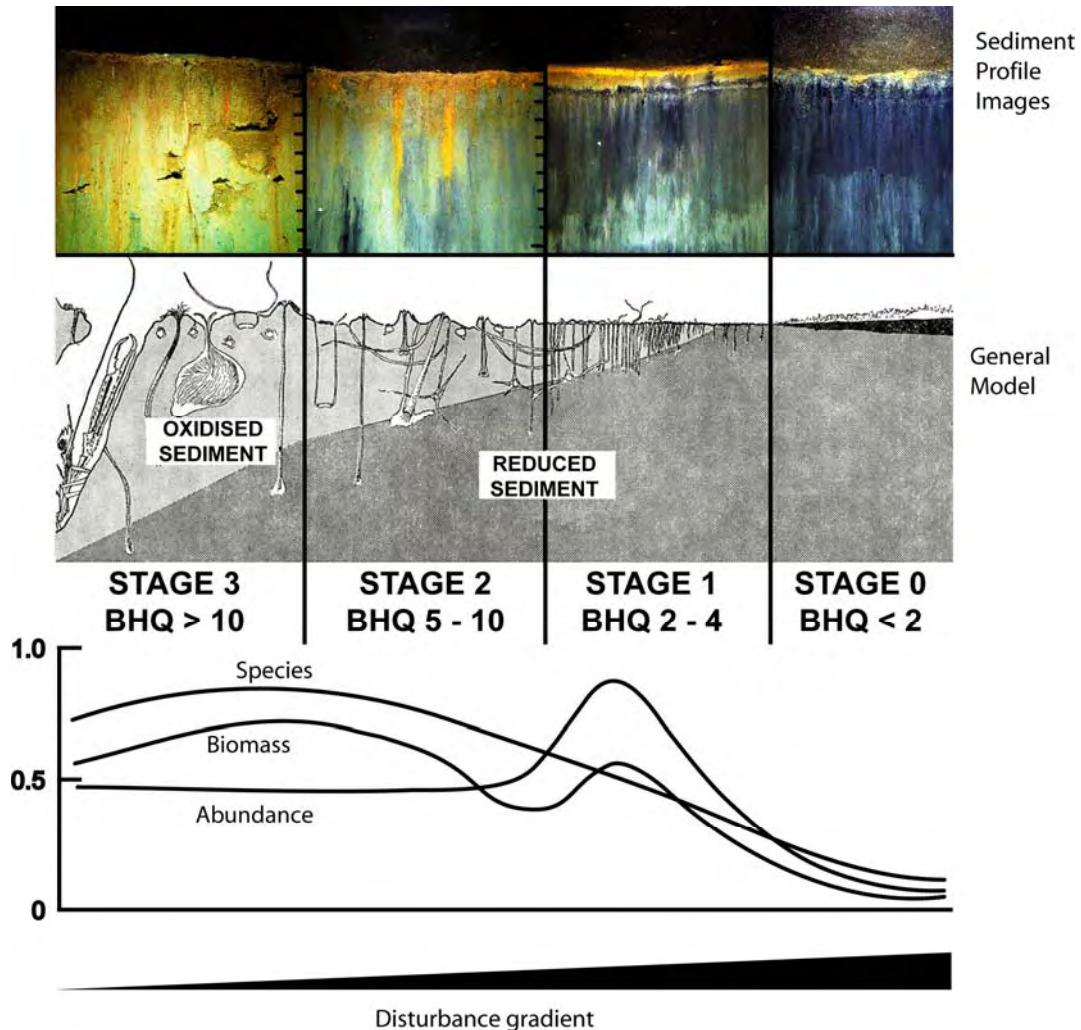
**Figure 4.** The distribution of benthic infaunal successional stages along a gradient of increased environmental disturbance from left to right (after Pearson and Rosenberg 1978) and the associated Benthic Habitat Quality (BHQ) index (Nilsson and Rosenberg 1997). Sediment profile images assigned to a successional stage are mounted above the general model (colours are digitally enhanced), where oxidized sediment is rust-brown and reduced sediment is grey or black. In the bottom of the figure the generalized species (S), abundance (A), biomass (B) diagram is illustrated (after Pearson and Rosenberg 1978).

## 4.2 Classification of habitat quality according to the Water Framework Directive (Rosenberg et al. 2004)

According to the European Union Water Framework Directive (WFD), coastal environmental status should be classified into 5 categories for each coastal area based on the typology of that area. Rosenberg et al. (2004) provide evidence that the BHQ index would be a useful tool for the WFD in assessing benthic habitat quality if divided into five classes rather than the earlier division into four successional stages (**Figure 5**). Nilsson and Rosenberg (2000) and Rosenberg et al. (2002a) showed that each of three key assessment variables [number of species (S), abundance (A), and biomass(B)] are strongly correlated with the BHQ index under changing oxygen concentrations. Dividing the range of BHQ index scores into five bins rather than four is ecologically consistent with a general recognition that the actual response of benthic fauna to stressors in nature occurs over a gradient rather than in stages (Pearson and Rosenberg 1978, Grizzle and Penniman 1991, Gray et al. 2002,

Rosenberg et al. 2004), and the determination of these new boundaries was based on a statistical reanalysis of about 3000 images (Rosenberg et al. 2004). To illustrate the WFD approach, Rosenberg et al. (2004) suggested that coastal soft bottoms in major water bodies such as the Skagerrak, Kattegat and Öresund (Sweden) should be separated into similar ecological units by water depth (i.e. depth ≤20m and depth >20m). Stratification according to depth was made for these water bodies because of differences in salinity above and below the halocline at about 20 m. The BHQ scores for sediment profile image surveys in this region would then be divided into 5 categories, and the area would be assessed according to the WFD directive.
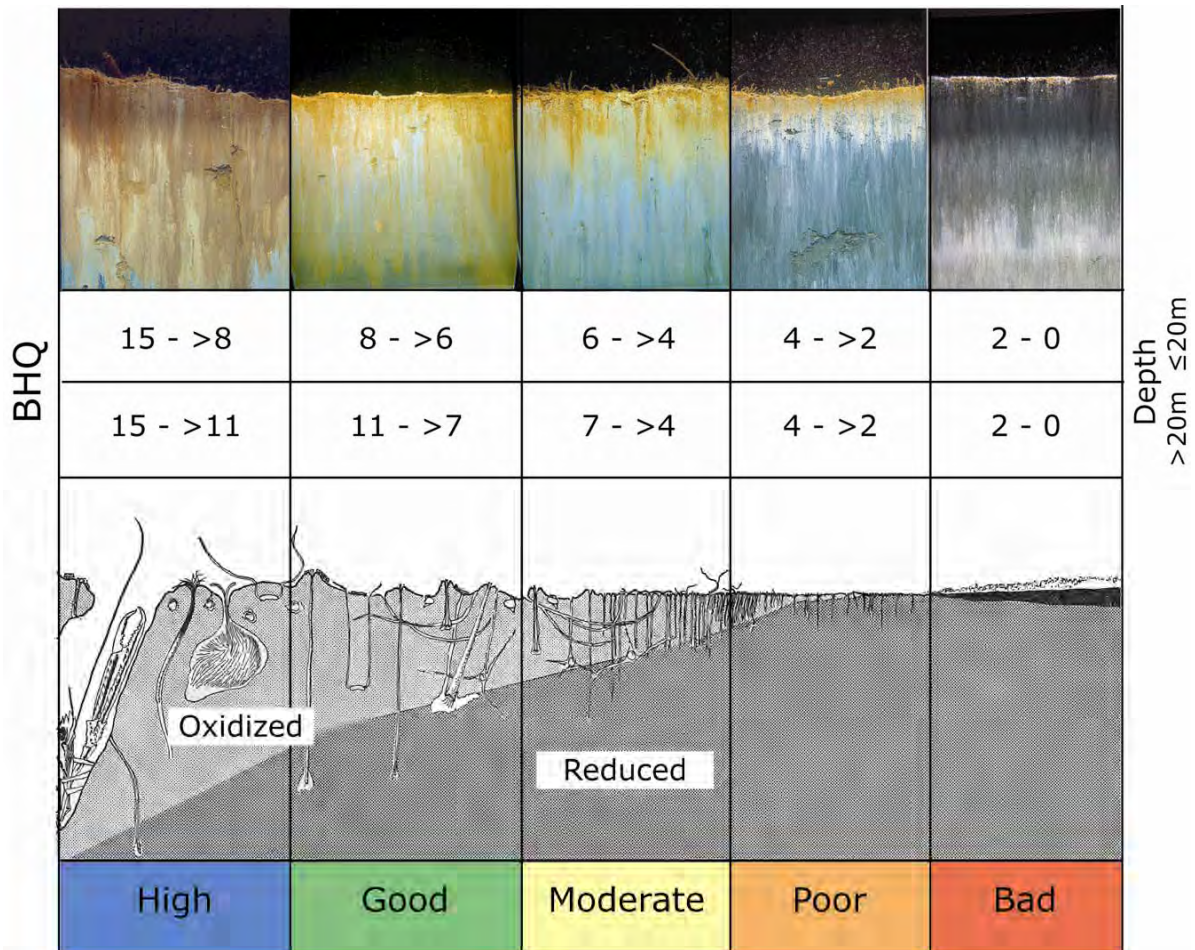


**Figure 5.** Model of the faunal successional stages along a gradient of increasing disturbance from left to right (after Pearson and Rosenberg, 1978). Sediment profile images (colours enhanced) are shown on the top where brownish colour indicates oxidized conditions and black reduced conditions, and the benthic habitat quality (BHQ) indices (Nilsson and Rosenberg, 1997) are presented for depths >20m and ≤20m. Figure modified from Rosenberg et al. (2004).

## 4.3 Classification of sediment profile images collected in Norwegian waters

Rosenberg et al. (2004) reanalysed statistically about 3000 sediment profile images during the study to divide the BHQ indexs into 5 classes compared to the earlier successional model with 4 stages. The same analyse have been performed in this study with about 1000 images from the Skagerrak and North Sea coastline of Norway (**Figure 6**). A large part of these sediment profile images from Norway have been sampled in industrial stressed areas and in fjords, which could be indicated by a slightly lower number of images with high BHQ index (BHQ >10) collected at depths deeper than 20m. However, the distribution observed in Swedish waters dividing the classification at about 20m depth correlates with the observed distribution in Norwegian waters ($r^2$=0.91 at ≤20m depth and $r^2$=0.80 at >20m depth, **Figure 7**). The stratification in salinity was argued to be the main reason to divide the classification in Swedish waters to 20m depth. In Norwegian waters the halocline varies more in depth, because the Norwegian coastline is generally more exposed and physically stressed, which could explain that larger features is not so often observed in the images at shallow depth.
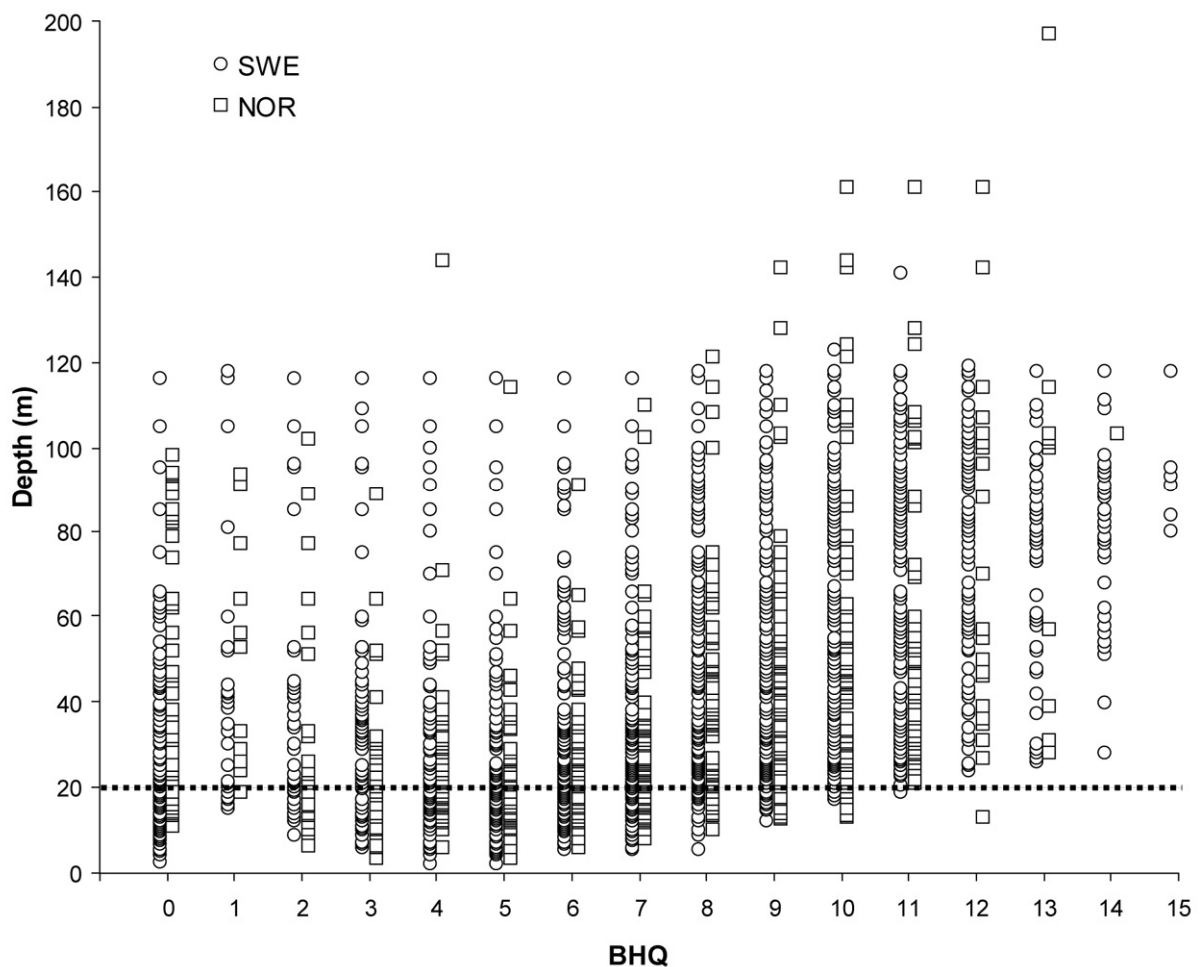


**Figure 6.** Plot of the distribution of BHQ against depth (m) of 4282 images collected along the Swedish (SWE) and Norwegian (NOR) coastline. The suggested depth intervals (≤20m and >20m depth) is marked with a doted line.

The high correlation in the distribution of the BHQ indices suggests that the same boundaries in the classification of sediment profile images used for Swedish waters also could be used in Norwegian waters.
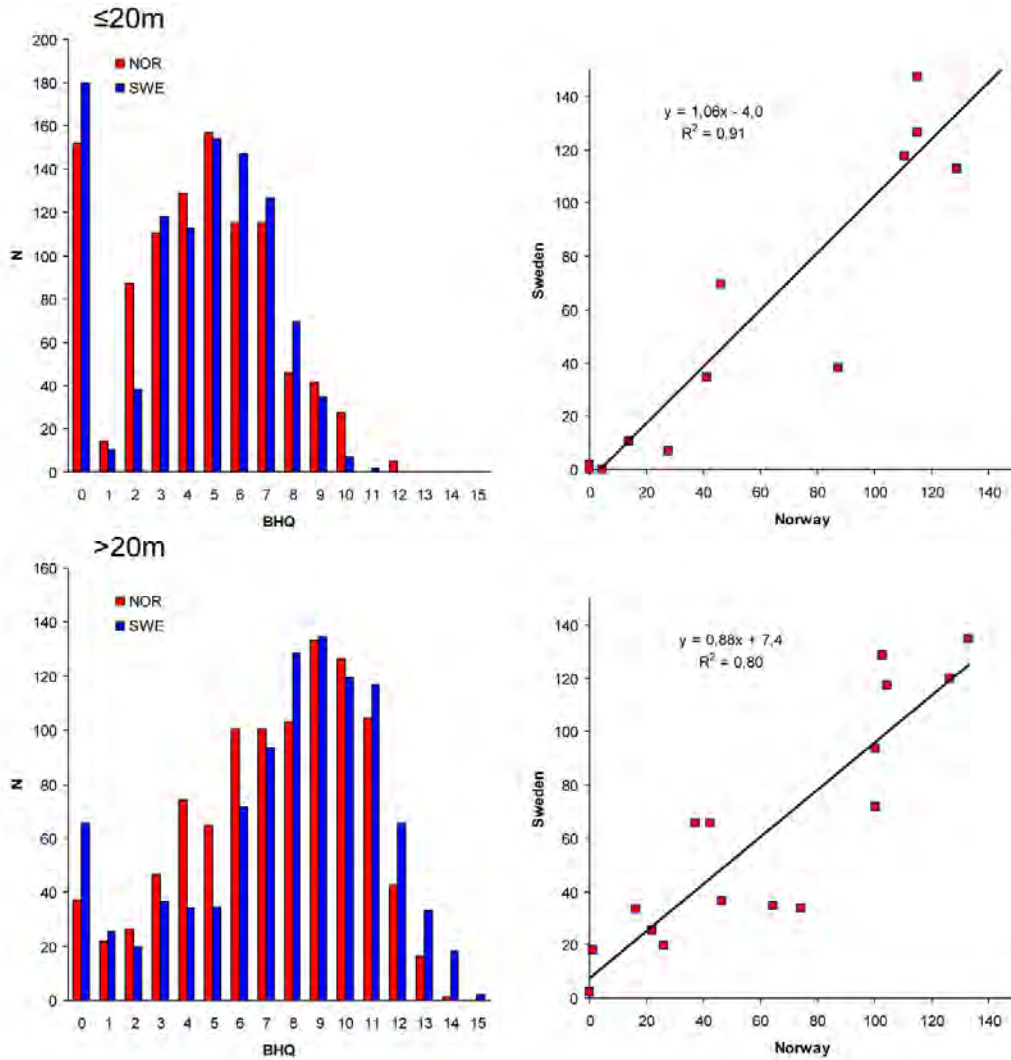


**Figure 7.** Statistical comparison between sediment profile images (SPI) collected in Sweden (3338 images) along the Kattegat and Skagerrak coastline, and in Norway (944 images) along the Skagerrak and North Sea coastline. The distribution is normalized to 1000 images per area and divided between images collected at depth ≤20m and >20m depth according to Rosenberg et al. (2004).

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