Macroalgal communities in Kongsfjorden, Spitsbergen

Analysis of video transects

BACHELOR THESIS

LUDWIG-MAXIMILIANS-UNIVERSITY
ALFRED-WEGENER-INSTITUTE

AUTHOR ....Katherina Schimani, k.schimani@gmx.de
SUPERVISOR AWI ....Prof. Dr. Thomas Brey
SUPERVISOR LMU..........Prof. Dr. Herwig Stibor

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ALFRED-WEGENER-INSTITUT
HELMHOLTZ-ZENTRUM FÜR POLAR-
UND MEERESFORSCHUNG

LMU
LUDWIG-
MAXIMILIANS-
UNIVERSITÄT
MÜNCHEN

Abstract

Climate change is likely to be first perceptible in the polar regions due to an accelerated temperature increase and alterations in ice conditions. Especially Kongsfjorden is a suitable study site since climate change is influencing from two directions. The end of the fjord is influenced by changing water currents and the inner side by melting glaciers.

In 2009 the Alfred-Wegener-Institute Helmholtz Centre for Polar and Marine Research conducted video recordings of the sea floor at six areas in Kongsfjorden with a remote operated vehicle. The sea bed was filmed between 5 and max. 140 m depth. This technique allowed an analysis of a vast area without disturbing the benthic community. A geographic information system of the Kongsfjorden was established and a digital elevation profile was generated.

Macroalgae were distributed throughout the fjord, mainly on hard bottom substratum but also to some extent on soft bottom with drop stones. Chlorophyta were recorded at the middle to inner fjord and at areas influenced by physical disturbance. The cover of Rhodophyta was high at the outer fjord and decreased with proximity to the inner fjord. Phaeophyceae were distributed at the entire fjord. The depth distribution of macroalgae was changing along the fjord axis. Macroalgae could be identified at the outer fjord growing down to 74 m. With proximity to the inner fjord the distribution decreased to shallower depths.

Benthic communities (including zoobenthos and microphytobenthos) were significant different between outer and inner locations of the fjord as well as between soft bottom and hard bottom locations when zoobenthos was excluded. Every transect had a distinct depth zonation but the dissimilarities between the depth zones were mainly not higher than the ones within a zone.

A substantial detrital macroalgal biomass was quantified at the middle to inner fjord and entered the deep-water food web. The detrital cover was probably a result of the hydrodynamic situation due to a deep trench and has even increased due to a previous storm.

Zusammenfassung

Der Klimawandel ist in den Polarregionen aufgrund eines beschleunigten Temperaturanstiegs und Änderungen der Eisbedeckung wahrscheinlich zuerst spürbar. Insbesondere der Kongsfjord ist für den Klimawandel ein geeigneter Untersuchungsort, da dieser aus zwei Richtungen Einfluss nimmt. Das Ende des Fjords wird von wechselnden Wasserströmungen und die Innenseite von schmelzenden Gletschern beeinflusst.

Das Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung hat 2009 an sechs Orten im Kongsfjord Videoaufnahmen des Meeresbodens mit einem ferngesteuerten Fahrzeug vorgenommen. Der Meeresboden wurde zwischen 5 und max. 140 m Tiefe untersucht. Diese Technik ermöglichte dabei die Untersuchung einer großen Fläche ohne die benthische Gemeinschaft zu stören. Ein geografisches Informationssystem wurde für den Kongsfjord eingerichtet und ein digitales Geländemodell erstellt.

Makroalgen waren im ganzen Fjord verbreitet, hauptsächlich auf hartem Untergrund und teilweise auch auf weichem Untergrund mit Fallsteinen. Chlorophyta wurden von der Mitte bis zum inneren Bereich des Fjords vorgefunden sowie in Gebieten, die durch physische Störungen beeinflusst wurden. Die Bedeckung mit Rhodophyta war höher im Außenbereich des Fjords und nahm mit der Nähe zum inneren Bereich ab. Phaeophyceae waren über den gesamten Fjord verteilt. Die Tiefenverteilung der Makroalgen änderte sich entlang der Fjordachse. Im Außenfjord konnten Makroalgen in 74 m Tiefe nachgewiesen werden. Mit der Nähe zum Innenfjord verschob sich die Tiefengrenze in flachere Bereiche.

Benthische Gemeinschaften (einschließlich Zoobenthos und Mikrophytobenthos) unterschieden sich signifikant zwischen äußeren und inneren Standorten des Fjords sowie zwischen Standorten mit weichem und hartem Boden, wenn Zoobenthos aus der Analyse ausgeschlossen wurde. Jedes Transekt wies eine Tiefenzonierung auf, aber die Unterschiede zwischen den Tiefenzonen waren meist nicht größer als die Unterschiede innerhalb einer Zone für alle Standorte.

Im mittleren Bereich des Fjordes wurde eine beträchtliche Menge an Makroalgendetritus quantifiziert, die in das Nahrungsnetz des Tiefenwassers gelangt ist. Die Bedeckung mit Detritus war wahrscheinlich eine Folge der hydrodynamischen Situation aufgrund des nahegelegenen Grabens und wurde aufgrund eines vorherigen Sturms vergrößert.

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1 Introduction

1.1 Hydrology and biogeography of Kongsfjorden

According to Lünning (1985) the earth is divided into seven climate regions: the Arctic region, the cold and temperate regions of the northern hemisphere, the tropical region, the cold and temperate regions of the southern hemisphere and the Antarctic region. The borders of those regions are resulting through considerable changes in fauna and flora. Mostly they follow critical isothermal curves of the ocean, since water temperature is one of the most important factors for their geographical distribution. The winter isothermal curve of 0°C is often considered as the Arctic border (Lüning 1985). In contrast to Antarctica, glaciation and winter ice covering developed in the Arctic just 2 million years ago. It is covered by multiyear pack ice surrounded by continental landmasses. Through the continuous connection to the temperate coast of Eurasia and America an exchange of species is occurring resulting in a low number of endemic species (Wulff et al. 2009).

The island of Spitsbergen of the Svalbard archipelago is located within the Arctic. Kongsfjorden is a glacial fjord on the western coast of Spitsbergen (Figure 1). It is about 26 km long with a varying width from 4 to 10 km. Joining with Krossfjorden in the north, it opens to the Greenland Sea.

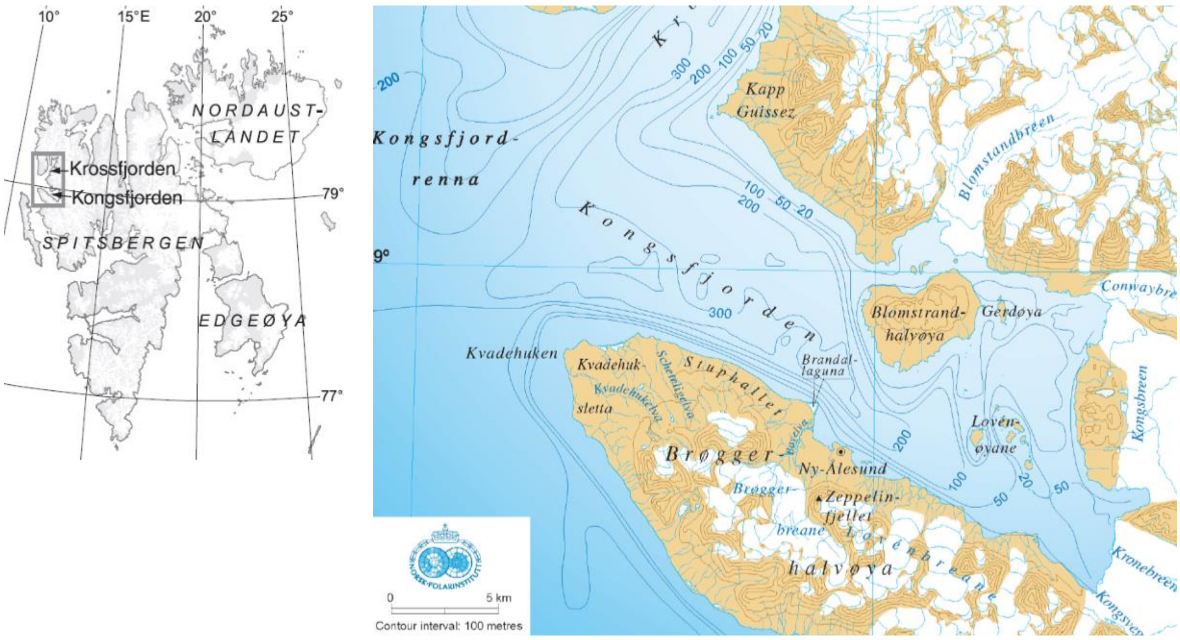

Figure 1 Maps of Spitsbergen with the location of Kongsfjorden (Howe et al. 2003), Norwegian Polar Institute

The fjord is influenced by two ocean currents: the West Spitsbergen Current, dominated by warmer and more saline waters from the Atlantic, and the Arctic Coastal Water with lower salinity and temperature (Howe et al. 2003). The temperature of the Atlantic waters has increased linked to an augmented North Atlantic Oscillation index (NAO) and temperatures in the West Spitsbergen Current have reached the highest values ever recorded (Svendsen et al. 2002, Walczowski et al. 2012). This change in water temperature had a strong influence on the oceanic climate and sea-ice conditions of Svalbard. Since 2005/2006 the pack ice formation declined and was only present at the inner part of the fjord close to the glacier (Bartsch et al. 2016, Cottier et al. 2007).

With the onset of spring until August, the water body gains heat. During this period the salinity decreases due to glacial melt water since several tidewater glaciers drain into the fjord. A large glacial complex in the inner part of the fjord is calving at the head of the fjord. Along with the raising input of freshwater the concentration of suspended inorganic matter is increasing (Svendsen et al. 2002). The winter cooling of the water starts in October (Ito and Kudoh 1997). The outer basin of Kongsfjorden has his maximum depth at 394 m. The inner fjord is shallower with water depths less than 100 m. The central and outer Kongsfjorden is dominated by outcrops of bedrock with a sediment cover less than 10 cm. The highest concentration of suspended inorganic matter is located at the inner fjord influenced by the glaciers run-off resulting in soft bottom dominated areas (Howe et al. 2003). Thus, the melt water creates a gradient in sediment and salinity along the length of the fjord.

1.2 Benthic communities of Kongsfjorden

The benthic zone comprises the habitat of organisms connected to the bottom substrate of the sea floor. This zone is one of the main habitats of the ocean next to the pelagic one (habitat of the open water). The benthic communities are divided into zoobenthos and phytobenthos (Lüning 1985). Microphytobenthos are unicellular algae growing on various hard and soft inorganic substrata (Fredriksen et al. 2019). In Kongsfjorden thick mats of microalgae dominated by diatoms are reported to grow on all kinds of substrata in shallow areas (Hop et al. 2002). Studies in Kongsfjorden showed that they demonstrated significant rates of primary production that is comparable to pelagic production (Wölfel et al. 2009). Multicellular algae are called macrophytobenthos or macroalgae. They form highly productive systems which comprise rich associated communities. Furthermore, they provide shelter, substrate, nursery grounds and feeding area for zoobenthos (Christie et al. 2009, Fredriksen et al. 2019). Studies in Kongsfjorden showed that zoobenthos differs regarding the bottom substrate. Actinaria, Ascidia, Bryozoa and Porifera are common at hard bottom locations (Beuchel et al. 2006, Laudien et al. 2012). In contrast, Polychaeta, Mollusca and Crustacea colonize soft bottom substrate (Laudien et al. 2004).

1.3 State of research on macroalgal communities of Kongsfjorden

The term macroalgae combines taxa of the phyla Phaeophyceae (brown algae), Chlorophyta (green algae) and Rhodophyta (red algae). Macroalgae are a common element of nearshore hard substrate communities. The species at the Arctic are of Atlantic and Pacific origin with a few cosmopolitan or endemic species (Lüning 1985). The communities in glacial fjords are exposed to changing osmotic conditions due to the gradient in sediment and salinity and require therefore high physiological adaptation. Other environmental factors exhibit a strong seasonality as well. Light conditions and temperature are extremely low for part of the year due to polar night of around four months (Zacher et al. 2009).

Macroalgal beds are an important part of marine shelf ecosystems, both as primary producers and habitat builders (Christie et al. 2009). Kelps (brown algae of the order Laminariales) are often perceived as cold-water analogues of tropical coral reefs. Their species richness in polar regions remained largely unexplored (Włodarska-Kowalczuk et al. 2009). On Spitsbergen however, several floristic studies on macroalgae have been published starting in the middle of the 19th century (Fredriksen et al. 2019). In Kongsfjorden, Spitsbergen, an evaluation of the species composition took place through the entire length axis of the fjord at 5 transects from 0 to 30 m in the years 1996/98 by SCUBA diving (Hop et al. 2012, 2016). Chlorophyta and Phaeophyceae grew in the littoral and sublittoral zone mainly in the range of 0 to 20 m. Rhodophyta were found in greater depths (Hop et al. 2012). Biomass maxima were recorded at the outer fjord between 5 and 10 m and at the inner fjord shallower than 5 m (Hop et al. 2016). The communities varied with substratum and location in the fjord. Well established macroalgae communities only occurred at hard bottom locations. At areas dominated by soft bottom macroalgae sometimes grew attached to drop stones which were left by melting glacial ice and drifted with the current. Most of the species were of Arctic or cold temperate biogeographic origin. However, a majority of the species were newly recorded for Svalbard, demonstrating the scarcity of previous investigations (Hop et al. 2016). One location (Hansneset) analysed in 1996/98 was revisited in 2012-14 (Bartsch et al. 2016). In comparison to 1996/98 the seaweed biomass increased and the peak in kelp biomass shifted to shallower depths from 5 to 2.5 m. The entire zonation seemed to have shifted upwards (Bartsch et al. 2016).

In another study from Kongsfjorden, Kruss et al. (2012) were mapping the distribution of macroalgae in the depth range 0 to 30 m by echo sound. Almost 50% of their coastal study area in Kongsfjorden was covered by macroalgae (Kruss et al. 2017). The University of Tromso implemented a photographic time series at sublittoral hard bottom locations at several fjords at 15 m since 1980. They could show that the biodiversity varies with the NAO index, whereby a positive index corresponding to warmer conditions leads to a lower biodiversity (Beuchel et al. 2006). The results of this time series indicated a community shift as well with a fivefold increase in macroalgae cover (especially brown algae) between the years 1995/96 (Kortsch et al. 2012). Over all 197 macroalgal species are described for Svalbard: 51 green, 76 brown and 70 red algae. At Kongsfjorden 84 species were recorded: 19 green, 36 brown and 29 red algae (Fredriksen et al. 2019). However, macroalgal communities are changing in the fjord due to the lack of ice scouring, the elongation of the open water period and deterioration of underwater irradiance (Bartsch et al. 2016). Furthermore, more temperate species are expected to be able to establish in the Arctic regions due to increasing temperatures (Fredriksen et al. 2019).

1.4 Macroalgal detritus

In marine environments sunlight is rapidly absorbed by the water column and primary production is restricted to shallower parts. However, the majority of marine ecosystems lie below this zone (Filbee-Dexter et al. 2018). Carbon export to this area is conventionally credited to the sinking of phytoplankton. However, coastal banks are highly productive ecosystems and macroalgae may contribute substantially to the carbon export into the deep sea (Dierssen et al. 2009, Krause-Jensen and Duarte 2016). Detached macroalgal transported into the deep sea cannot survive long periods due to the light conditions. Thus, in this study the term detritus is used for degraded parts of macroalgae as well as for detached. Detrital production rates are controlled by current and wave movement. The highest rates occur during severe storms (Krumhansl and Scheibling 2012). Studies indicate, that deep water communities adjacent to kelp forests depend on transport of food in form of detritus from the euphotic zone. It is estimated that over 80% of local primary production enter the detrital food web and are exported to deeper communities (Filbee-Dexter et al. 2018).

1.5 Research objectives

Climate change is likely to be first perceptible in the polar regions due to an accelerated temperature increase and alterations in ice conditions. Especially Kongsfjorden is a suitable study site since climate change is influencing from two directions. The end of the fjord is influenced by the changing water currents and the inner side by melting glaciers (Svendsen et al. 2002).

Benthic macroalgae can serve as useful measure to detect environmental changes since they are directly exposed to changes and integrate them over time. Furthermore, macrophytes are important primary producers in the Arctic, serving as habitat or functioning as ecological engineering species (Christie et al. 2009). However, until now the existing knowledge is based on a few studies at limited number of locations just at shallower waters to 30 m depth (Hop et al. 2012). For this reason, it is crucial to extent our knowledge on marine ecosystems and the benthic composition, especially in this changing environment.

In 2009 Christian Wiencke from the Alfred-Wegener-Institute Helmholtz Centre for Polar and Marine Research conducted video recordings of the sea floor at six areas in Kongsfjorden with a remote operated vehicle (ROV). The sea bed was filmed between 5 and max. 140 m depth, depending on the transect. For the first time deep water macroalgae and detrital macroalgae, detached from its former habitat were recorded. Furthermore, this technique allowed an analysis of a vaster area without disturbing the benthic community (non-destructive sampling).

The transects were recorded across the shore in different locations of the fjord. Two of the recorded areas were previously analysed in 1996/98 by Hop et al. (2012, 2016) and 2012-14 by Bartsch et al. (2016) (Figure 2). The other four locations have never been evaluated regarding their macroalgal community structure and cover, increasing our knowledge on macroalgal distribution over depth and along the fjord axes. Furthermore, the transport of macroalgal detritus could be investigated for the first time in Kongsfjorden.

This Bachelor thesis had the following objectives:

1) Investigation of the location of the transect within the fjord and characterisation regarding depth profiles and morphology (substratum)
2) Determination and classification of micro- and macroalgae, macroalgal detritus and macrozoobenthos (presence/absence and percent cover).
3) Analysation of the community structure of the coastal community

2 Methods

2.1 Collection of data and sampling

Macroalgae communities were recorded in June 2009 along transects at six locations in Kongsfjorden, Spitsbergen. These six stations were situated along the fjord axis at the south cost and at an island further north (Figure 2). Two stations were situated close to each other in the middle of the fjord at the island Hansneset. The transect Kongsfjordneset was situated at the outer fjord. Furthermore, two transects were located in the middle part of the fjord at the south coast: at Prince Heinrich Island and Brandal. The last transect at Tyskahytta was situated in the inner bay.

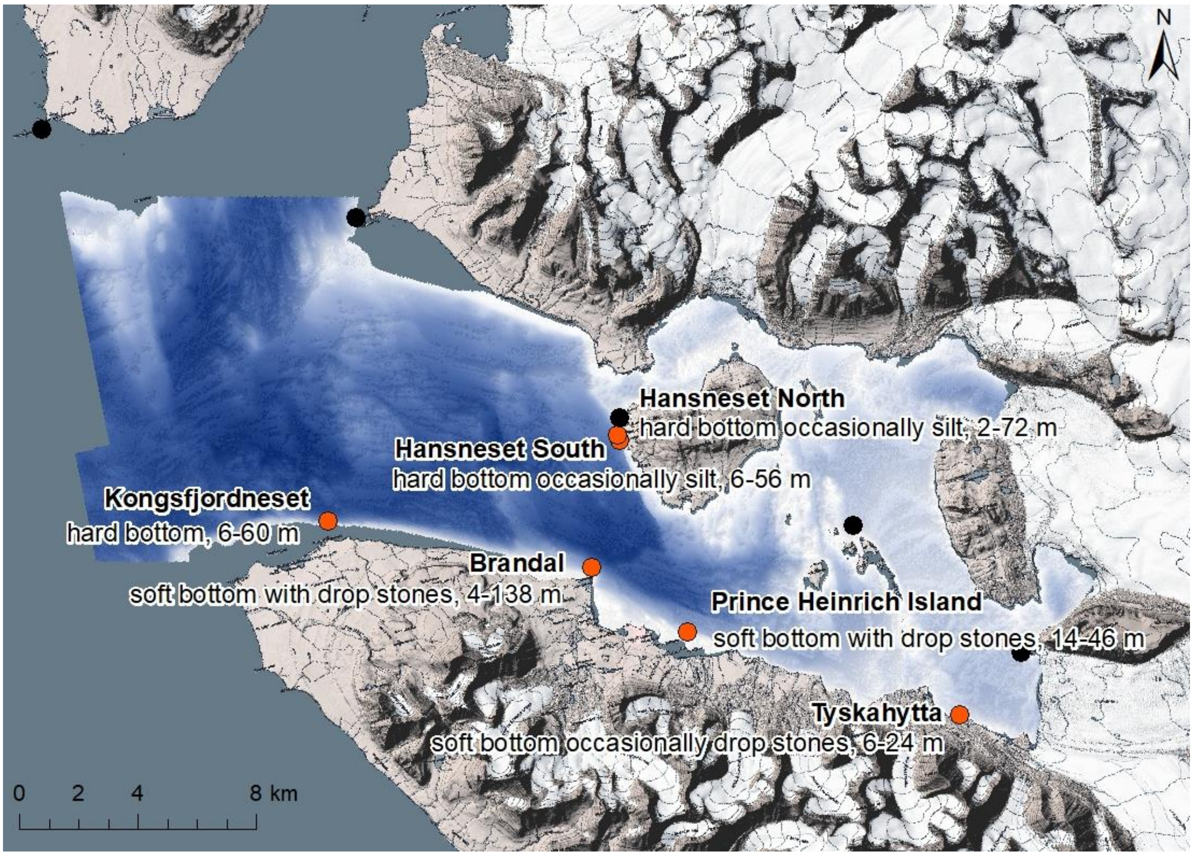

Figure 2 Location of the six transects in Kongsfjorden (orange) and the location of transects from Hop et al. (2016) (black) with a Digital Elevation Model (DEM) of Kongsfjorden, Norwegian Mapping Authority, Norwegian Polar Institute, modified

The recording was conducted with the remotely operated vehicle (ROV) ACHILLE M4 (Institut Polaire Français Paul Emile Victor IPEV, France) from on-board the research boat Teisten (Kings Bay AS, Norway) as described in Laudien et al. (2012). The ROV was behind the ship connected by a cable. During the dive, the boat was drifting and the speed was limited to 0.5 knots. At the same time the length of the electric cable was adjusted to ensure the ROV was diving with the same velocity. The primary video camera was a SONY HVR-A1E HDV 1080i fitted with a 300 m Extreme Vision Lens. Two halogen lights were arranged to provide broad illumination in the direction of travel and three laser pointers (3 cm horizontal distance and 2 cm vertical distance) provided the surface estimation. The boat proceeded along the same vector and at about the same forward speed as the ROV, thus preventing the boat from dragging the ROV off course.

2.2 Spatial analysis

Longitude and latitude were measured every two seconds by the ship. The depth was measured in the same interval by the ROV. The accuracy of the depth sensor is 1 or maximum 2 m at deeper spots (D. Fleury, IPEV, personal communication). Problems with the sensor occurred, when the sea bed was steep. Here the recorded depth fluctuated considerably that interpolation was occasionally necessary. This georeferenced data was imported and processed in a geographic information system (GIS). The geographic coordinate system *WGS 84 (EPSG 4326)* and the projection *North Pole Lambert Azimuthal Equal Area (EPSG 102017)* were applied. In particular the software ArcGIS was used. To enable an import of the data into the GIS software, an R-Script was written, which transferred the data such as date, time and coordinates into a GIS-capable format. Furthermore, the point coordinates were connected with the R script to generate a polyline. Hence the position and depth at each point of the transect was calculated and linked to the time code of the video. To verify the depth data, the coordinates of the ROV were compared to a digital elevation model (DEM) of Kongsfjorden. The DEM was created from a point shape file given by the Norwegian Mapping Authority with a resolution of 10 m x 10 m. The generation of the raster was conducted using the interpolation method *spline*. This method estimates values using a mathematical function that minimizes overall surface curvature. The result is a smooth surface that passes exactly through the input points. Hence it is suitable for generating gently varying surfaces such as elevation (ESRI 2018).
The depth data recorded by the ROV and extracted of the DEM was used to establish an elevation profile of the six transects. Hence the zonation of the macroalgae distribution by depth was possible.

2.3 Image analysis

As the velocity of the ROV was not constant over time, a script was created with the software R to generate points on the transects with a distance of 5 m respectively 10 m apart from each other to achieve a consistent sampling pattern of the seabed. The coordinates and the timecode of the neighbouring ROV points were determined for every sampling location. Via ArcGIS the timecode of the sampling points was interpolated. The transects were usually sampled every

5 m. Only the Tyskahytta transect was sampled every 10 m, since the environment and the benthic cover was not changing intensely over distance.

The video sequences were viewed with the software Avidemux 2.7. The videos are interlaced scans digitalized to MOV files. Frames recorded with this technique contain two fields captured at two different times. If recorded objects are moving too fast, they are at two different positions in one frame causing motion artefacts. This interlacing effect was visible on the frames. Deinterlacing for a sharper image was accomplished with the filter Yadif in the Avidemux software. The same software was used to extract a frame of the video at the desired timecode and saved as a bitmap file. When the image was unsuitable due to turbulences of the seabed or the camera was covered by macroalgae thalli, the next appropriate frame was used. Particular attention was paid to ensure the frame was showing the same area of the sea bed as the original one.

The sampling points were determined via the coordinates, which were measured on the ship. The ROV was operated with the same speed as the ship, so the estimation of 5 m distances was accurate. On some occasions, the ship was slower than the ROV. This occurred especially when the ship was turning or passing locations with steep bedrock. The resulting sample points were too close to each other and therefore removed. On the other hand, some distances between the sample points are longer than 5 m when they were compared to the video. Hence the ROV was faster than the ship. On these occasions, an additional frame was extracted in the middle of the two original frames.

The extracted images were viewed with the software ImageJ. Additionally, the ImageJ plugin GRID was used for assessment of the cover, since species abundance was estimated as percent cover data. Thereby a raster was applied over the frame where every grid cell was covering 5 % of the area (20736 pixel^2). The area displayed on the frames was estimated with the help of three laser spots. The pixel in between the spots were measured. Since their actual distance was known, the total length and width of the frame could be measured in pixel and converted into meter. The laser spots were not always visible and switched off at Kongsfjordneset and Hansneset north. Since Hansneset south was filmed with similar conditions (estimated distance from the sea floor), the mean area per frame from this transect was used for area estimation of Kongsfjordneset and Hansneset north. Furthermore, the points were not visible at locations with high macroalgal cover. On this occasion the mean area per frame of the transect was applied. Where flat sea ground was predominant, the pictures are showing a vaster area due to the angle of the camera. On many images, the background is not clearly visible and the individuals are not identifiable. On these occasions, just a proportion of the image was evaluated. Degree of coverage of the taxa and area estimation was adjusted subsequently.

At each frame, presence/absence of macroalgae, macroalgal detritus, microalgae and zoobenthos was analysed and the substrate type was recorded. The present macroalgae taxa were identified after Klekowski and Weslawski (1995) and Mølller Pedersen (2011) updating of nomenclature after Guiry and Guiry (2019). Additionally, the degree of coverage was estimated for the following groups in percent: foliated Phaeophyceae (kelp), filamentous Phaeophyceae, foliated Rhodophyta, filamentous Rhodophyta, coralline Rhodophyta, foliated Chlorophyta and filamentous Chlorophyta. The percent cover of single taxa was estimated as well, if distinguishable. Presence and cover of detached or degraded macroalgae were analysed as well and classified as “detritus”. For the presence and coverage of zoobenthos no distinction between sessile and mobile was made. The appearance of sea urchins, sea stars and the crab *Hyas* were recorded on the species level, since they feed on macroalgae. The coverage estimation of all groups was conducted in 5 % steps including a 1 % cover for minimum coverage: 0, 1, 5, 10, 15, …%.

The percent cover of microphytobenthos was analysed in five classes. Class 1 represent a microphytobenthic coverage up to 10 %, class 2 from 10 % to 25 %, class 3 from 25 % to 50 %, class 4 from 25 % to 75 % and class 5 from 75 % to 100 %.

The bottom substrate was classified into soft bottom, soft bottom with drop stones, hard bottom and hard bottom with silt. The cover of hard bottom was estimated wherever possible. At locations with high macroalgal cover, an estimation of the bottom substrate and epifauna cover was not always feasible. However, a high macroalgal cover indicated hard bottom substrate or the presence of drop stones.

2.4 Data analysis

2.4.1 Depth zonation and benthic cover

An elevation profile of each transect was generated. These profiles were categorized into different individual depth zones with steps of 2 and 5 m (0-2 m, 2-4 m, etc. respectively 0-5 m, 5-10 m, etc.) All evaluated frames from one depth zone were then analysed together, resulting in several replica (images) per depth zone.

The total analysed area of every transect and the different depth zones was calculated as well as the area covered by the different algae groups (kelp, filamentous Phaeophyceae, foliated Rhodophyta, filamentous Rhodophyta, coralline Rhodophyta, foliated Chlorophyta and filamentous Chlorophyta). The calculation of the area was performed via the three laser points.

The general macroalgae percentage cover was analysed for both, 2 and 5 m steps in depth to obtain the best resolution for the community analyses. Furthermore, the percent cover of detritus, microphytobenthos and macrozoobenthos was evaluated per depth for every transect.

2.4.2 Community Analysis

To analyse the sample locations and their species composition multivariate statistics were used. Multivariate methods are characterised by their comparison of samples by more than one variable simultaneously. In community analysis this tool is based on similarity coefficients. Thereupon a classification of similar samples and even plots of samples are possible, where the distances between samples reflect their relative dissimilarity of species composition (Clarke et al. 2014). The communities at Kongsfjorden were compared regarding their location in the fjord, their depth zonation and bottom substrate utilizing the software PRIMER v5 (Clarke and Gorley 2006).

Input data for the community analysis was the presence/absence data of the sample points at species level. Missing values, e.g. when zoobenthos was not visible due to macroalgae thalli, were completed with null. The depth classification was as follows: 5 m followed by intervals of 10 m until 70 m. Deeper locations were not analysed. In another community analysis run the presence/absence data matrix without zoobenthos and one without detritus was. A further evaluation was conducted with the percent cover data. Since the estimation of the cover at species level was not feasible at several sample points, especially in the kelp forests, the community analysis was performed with the data of algae groups (kelp, filamentous Phaeophyceae, foliated Rhodophyta, filamentous Rhodophyta, coralline Rhodophyta, foliated Chlorophyta and filamentous Chlorophyta). Furthermore presence/absence and cover data with zoobenthos and detritus were analysed more detailed in a depth range until 26 m with an interval of 2 m.

Cover data was square-root transformed to lessen the contribution of dominant species. A similarity matrix was established subsequently based on the Bray-Curtis coefficient. The coefficient S_{jk} describes the similarity between two samples and is calculated as followed:

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

A value of 100 occurs when two samples are identical and takes the value 0 when two samples have no species in common (Bray and Curtis 1957). The software PRIMER does not calculate the similarity between samples, which have no species recorded. These rows were deleted from the input matrix.

Furthermore, a classification of the samples was conducted based on the similarity matrix. The performed cluster analysis fuses successively the samples into groups, starting with the highest similarities then lowering the similarity level at which groups are formed. The result of a hierarchical clustering is a dendrogram, where the x axis is representing the set of samples and the y axis is defining the similarity level of the groups (Clarke et al. 2014).

The results of the cluster are displayed graphically via an ordination process. This process generates a map of the samples, where their location represents the similarity of their biological communities. The ordination method of non-metric multidimensional scaling (MDS) was used. The dimensional placement of sample points into a map can cause distortion or stress between the similarity rankings. A stress value lower than 0.2 is indicating reliable plots.
To test the similarity of the samples an ANOSIM (analysis of similarities) was conducted. This is a nonparametric permutation procedure, which calculates the test statistic *R*. This value is reflecting the differences between and within groups. Furthermore, the test computes the statistics under permutations, where the sites are randomly rearranged. If the null hypothesis is correct ("no differences between sites"), the average *R* value is not changing. Afterwards the significance level is calculated by referring the observed value to its permutation distribution. The *R* value itself shows the distinctiveness of the groups. A higher value indicates a greater dissimilarity in between groups, whereby $R > 0.5$ suggests discriminability. In case of significance, a similarity percentages routine (SIMPER) was used to identify characteristic species, which contribute most to the statistical dissimilarity. The identification is based on the ratio of the species dissimilarity of all pairs of inter group samples to its standard deviation. The standard deviation is a measure of how consistently a species contributes to the difference. The smaller the ratio, the more the species contributes to the dissimilarity between groups (Clarke et al. 2014).

3 Results

A geographic information system of the Kongsfjord with information on the transects was established and a digital elevation model (DEM) was generated. The calculated slope of the sea ground shows a gentle gradient at the inner fjord and an increased slope at the transects at the middle fjord at the south coast (Figure 3). The outer reaches of Kongsfjordneset exhibit a steep gradient as well as Hansneset, where a steep cliff is located.

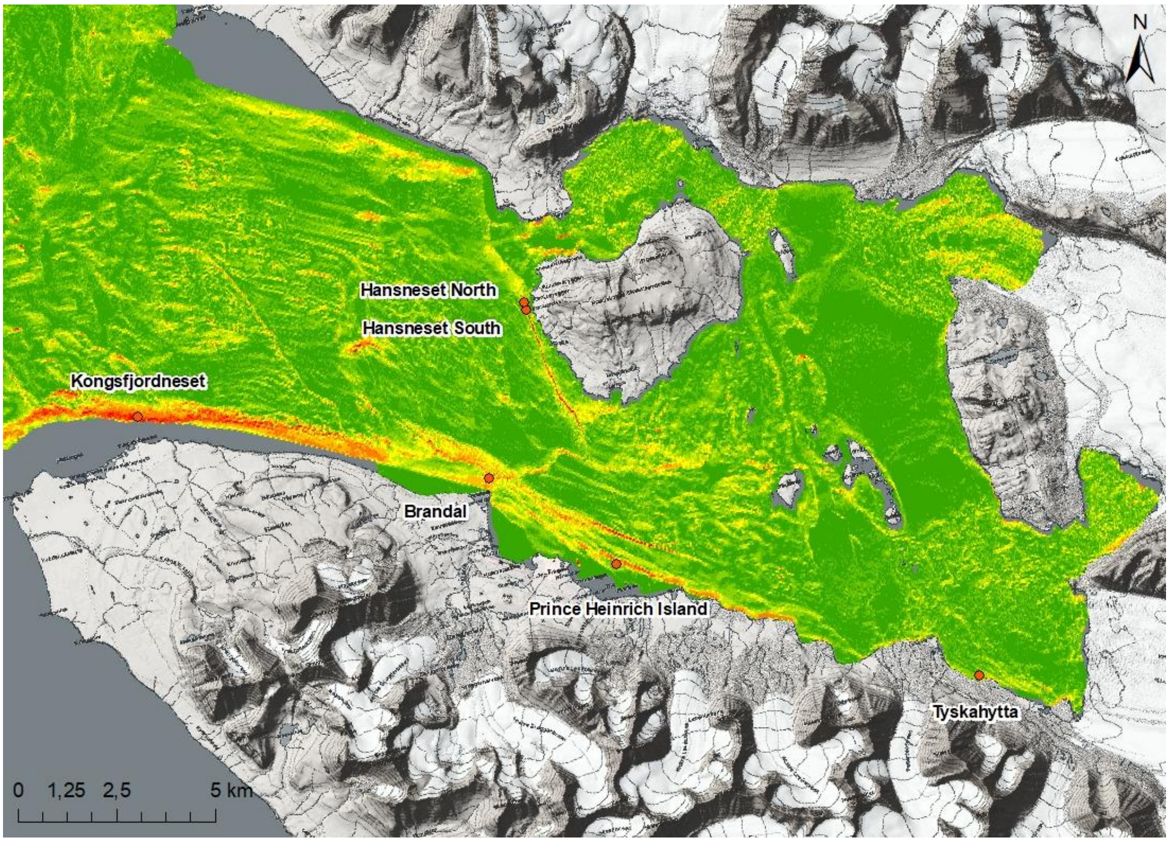

Figure 3 Slope of the sea ground at Kongsfjorden showing shallow (green) to steep (red) areas. Generated from the DEM, map data from Norwegian Mapping Authority and Norwegian Polar Institute

3.1 Course, elevation profile and sample points of the transects

In the following, the transects course, sample points and evaluation profiles of the six analysed transects are shown (Fig. 4- 14). Both transects at Hansneset (close to the island within the fjord) were located in close proximity. Hansneset north was situated approximately 50 m north of the transect Hansneset south (Figure 4). The area was characterised by hard bottom substrate, which was covered partly with silt. The total length of the transect Hansneset north was 800 m. It started at approximately 70 m water depth. At the beginning the ROV depth sensor was recording invalid data explaining the gap in the elevation profile (Figure 5). The course is showing that the ship moved into deeper waters hence the DEM depth reached a maximum of 140 m. Simultaneously the video is not showing a decent of the ROV. It remained at a same level, thus the depth of the ROV was interpolated to fill the gap for following evaluations. After that the transect followed a steep slope with increasing depth within short distance. After approximately 300 m the transect reached 20 m water depth and persisted between 0 and 20 m during the remaining 500 m. In average the depth from the DEM is 7 m lower than the one from the ROV with a standard deviation of 6 m. During some occasions the ship was moving faster than the ROV. Therefore, some sample points were discarded viewing the video, because they were too close to each other. An amount of 114 of 161 possible frames were analysed (Figure 4).

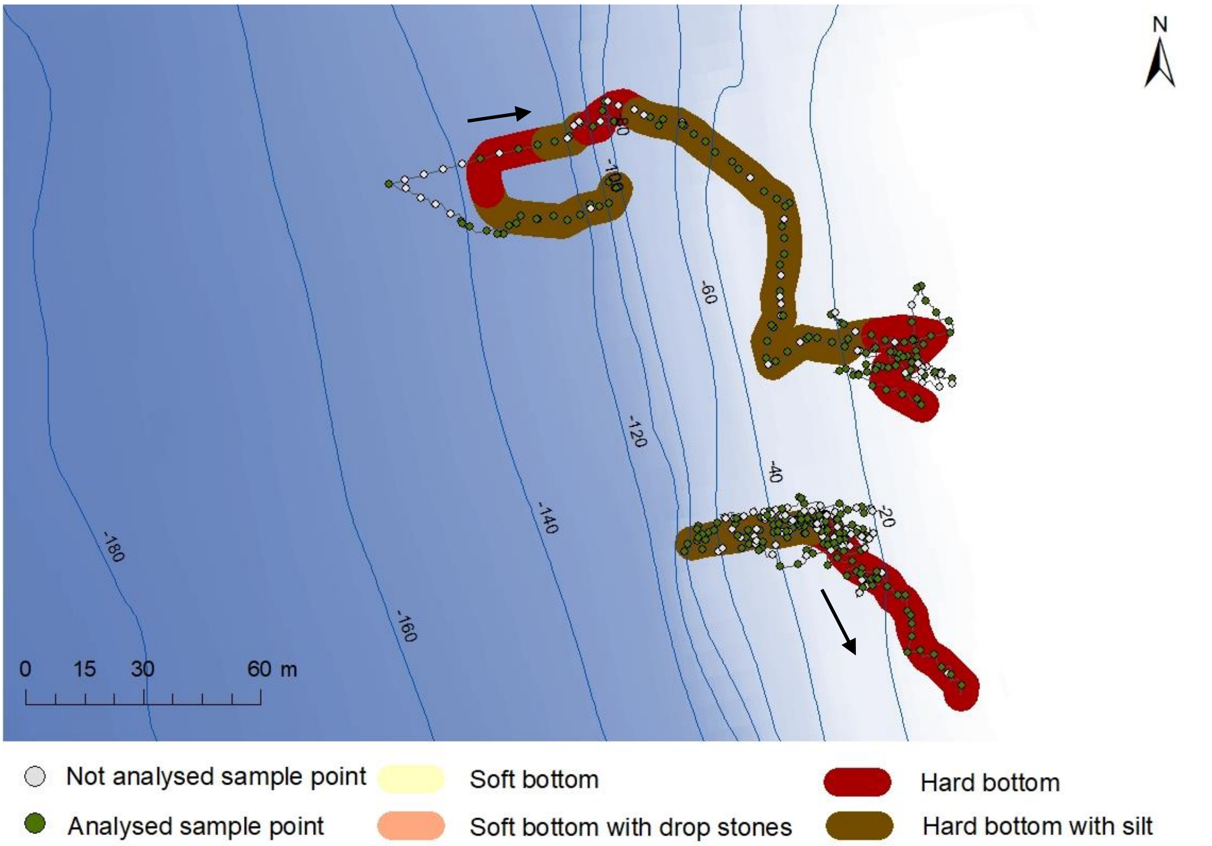

Figure 4 Hansneset: map of the course and sample points (analysed in green and discarded in grey) of the transects and bottom substrate, bathymetry by Norwegian Mapping Authority

The total length of the transect Hansneset south was 1000 m. It started at approximately 50 m water depth measured by the ROV sensor (Figure 6). The first 400 m the depth was fluctuating between 50 and 15 m. During the following 400 m the fluctuations decreased between 30 and 15 m. The last 200 m of the transect the ROV moved from a depth of approximately 20 to 6 m. However, these distinct depth changes were not visible on the recording. In average the depth of the DEM was 9 m (+/- 7 m SD) lower than the one from the ROV. During the recording the vessel approached several times the coastline and was dragged back again, possibly due to the current, resulting in an unequal velocity of ROV and ship. At this station 130 of possible 200 frames were evaluated (Figure 4).

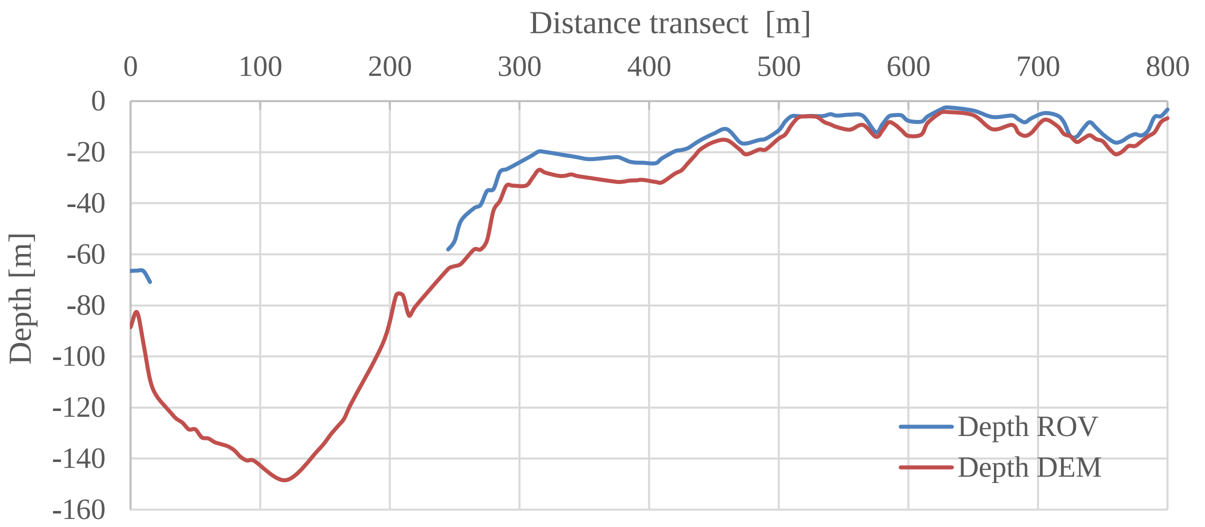

Figure 5 Hansneset north: elevation profiles based on ROV and DEM data, Norwegian Polar Institute. Gap induced by invalid measurement of the sensor

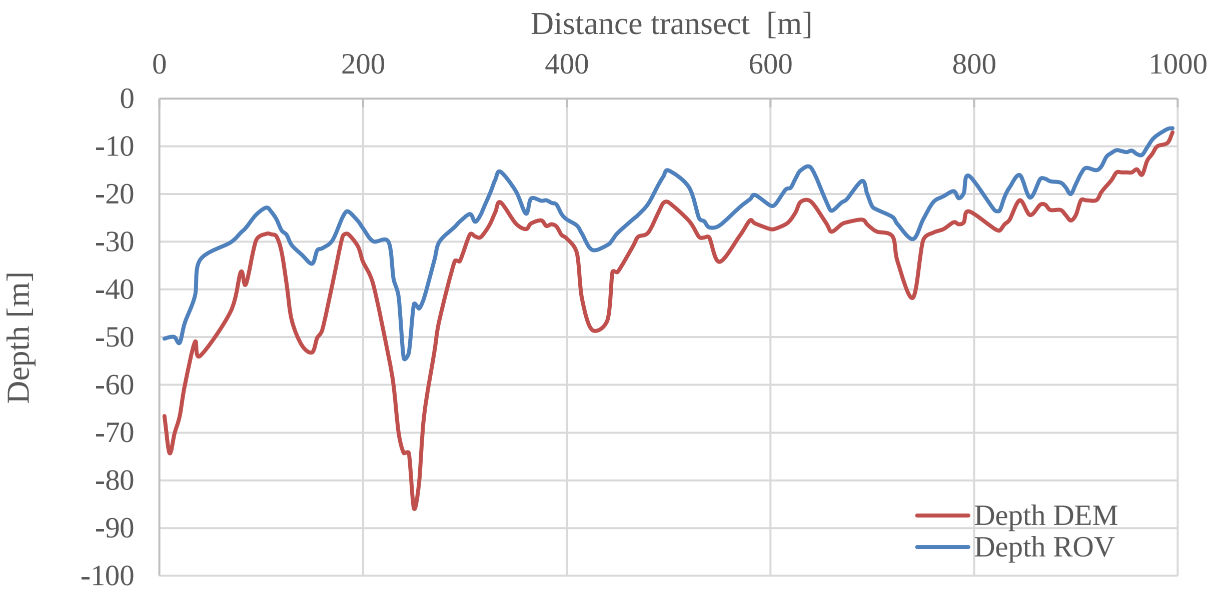

Figure 6 Hansneset south: elevation profiles based on ROV and DEM data, Norwegian Polar Institute

The course of the transect at Kongsfjordneset went first southwest and made then a curve into an eastern direction (Figure 7). The area was characterised mainly by hard bottom substrate. The total length of this transect was 900 m. It started at approximately 60 m water depth measured by the ROV sensor (Figure 8). The first 300 m the transect followed a slope with increasing depth to 12 m. After a short distance, where the depth decreased to 20 m, the ROV persisted at around 10 m for the remaining 500 m. The bathymetric data of the Norwegian Polar Institute does not reach as close to the coastline as the ROV was diving. Thus, the DEM depth is just available for the first 300 m of the transect (Figure 8). The first 50 m the DEM depth descends to over 90 m. The ROV depth suggests that the device was not included in this turn to deeper waters. The estimation of 5 m distance between the sample points was more accurate. Here 172 of 184 frames were analysed (Figure 7).

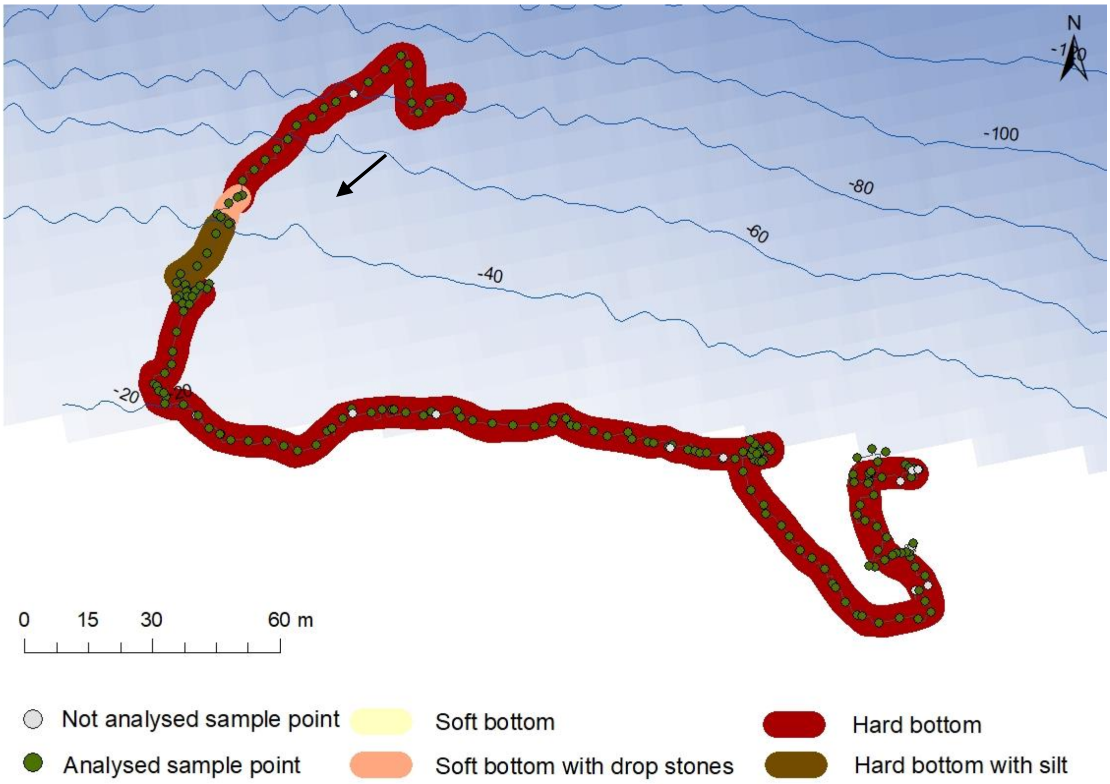

Figure 7 Kongsfjordneset: map of the course and sample points (analysed in green and discarded in grey), and bottom substrate, bathymetry by Norwegian Mapping Authority

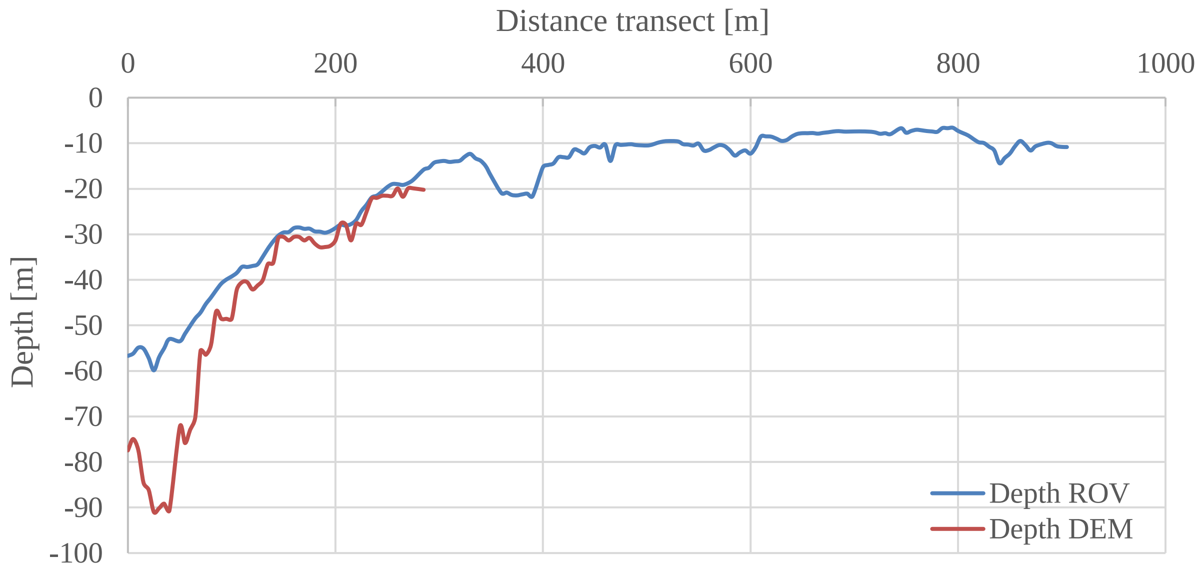

Figure 8 Kongsfjordneset: elevation profiles based on ROV and DEM data, Norwegian Polar Institute

The transect at Prince Heinrich Island had a north-south orientation heading towards the south coast of the fjord (Figure 9). The area is characterised mainly by soft bottom substrate with drop stones. The total length of this transect was 580 m. The transect started at approximately 44 m depth measured by the ROV sensor (Figure 10) and increased continuously to 15 m. The elevation profile of the ROV sensor and DEM lie close together. The mean difference amounts to 0 m (+/- 1 m SD). Most of the generated frames were analysed: 113 out of 117. At three locations the ship was slower than the ROV so that additional frames were extracted from the video. These were located after the distance of 280 m, 365 m and 370 m.

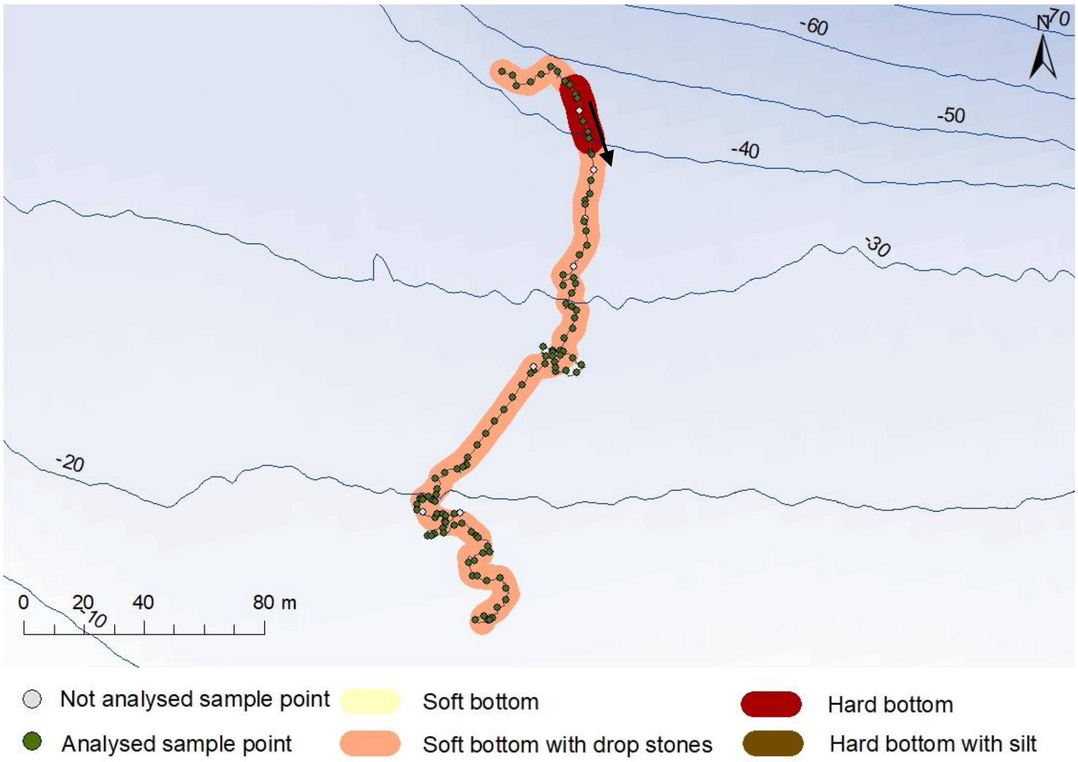

Figure 9 Prince Heinrich Island: map of the course and sample points (analysed in green and discarded in grey) and bottom substrate, bathymetry by Norwegian Mapping Authority

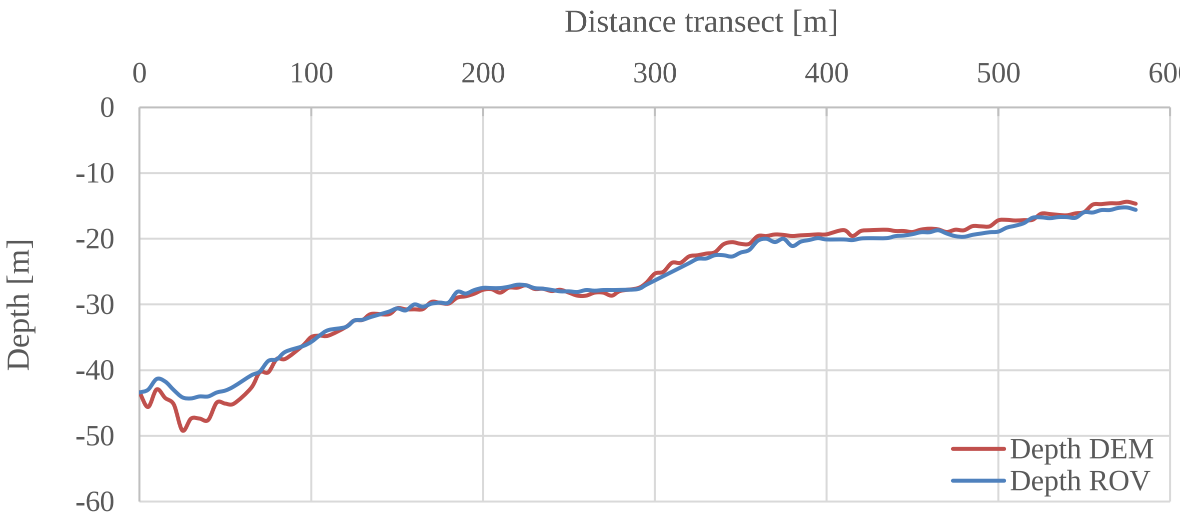

Figure 10 Prince Heinrich Island: elevation profiles based on ROV and DEM data, Norwegian Polar Institute

The course at Tyskahytta went circular (Figure 11). The area was characterised by soft bottom substrate and soft bottom with drop stones. The total length of this transect was 2400 m. The inner fjord is characterised by shallower waters. Hence the transect did not reach deep. It started at approximately 15 m water depth measured by the ROV sensor (Figure 12) and descended to 24 m in the first 500 m. After that the transect followed a slope with increasing depth up to almost 5 m within the following 400 m. After about 900 m the depth decreased again down to 15 m and rose up to 5 m again. The elevation of the ROV sensor and DEM showing similar values (Figure 12). In average the difference between the depths is 1 m (+/- 1 m SD). This transect was sampled every 10 m since the conditions were not changing as swift as at the other transects. However, here some frames had to be discarded as well. It seems like the ship was dragged by the water movement. This movement was not visible in the drive of the ROV. In the second part the ship drove an additional turn closer to the cost. In conclusion 157 out of 230 frames were analysed (Figure 11).

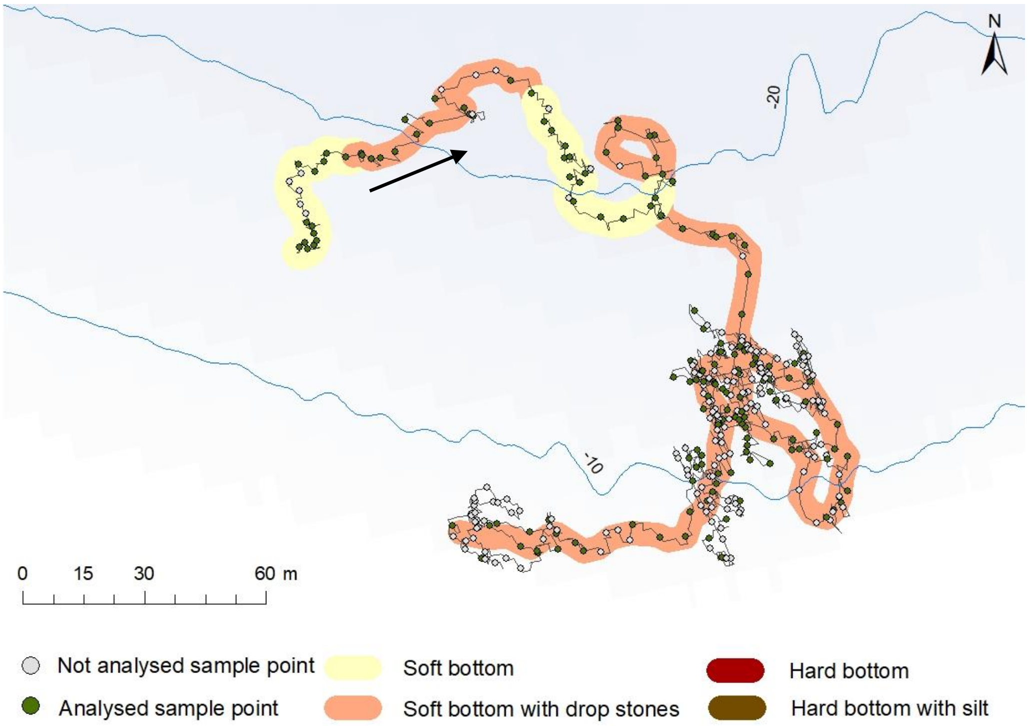

Figure 11 Tyskahytta: map of the course and sample points (analysed in green and discarded in grey) and bottom substrate, bathymetry by Norwegian Mapping Authority

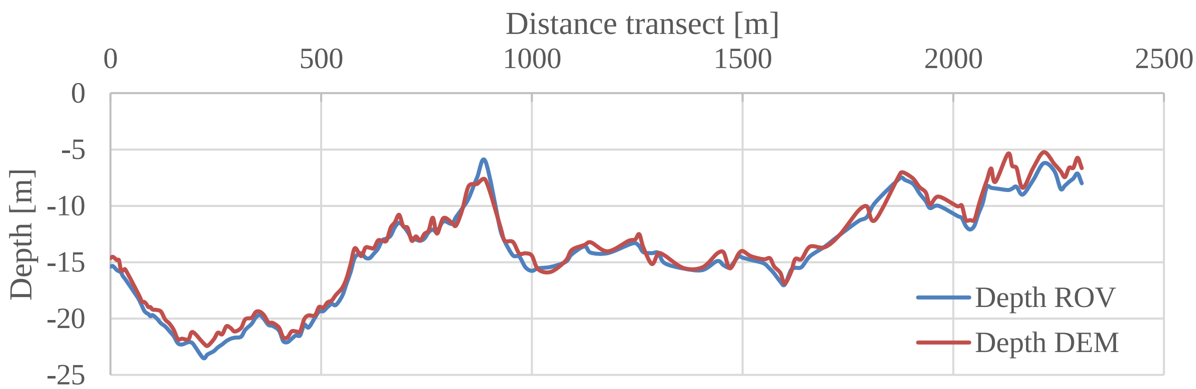

Figure 12 Tyskahytta: elevation profiles based on ROV and DEM data, Norwegian Polar Institute

The course at Brandal had a north-south orientation heading towards the south coast of Kongsfjorden (Figure 13). The area was characterised by soft bottom substrate and soft bottom with drop stones. The total length of this transect was 1200 m. The transect started at approximately 135 m water depth measured by the ROV sensor (Figure 14) and remained at this depth the first 200 m. The following 1000 m the transect increased continuously to a depth of over 5 m. The elevation profile of the ROV sensor and DEM lie close together. The mean difference amounts to 0 m (+/- 2 m SD). Here 221 of 236 frames were analysed.

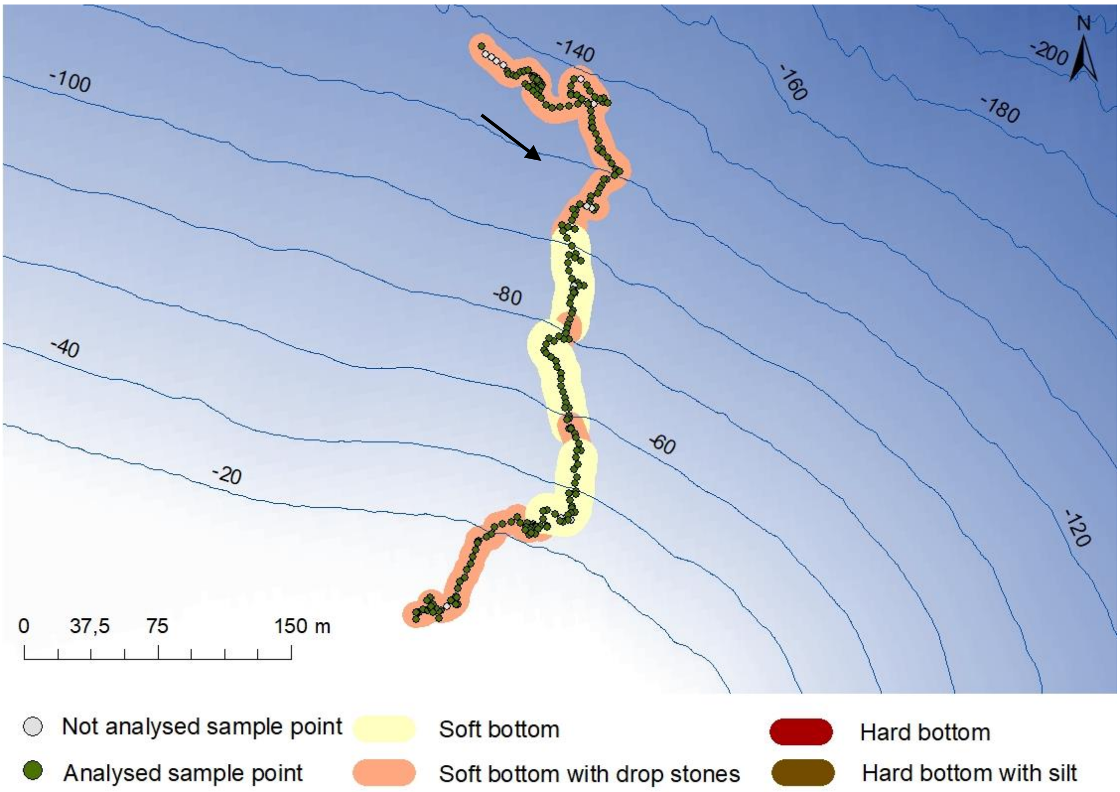

Figure 13 Brandal: map of the course and sample points (analysed in green and discarded in grey) and bottom substrate, bathymetry by Norwegian Mapping Authority

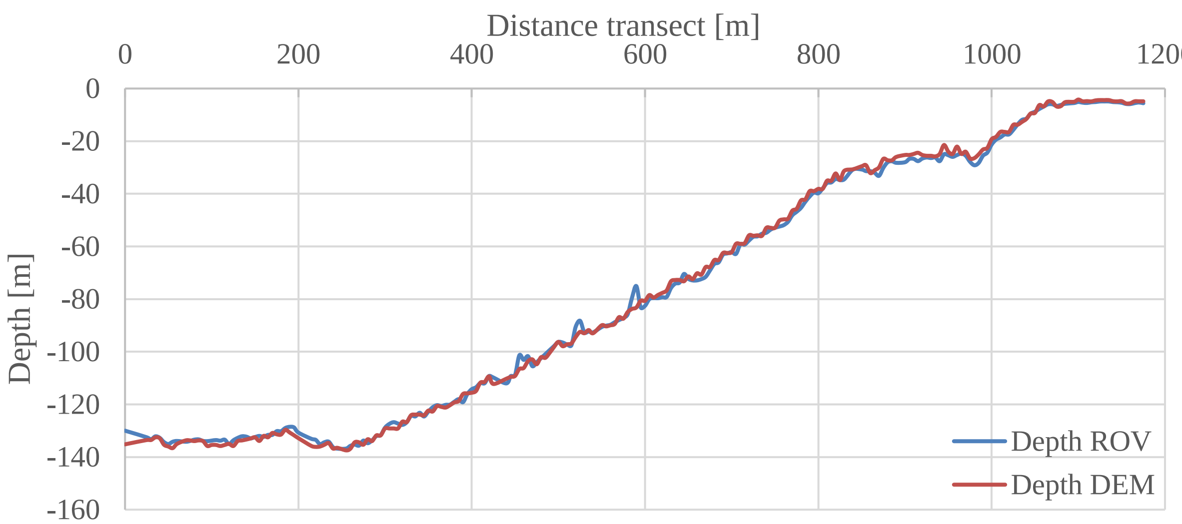

Figure 14 Brandal: elevation profiles based on ROV and DEM data of the Norwegian Polar Institute

3.2 Identified species

Overall 16 macroalgal species were found within the six transects in Kongsfjorden, with 2 Chlorophyta, 8 Phaeophyceae and 6 Rhodophyta (Table 1, Figure 15).

Two species of Chlorophyta could be identified: *Ulvaria obscura* and on genus level *Acrosiphonia sp*. *Ulvaria obscura* was recorded at the inner fjord mainly in the upper range of the sublittoral until 16 m depth. *Acrosiphonia sp.* was found at Prince Heinrich Island, Tyskahytta, at Brandal down to 24 m and appeared at Hansneset north until 14 m (Table 1).

Six Phaeophyceae could be identified on species level: *Alaria esculenta, Desmarestia aculeata, Desmarestia viridis, Dictyosiphon foeniculaceus, Halosiphon tomentosus, Laminaria solidungula, Saccharina latissima and Laminaria digitata/Saccharina nigripes.* Since *Laminaria digitata* and *Saccharina nigripes* were not distinguishable by picture, they were recorded as one. The brown algae *Alaria esculenta, Desmarestia aculeata* and *Saccharina latissima* were found at all transects. They were recorded from the upper part of the sublittoral until depths of approximately 30 m. *Desmarestia viridis* and *Laminaria digitata/Saccharina nigripes* were only recorded from Hansneset and Kongsfjordneset. Some individuals of *Desmarestia viridis* were found down to depths of 60 m. The species *Halosiphon tomentosus* and *Dictyosiphon foeniculaceus* occurred just in Brandal with depths of 14 respectively 10 m. *Laminaria solidungula* as the only endemic Arctic species was only found at Prince Heinrich Island between 20 and 24 m depth (Table 1).

From the Rhodophyta four species could be identified to species level: *Coccotylus truncatus*, *Devaleraea ramentaceae*, *Phycodrys rubens* and *Ptilota gunneri*. Coralline red algae and filamentous red algae were recorded but could not be identified to species level. *Coccotylus truncatus* occurred at Hansneset and Prince Heinrich Island with its deepest location 48 m (Hansneset north, Table 1). *Phycodrys rubens* was found at the same transects as *Coccotylus* but occurred down to 68 m at Hansneset north. *Devaleraea ramentacea* and *Ptilota gunneri* were found only at Hansneset. A filamentous red alga, possibly *Polysiphonia*, occurred at Kongsfjordneset and Prince Heinrich Island. The coralline red algae were distributed at Kongsfjordneset down to 60 m, at Hansneset down to 72 m and occurred occasionally at Prince Heinrich Island with a depth of 44 m. Overall Hansneset showed the highest number of Rhodophyta. At Brandal and Tyskahytta no red algae were recorded.

Most of the species were of arctic and cold-temperate distribution. Just one identified species had an arctic distribution (*Laminaria solidungula)* and three species have a distribution into warm-temperate regions (*Ulvaria obscura, Saccharina latissima, Ptilota gunneri).*

Table 1 Macroalgal species recorded at the transects and their depth range (m) in intervals of 2 m divided into Chlorophyta, Phaeophyceae and Rhodophyta and their biogeographic distribution centres: Arctic (a), cold-temperate (c) and warm-temperate (w), HN: Hansneset north, HS Hansneset south, KN Kongsfjord-neset, TH Tyskahytta, BL Brandal

		Depth range (m)					
	Distr.	HN	HS	KN	PHI	TH	BL
Chlorophyta							
Acrosiphonia sp.	ac	2-14			18-20	6-18	4-24
Ulvaria obscura	acw					6-12	8-16
Phaeophyceae							
Alaria esculenta	ac	2-16	10-30	6-16	16-20	6-12	8-28
Desmaresta aculeata	ac	2-14	18-30	6-30	14-32	6-18	4-30
Desmarestia viridis	ac	4-60	14-56	6-58			
Dictyosiphon foeniculaceus	ac						4-10
Halosiphon tomentosus	ac						8-14
Laminaria solidungula	a				20-24		
Laminaria digitata/ Saccharina nigripes	ac	2-18	6-24	6-8			
Saccharina latissima	acw	4-14	10-30	6-12	14-22	6-18	4-30
Rhodophyta							
Coccotylus truncatus	ac	10-48	20-22		18-22		
Coralline red algae		4-72	14-32	6-60	20-44		
Devaleraea ramentacea	ac	4-14					
Phycodrys rubens	ac	2-68	14-56		20-44		
filamentous red algae (*Polysiphonia)*	ac			10-40	18-36		
Ptilota gunneri	acw	26-28	18-34				

Figure 15 Images and identification of all recorded macroalgal species within the six transects of Kongsfjorden

3.3 Evaluated area and area distribution of the macroalgal groups

The analysed area per transect as well as the fraction of area covered by the macroalgal groups was evaluated (Table 2). The evaluation of the area was conducted via the laser spots. At Kongsfjordneset, Hansneset north and at the kelp dominated zone the area was estimated (see method section).

Table 2 Analysed area of the transects and area of algal groups (values in grey are estimated)

	Analysed Area [m 2]	Kelp [m 2]	filamentous brown algae [m 2]	foliated green algae [m 2]	filamentous green algae [m 2]	foliated red algae [m 2]	filamentous red algae [m 2]	coralline red algae [m 2]
Hansneset North	98.04	15.88	7.63	0.00	2.15	6.10	0.26	3.65
Hansneset South	111.99	31.36	7.70	0.00	0.00	9.02	0.00	4.74
Kongsfjordneset	147.92	6.89	7.33	0.00	0.00	0.00	0.09	47.09
Prince Heinrich Island	32.86	6.82	1.92	0.00	0.03	0.12	0.19	0.08
Tyskahytta	29.61	0.52	1.16	0.02	0.16	0.00	0.00	0.00
Brandal	101.64	2.91	1.91	0.08	1.04	0.00	0.00	0.00

Analysed areas between the different transects varied between 30 and 148 m^2 (Table 2) with the highest analysed area for Kongsfjordneset and the lowest for Tyskahytta. Analysed areas for Hansneset south, Hansneset north and Brandal were also high (112, 100 and 100 m^2, respectively) and for Prince Heinrich Island similar low as for Tyskahytta (33 m^2).

The evaluated area per depth class as well as the amount of replica were smaller in shallower waters because a navigation of the ROV was here not always possible (Table 9 and 10 appendix). The analysed area was mostly located in a depth range of 10 to 30 m (in average for all transects without Brandal: 79 % +/- 12 % SD) and decreasing with depth. However, at Brandal the majority of the analysed area lied under 30 m (75 %).

Most stations showed a high fraction of kelp (Table 2). The highest areas covered with kelp were recorded for Hansneset north and south with 16 and 31 m^2. An exception is Tyskahytta, which was thinly populated with macroalgae in general as well Brandal. Furthermore, filamentous brown algae were occurring at every station (1-8 m^2). At Hansneset a higher area was covered by foliated red algae. Noticeable as well is the extraordinary area of coralline red algae at Kongsfjordneset with 47 m^2. This is the vastest area measured of any macroalgae in this study.

3.4 Macroalgal cover of the transects at different depths

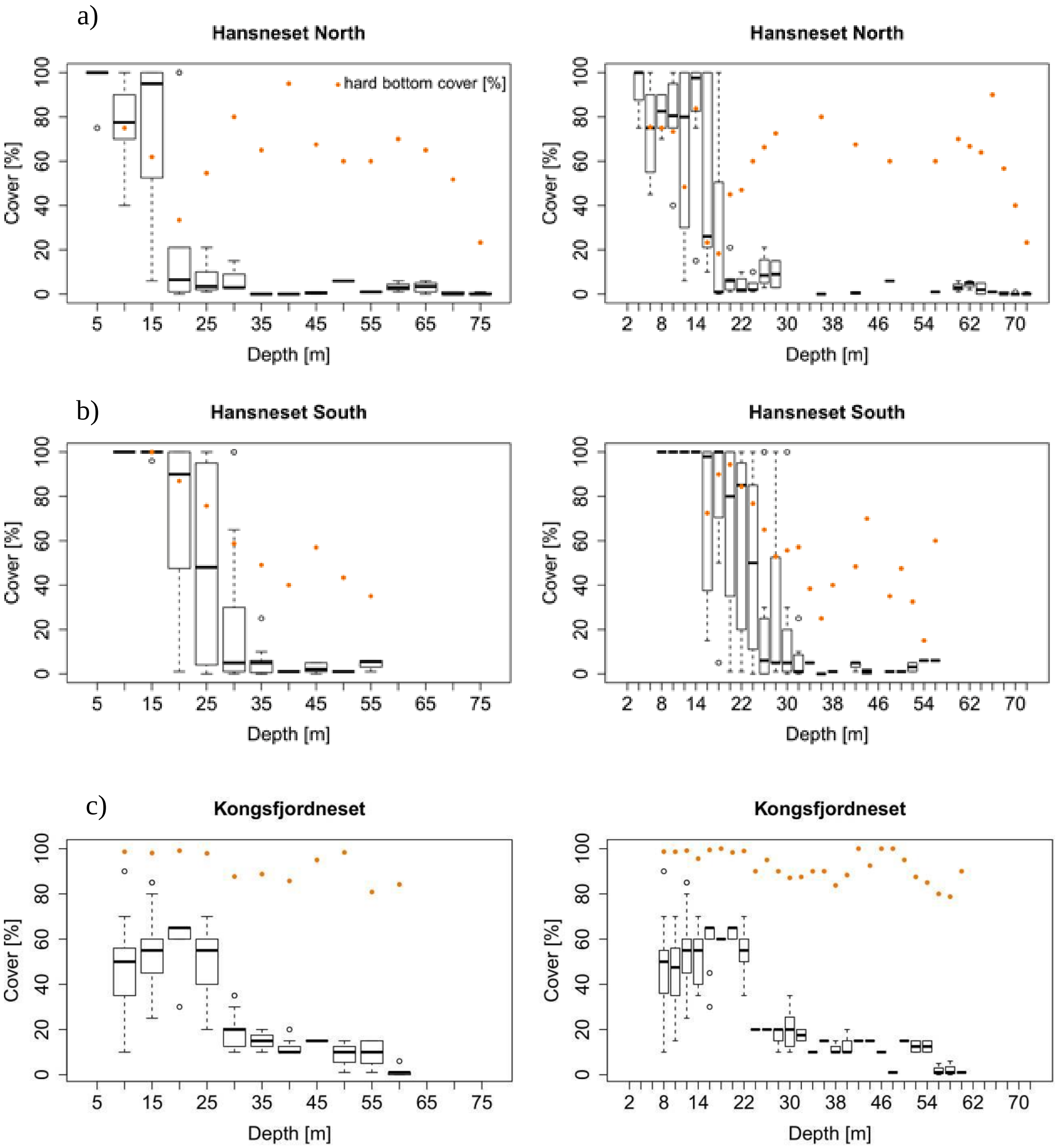

Figure 16 Macroalgal cover (median, 25 and 75 % quantile, maximum, minimum and outliers) at a) Hansneset north b) Hansneset south c) Kongsfjordneset every 5 m (left) and every 2 m (right). The labelling of the x axis is always showing the lower border of a depth category. Mean hard bottom cover is noted with orange points. Evaluated area and replica per depth are listed in Table 9 and Table 10. Depth classes, where no sample was taken, have no marking in the figure.

Macroalgal and hard bottom cover were evaluated with a 5 m and 2 m resolution. The station Hansneset north exhibited an almost complete macroalgal cover (70-100 %) at shallower depths down to 15 m (Figure 16a). Between 12 and 18 m the cover is showing an increased scatter. The interquartil range amounts up to 80 %. At depths lower than 18 m the macroalgal cover was decreasing and did not extend 20 %. However, even at 70 m macroalgae were found.

The neighbouring station Hansneset south was densly covered (100 %) by macroalgae down to 10 m (Figure 16b). From 10 m depth onward the cover decreased and showed more variation. However, until 30 m the macroalgal cover was reaching higher percentages than in the northern station by approximatly 50 %. The transect went down to 55 m were macroalgea were still detectable. In lower depth individuals covered the sea ground occasionally. The hard bottom cover for both locations was similar (20-80 %). The sea ground was covered with silt in deeper regions.

Macroalgal cover at Kongsfjordneset ranged around 60 % down to 22 m (Figure 16c). At sites from 24 m and deeper macroalgal cover declined strongly to approximately 20 %. The hard bottom substrate cover at Kongsfjordneset was constantly high in the range of 80-100 %.

At Prince Heinrich Island a dense macroalgal cover of almost 100 % was dominating at 14 m to 18 m depth (Figure 17a). Between 18 m and 22 m the cover was declining abruptly and lower 22 m the median cover did not exceed 5 %. The ground was just covered occasionally indicated in the boxplot by outliers at 28-32 m and 42 m depth, which reached values of 40 %. This transect was dominated by soft bottom with drop stones. Thus, the hard bottom cover was lower than at the locations further north or at the outer fjord with values between 0 and 60 %.

Macroalgae was found at the transect in Tyskahytta mainly in the second shallower part of the transect. At the depth range of 6 to 10 m the median cover was around 20 % (Figure 17b). From 12 to 18 m the coverage was close to zero with several outliers reaching up to 70 %. Lower 18 m there was no macroalgal cover. The dominant substrate at Tyskahytta was soft bottom. The hard bottom cover varied between 0 and 20 % at depths lower 12 m due to drop stones. However, at some parts at lower depths between 6 and 12 m the ground was covered completely by scree entering the fjord through the glaciers resulting in a mean hard bottom cover of almost 60 %.

The macroalgal cover in Brandal was increasing from 4 m to 10 m depth with its peak at 60 % (Figure 17c). From 10 m downwards the macroalgal cover was decreasing. Just at 26 and 30 m the median cover reached values of approximately 40 % again. Macroalgae were recorded down to 30 m and then no attached algae was found. Soft bottom was the dominant substrate as well in Brandal with just a few drop stones. The cover of hard bottom substrate never exceeded 20 %.

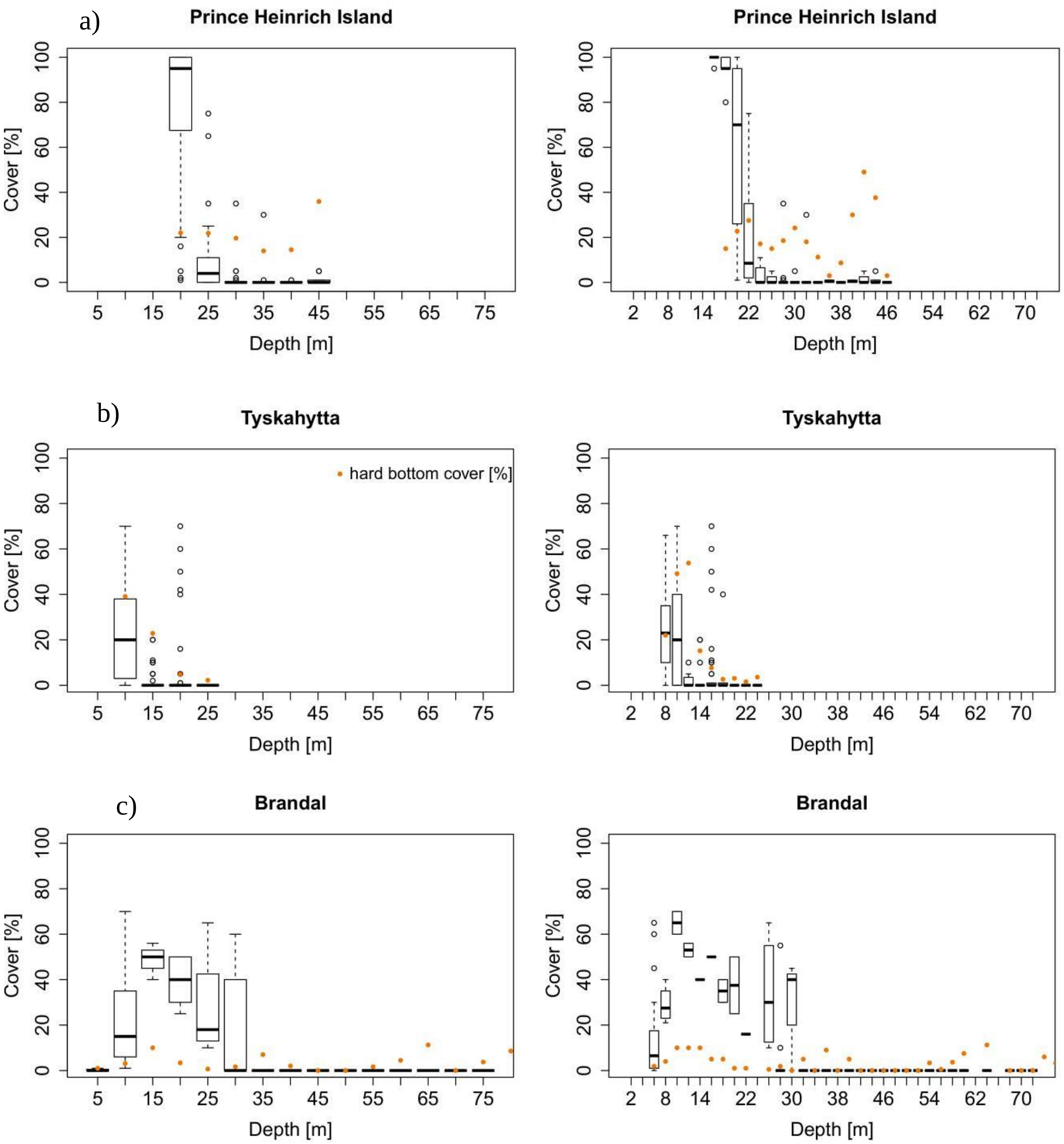

Figure 17 Macroalgal cover (median, 25 and 75 % quantile, maximum, minimum and outliers) at a) Prince Heinrich Island b) Tyskahytta c) Brandal every 5 m (left) and every 2 m (right). The labelling of the x axis is always showing the lower border of a depth category. Mean hard bottom cover is noted with orange points. Evaluated area and replica per depth are listed in Table 9 and Table 10. Depth classes, where no sample was taken, have no marking in the figure.

3.5 Classification of the macroalgal cover

The macroalgal cover of all transects was evaluated for all transects classified into the seven groups. At Hansneset north the ROV was passing three different regions all of them extended between 2 and 14 m depth (Figure 18). The first region was an area with low growing vegetation, dominated *Acrosiphonia*, *Devaleraea ramentacea* and short *Laminaria digitate/Saccharina nigripes*. A physical disturbance has taken place. Probably an ice berg scratched over the area. A mixture dominated by *Desmarestia viridis*, *Desmarestia aculeata*, *Phycodrys rubens* and coralline red algae was following. At some parts the cover of *Phycodrys rubens* was very dense. This vegetation was replaced by a kelp forest, dominated by *Alaria esculenta*, *Laminaria digitate/Saccharina nigripes* and *Saccharina latissima*. The proportion of this kelp forest increased from 10 m depth down to 14 m to a mean cover of 60 %. Between 14 m and 18 m the kelp species *Laminaria digitate/Saccharina nigripes* was dominant with a mean cover of 60 % decreasing to 20 %. Lower than 20 m the proportion of Rhodophyta got higher, mostly *Phycodrys rubens*. Furthermore, the filamentous brown algae *Desmarestia viridis* and some coralline red algae were found. Due to the steep underground the ROV ascended fast over short distance resulting in not analysed depth classes. These are marked in the figure by *nd* (no data).

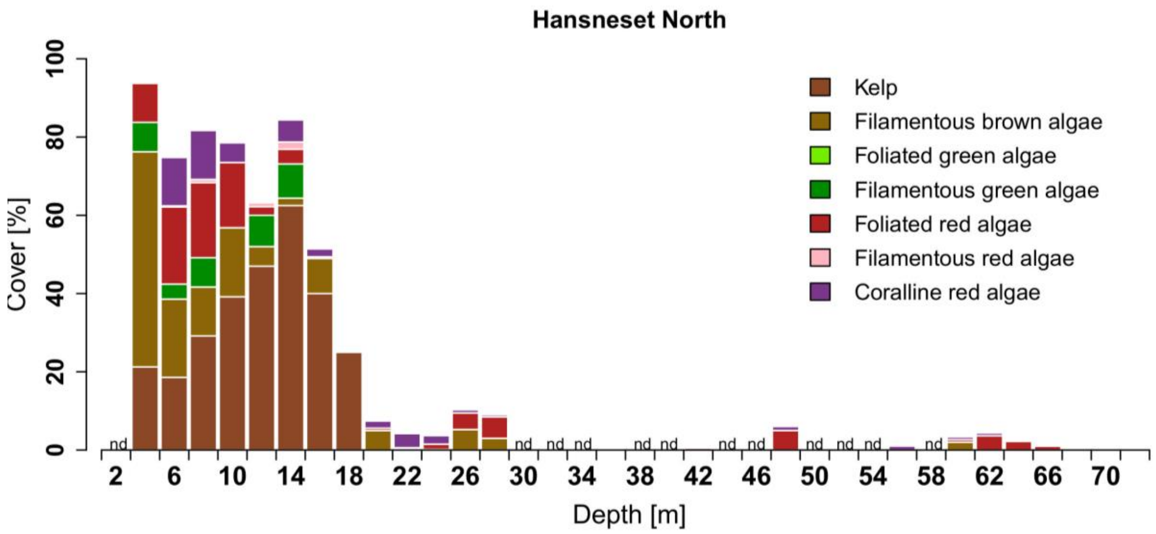

Figure 18 Mean macroalgal cover classified into macroalgae groups for the station at Hansneset north in depth intervals of 2 m. Not analysed depths are marked with *nd*

At the transect Hansneset south a kelp forest covered the ground completely down to 14 m dominated by *Laminaria digitata/Saccharina nigripes* from 6 m to 10 m and by a mixture of *Alaria esculenta*, *Saccharina latissima* and *Laminaria digitata/Saccharina nigripes* from 10 m to 14 m (Figure 19). The cover of the kelp decreased lower 14 m and *Alaria esculenta* and *Saccharina latissima* got more dominant in the mixture. Deeper 30 m no kelp was found. Lower 14 m filamentous Phaeophyceae (mostly *Desmarestia viridis)* were recorded and covered the ground down to 30 m continuously with 5 to 20 %. Furthermore, foliated Rhodophyta, dominated by *Phycodrys rubens,* and coralline red algae covered 10 to 30 % of the sea floor in this depth range. Lower 32 m foliated red algae were dominant.

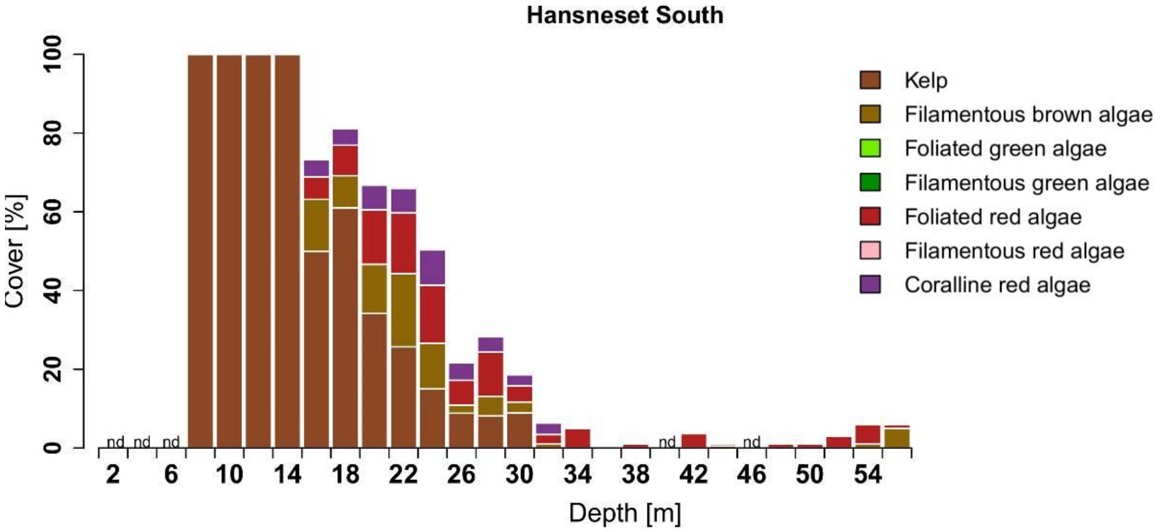

Figure 19 Mean macroalgal cover classified into macroalgae groups for the station at Hansneset south in depth intervals of 2 m. Not analysed depths are marked with *nd.*

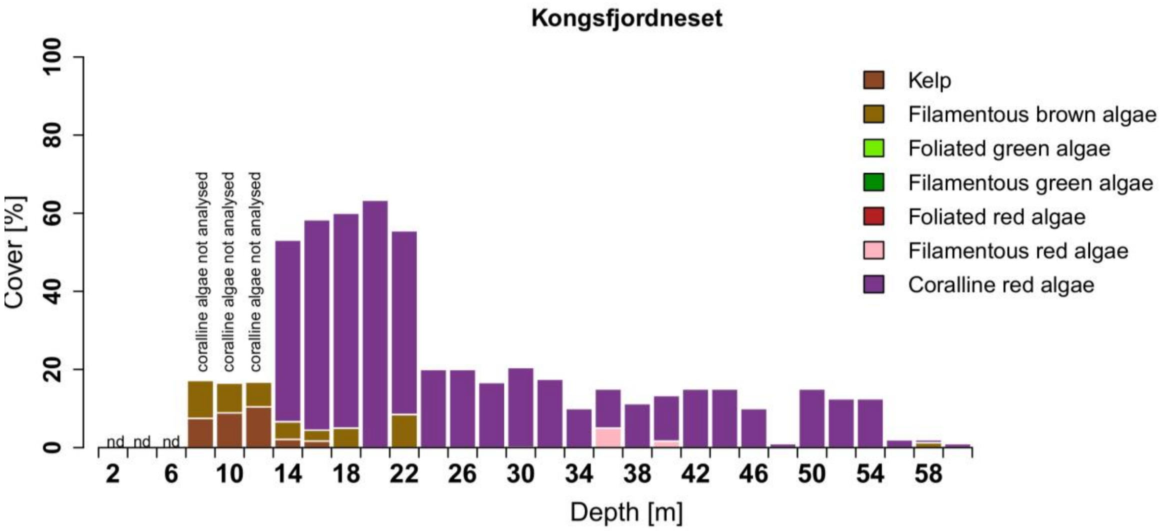

Figure 20 Mean macroalgal cover classified into macroalgae groups for the station at Kongsfjordneset in depth intervals of 2 m. Not analysed depths are marked with *nd.*

At Kongsfjordneset kelps, dominated by *Alaria esculenta*, were recorded from 6 to 16 m with a cover of 10 % (Figure 20). They were growing in patches surrounded by the two filamentous brown algae species *Desmarestia viridis* and *Desmarestia aculeata*, which were growing down to 22 m. The kelp free areas until 12 m were covered by coralline red algae. However, the light conditions here were unsuitable to estimate their coverage properly. Between 12 and 22 m the macroalgal cover was dominated by coralline red algae with values up to 60 %. Lower 22 m the cover of coralline algae declined to approximately 20 %. Here some filamentous red algae were recorded as well at 36 and 40 m depth.

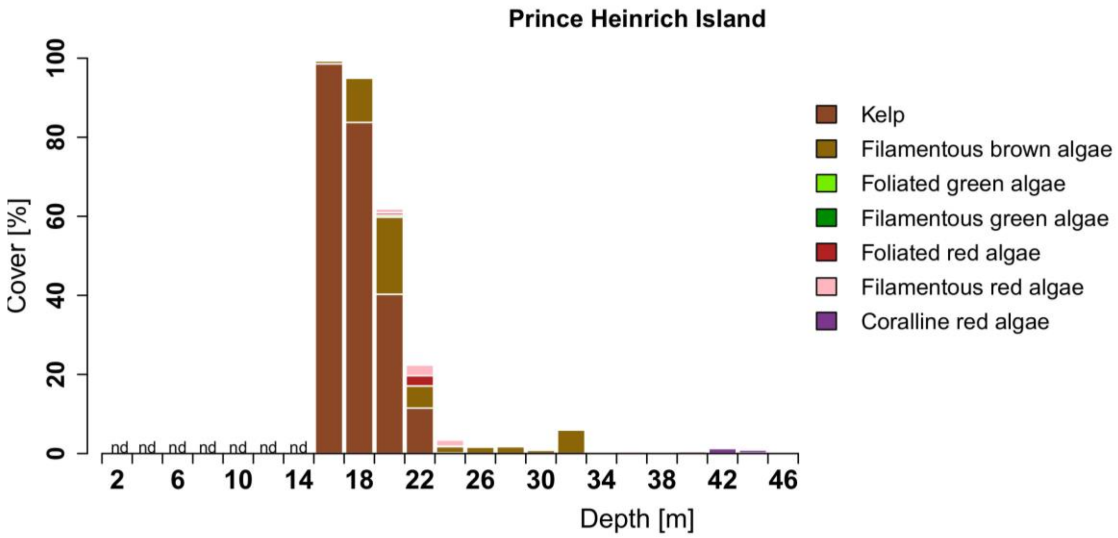

Figure 21 Mean macroalgal cover classified into macroalgae groups for the station at Prince Heinrich Island in depth intervals of 2 m. Not analysed depths are marked with *nd*.

At Prince Heinrich Island the macroalgal cover was dominated by the kelp species *Saccharina latissima* between 14 and 16 m (Figure 21). From 16 to 22 m kelp in combination with the filamentous brown algae *Desmarestia aculeata* were covering the ground with declining density to approximately 20 %. Filamentous brown algae were recorded down to 32 m. Foliated and filamentous red algae appeared at depths between 18 and 24 m with a cover of maximum 5 %. At 40 to 44 m coralline algae were recorded with a cover about 1 %.

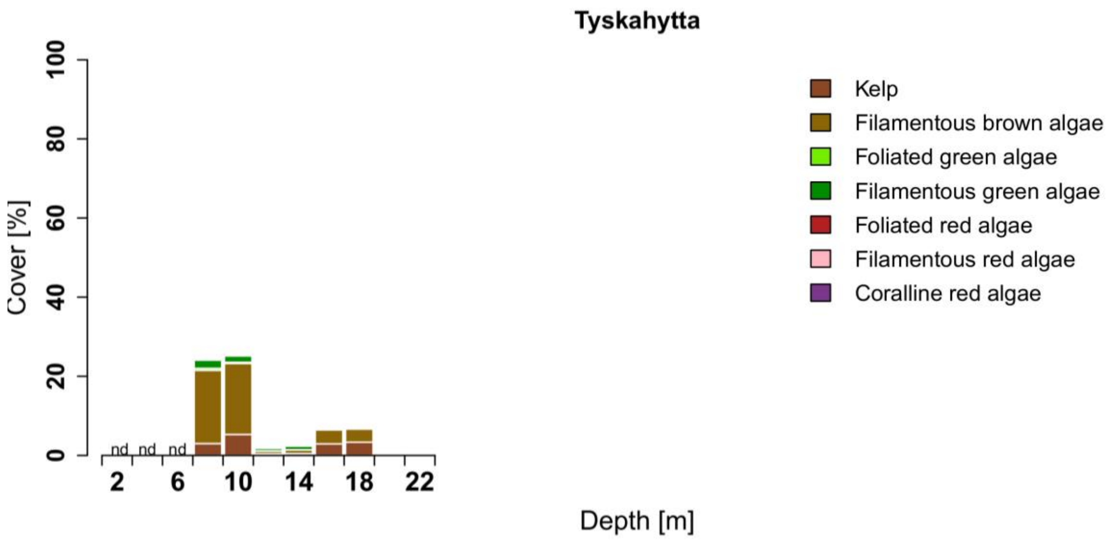

Figure 22 Mean macroalgal cover classified into macroalgae groups for the station Tyskahytta in depth intervals of 2 m. Not analysed depths are marked with *nd*.

The station Tyskahytta was less covered by macroalgae (Figure 22). At 6 to 10 m depth *Desmarestia aculeata* dominated with a cover of around 20 %. Furthermore, the filamentous green algae *Acrosiphonia sp.* and single individuals of the foliated green algae *Ulvaria obscura* were detected. *Saccharina latissima* was recorded with a cover of approximately 5 % at this depth range. Between 10 and 14 m a low macroalgal cover (<5 %) of filamentous green and brown algae was found. At 14 m to 18 m depth *Saccharina latissima* and *Desmarestia aculeata* covered 10 % of the ground.

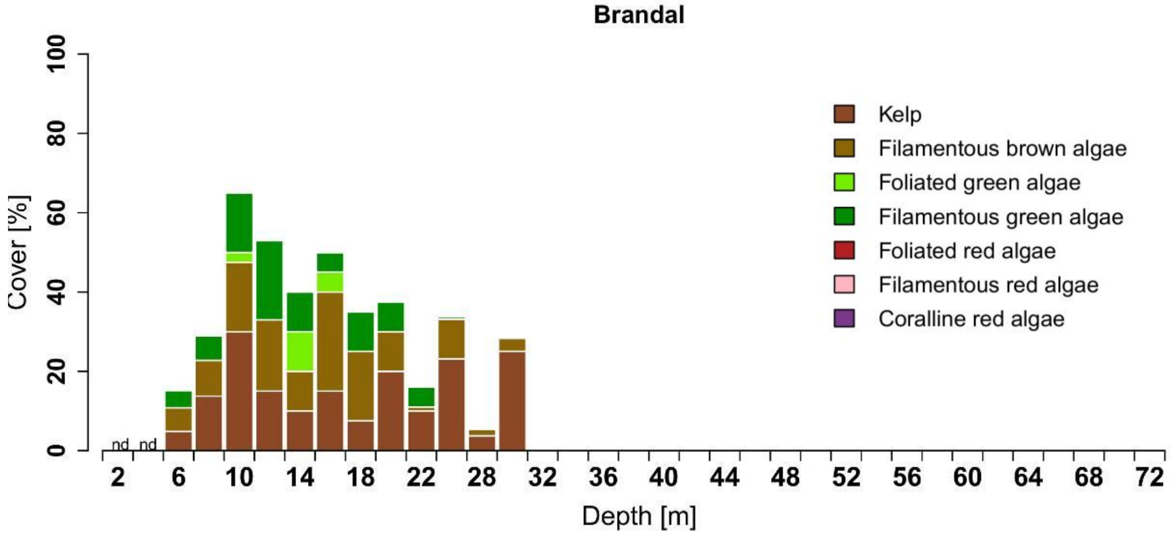

Figure 23 Mean macroalgal cover classified into macroalgae groups for the station Brandal in depth intervals of 2 m. Not analysed depths are marked with *nd*.

At Brandal the increasing macroalgal cover between 4 and 8 m comprised a mixture of the kelp *Saccharina latissima*, the filamentous brown algae *Desmarestia aculeata* and the green algae *Acrosiphonia sp.* (Figure 23). Next to these species the filamentous green algae *Ulvaria obscura* was recorded with a cover of up to 10 % between 8 and 16 m. In this depth range several species of filamentous brown algae were detected as well: *Desmarestia aculeata*, *Dictyosiphon foeniculaceus* and *Halosiphon tomentosus*. From 10 m depth the macroalgal distribution was decreasing and lower 30 m no macroalgae was recorded. In this lower depth range *Saccharina latissima*, *Desmarestia aculeata* and *Acrosiphonia sp.* were dominating the macroalgal cover again.

3.6 Cover of detritus and detached algae

Figure 24 is showing the cover of detached or degraded macroalgae (detritus) of the six transects. The ones at the outer fjord generally exhibited lower values. At Hansneset a detritus cover of maximum 10 % was recorded but only for depths deeper 18 m, while at Kongsfjordneset only 1 % detritus was recorded at 58 m. The inner stations showed a higher detrital cover compared to the outer transects. At Prince Heinrich Island detritus with a cover of up to 15 % was found at depths lower than 16 m. At Tyskahytta detritus was recorded at every depth. The cover was reaching relatively high 10 % compared to the low cover of attached macroalgae here. However, Brandal showed the highest detrital cover of all transects. From 24 m down detritus was covering a remarkable percentage of the sea ground reaching occasionally 40 % and at 132 m depth over 60 % in average. At several areas piles of detritus were formed, whereby the algae at higher locations until 40 m appeared to be detached recently. Lower located detritus was a compound of lately detached and more degraded algae.

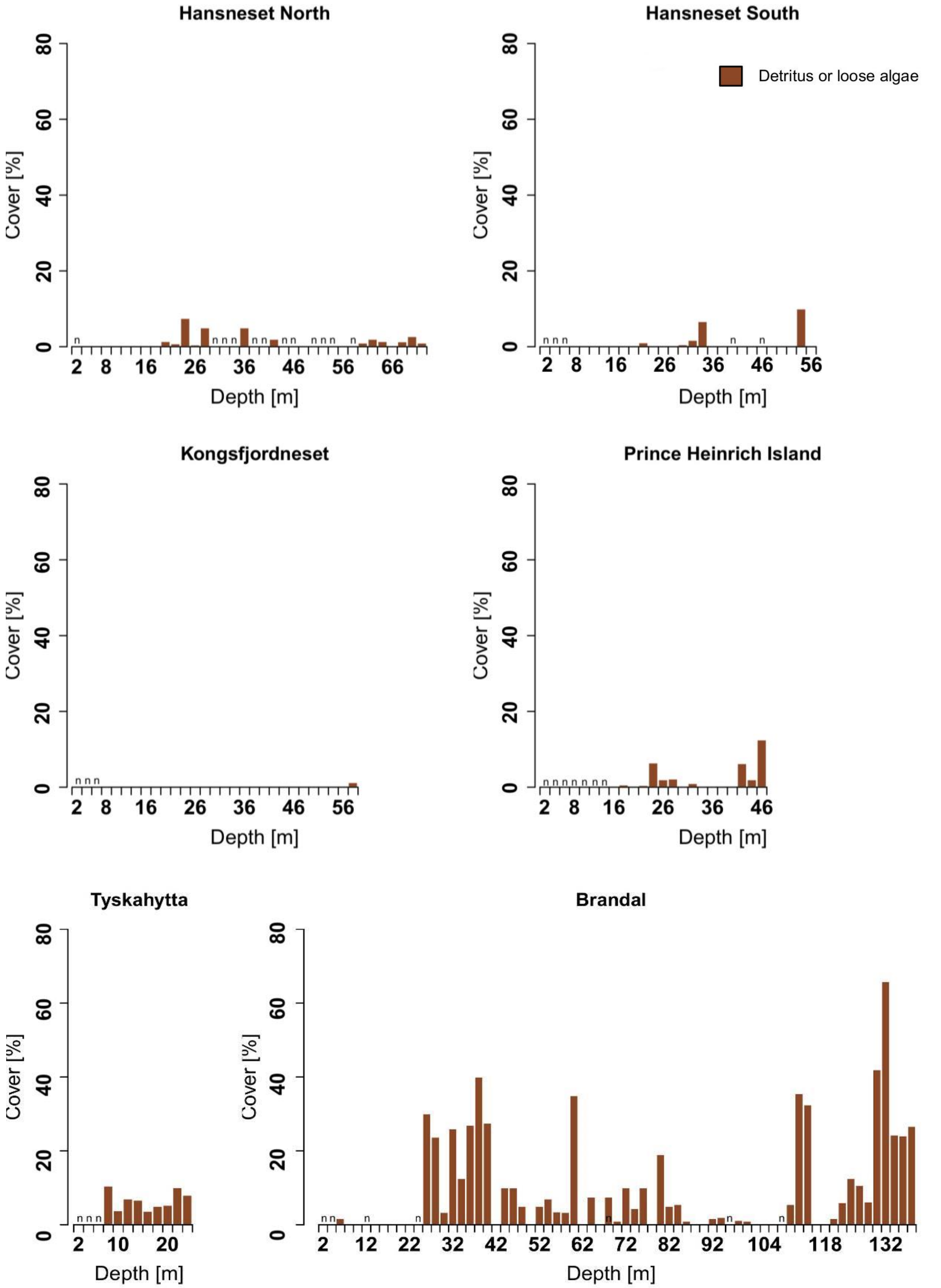

Figure 24 Cover of degraded or detached algae of all transects in depth intervals of 2 m. Not analysed depths are marked with *n*.

3.7 Microphytobenthic cover

In general, microphytobenthic cover was only found at locations with soft bottom or on hard bottom with silt (Table 3). The latter case was recorded at Hansneset and Kongsfjordneset. Microphytobenthos was situated occasionally on silt at 15 to 60 m at Hansneset north respectively at 18 to 53 m at Hansneset south with a classification of cover, which correspond to 10 %. At Kongsfjordneset microalgal lawns appeared at 40 to 56 m with a cover of 10 % and partially 25 %. The station at Prince Heinrich Island was widely covered. At lower depths (44 to 38 m) the cover amounted 10 %. Until 22 m the cover increased to values of around 50 % and occasionally higher. At the areas, which were covered by kelp and *Desmarestia*, no microalgae were found. Furthermore, the station at Tyskahytta showed the same widespread microalgal cover. Just the last 800 m of the transect with depth down to 15 m, which were covered with scree and later with sand, were microalgal free. Although the station at Brandal was covered by soft bottom no microalgae were detected. Only a small groove of microphytobenthos was found at 28 to 32 m.

Table 3 Microphytobenthic distribution at the transects with depth range [m] and cover [%]

Transect		Depth range [m]	Cover [%]
Hansneset north	Occasionally on silt	15 - 60	10
Hansneset south	Occasionally on silt	18 - 53	10
Kongsfjordneset	Occasionally on silt	40 - 56	10 - 25
Prince Heinrich Island	Widespread on soft bottom	38 - 44 22 - 38	10 25 - 50
Tyskahytta	Widespread on soft bottom	15 - 25	25 - 50
Brandal	Just one location	28 - 32	25

3.8 Macrozoobenthic cover

Figure 25 shows the zoobenthic cover. Due to a dense macroalgae canopy at shallower depths zoobenthos was not visible and therefore not analysed and marked with “n”. At Hansneset the cover increased from shallower waters to 35 m to a value over 30 % and decreased afterwards. Just at the northern transect the cover rose up thereafter again. Sponges, tunicate and individuals of the order Actiniaria dominated these locations. Actiniaria were also dominant at Kongsfjordneset located mostly at the lower depths. Sea urchins were recorded here in high abundances as well. They were found at a depth of 15 m and higher and covered up to 20 % of the ground. At

Prince Heinrich Island and Brandal, both characterised by soft bottom, zoobenthic cover remained low with values reaching up to 10 % and marginally higher. Whilst epibenthic tunicate were found at the first in higher numbers, mobile crustaceans and small fish were recorded at the latter. The first part of the transect at Tyskahytta was populated with a large number of Sabellidae of the class Polychaeta. From 15 m and lower they covered 30 % of the sea floor continuously. At shallower locations zoobenthos was recorded scarcely.

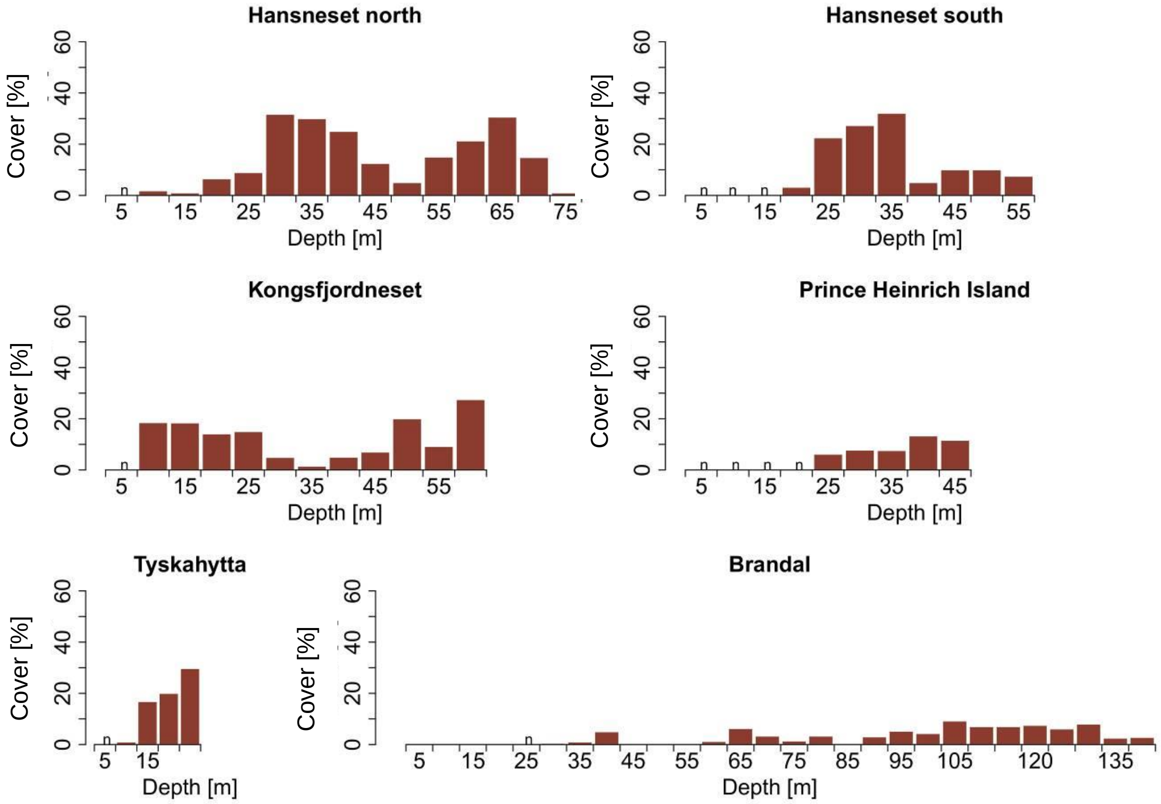

Figure 25 Macrozoobenthic cover of all transects in depth intervals of 5 m. Not analysed depths are marked with *n*.

3.9 Community analysis

The community analysis regarding depth, location at the fjord and bottom substrate showed that the benthic communities were significant different between outer and inner locations of the fjord as well as between soft bottom and hard bottom locations when zoobenthos was excluded. Every transect had a distinct depth zonation but the dissimilarities between the depth zones were mainly not higher than the ones within a zone.

The results of the ANOSIM (Table 4) showed that the observed differences between the depth zones were mainly not larger than dissimilarities among replicates within one zone. Species composition was just significantly different between 5 m to 30, 40, 50, 60 and 70 m considering the presence/absence of species ($R > 0.5$, $p < 0.05$). Regarding the cover of the species community, almost the same results were obtained (Table 4). The similarities of the community structure between sample points are displayed graphically via the MDS plot. Based on the presence/absence data (Figure 26 left) the samples at lower depths, like 70 m and 50 m, lie closer to each other. The samples at 40 m and 20 m disperse wider, overlapping the area of the lower depths. At 30 m and 10 m the samples scatter intense thus their community structure was more divers. The MDS plot based on the cover data shows similar results (Figure 26 right).

Table 4 Results of ANOSIM (pairwise test and Global R, p) on species composition for sampling points until 70 m depth for presence/absence and cover data; evaluation of the factor depth (categorized)

		P/A		**Cover**				**P/A**		**Cover**	
Depth [m]		**R**	**p**	**R**	**p**	**Depth [m]**		**R**	**p**	**R**	**p**
70	**60**	0.124	0.001	0.036	0.073	**50**	**30**	-0.08	0.958	-0.071	0.945
70	**50**	0.16	0.001	0.069	0.014	**50**	**20**	-0.046	0.887	0.033	0.165
70	**40**	0.108	0.003	0.01	0.337	**50**	**10**	0.188	0.001	0.265	0.001
70	**30**	0.065	0.096	-0.075	0.934	**50**	**5**	**0.686**	**0.001**	**0.636**	**0.001**
70	**20**	0.049	0.1	0.024	0.228	**40**	**30**	0.019	0.297	0.012	0.374
70	**10**	0.216	0.001	0.271	0.001	**40**	**20**	0.026	0.19	0.099	0.003
70	**5**	**0.668**	**0.001**	**0.712**	**0.001**	**40**	**10**	0.235	0.001	0.29	0.001
60	**50**	0.017	0.16	-0.003	0.455	**40**	**5**	**0.584**	**0.001**	**0.506**	**0.001**
60	**40**	-0.012	0.611	-0.009	0.585	**30**	**20**	0.019	0.015	0.047	0.001
60	**30**	-0.006	0.506	-0.023	0.683	**30**	**10**	0.216	0.001	0.198	0.001
60	**20**	0.004	0.456	0.06	0.056	**30**	**5**	**0.519**	**0.001**	0.463	0.001
60	**10**	0.167	0.002	0.252	0.001	**20**	**10**	0.074	0.001	0.052	0.001
60	**5**	**0.543**	**0.001**	**0.531**	**0.001**	**20**	**5**	0.299	0.001	0.251	0.001
50	**40**	-0.056	0.999	-0.027	0.848	**10**	**5**	0.198	0.011	0.192	0.012

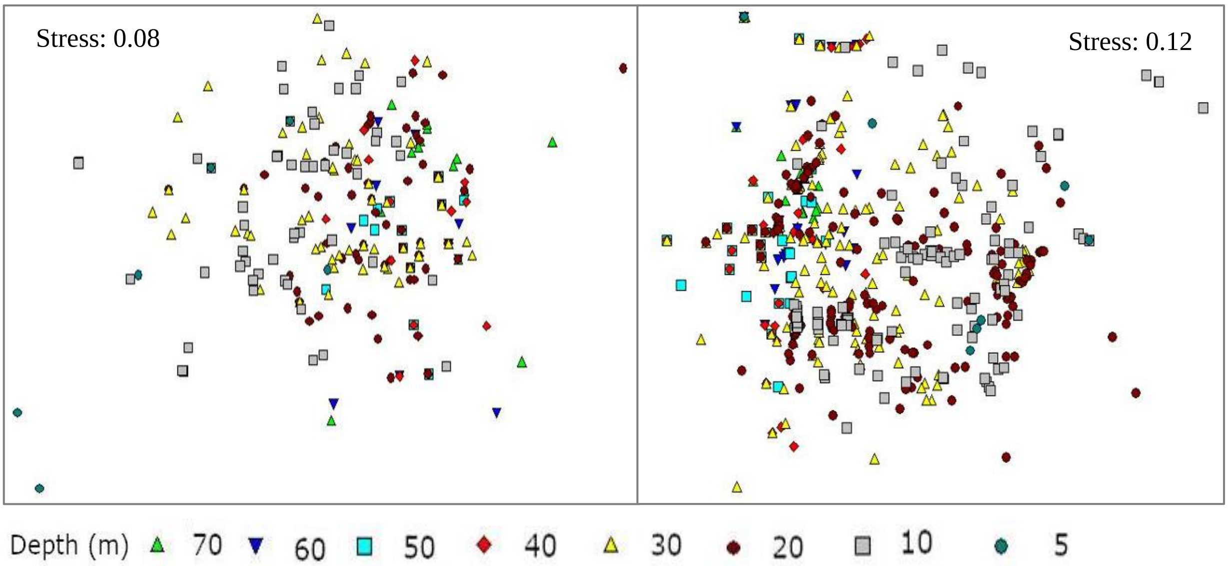

Figure 26 MDS plot based on the similarity of the presence/absence data on species level (left) and based on cover data of macroalgae groups (right) until 70 m categorized into depth zones

The results of SIMPER (Table 5) suggests that the differences of the 5 m depth zone to the deeper locations were mainly due to the lack of zoobenthos at shallower depths and the presence of detached *Acrosiphonia* at Brandal regarding the presence/absence data. Relating to the cover data the dissimilarities were mostly due to zoobenthos and the coverage of filamentous brown algae and kelp at shallower waters of Hansneset north.

Table 5 Results of SIMPER for significant results indicating the contribution of single species to total dissimilarity in species composition for presence/absence and cover data; evaluation of the factor depth (categorized)

Depth [m]	Contribution of species to total dissimilarity [%]			
	P/A		Cover	
70:5	zoobenthos	18.6	zoobenthos	34.3
	detritus *Acrosiphonia*	11.8	fil. brown algae	24.9
	Alaria esculenta	10.0	kelp	22.3
60:5	zoobenthos	16.0	fil. brown algae	26.0
	detritus *Acrosiphonia*	11.1	zoobenthos	23.7
	Alaria esculenta	9.6	kelp	22.5
50:5	zoobenthos	17.4	zoobenthos	25.7
	microalgae	12.0	fil. brown algae	24.8
	detritus *Acrosiphonia*	10.9	kelp	22.2
40:5	zoobenthos	15.5	fil. brown algae	24.8
	detritus *Acrosiphonia*	11.3	kelp	21.7
	microalgae	10.3	zoobenthos	19.9
30:5	zoobenthos	15.9		
	detritus *Acrosiphonia*	10.5		
	microphytobenthos	9.7		

Zoobenthos and detritus were contributing most to the dissimilarities at the presence/absence data. An ANOSIM without zoobenthos showed that the significant differences disappear between the depth. At another run without detritus the significant results remained between 5 m and the other depth zones (Table 11 appendix). Furthermore, no significant dissimilarity was found at a more detailed analysis to a depth of 26 m with an interval of 2 m for both the presence/absence and cover data (Table 17 appendix).

On the other hand, when analysing differences in community structure between the different transect significant differences occurred between some combinations (Table 6, Figure 27). The results of ANOSIM showed significant dissimilarities between Kongsfjordneset and the three stations at the inner fjord ($R > 0.6$, $p < 0.05$, Table 6). The differences between the locations based on cover data were less distinct. Significantly similar to each other were the transects at Hansneset ($R < 0.1$, $p < 0.05$). Furthermore, the stations Prince Heinrich Island and Tyskahytta resembled each other significantly ($R < 0.1/0.2$, $p < 0.05$).

The locations from the middle to the inner fjord accumulate at the MDS plot (Figure 27): Prince Heinrich Island, Tyskahytta and Brandal. The sample points from Hansneset and Kongsfjordneset are gathered at the upper part. However, some samples of Hansneset are located outside of this aggregation. These are the areas at Hansneset north, where low vegetation dominated by *Acrosiphonia* was found or just detritus was recorded.

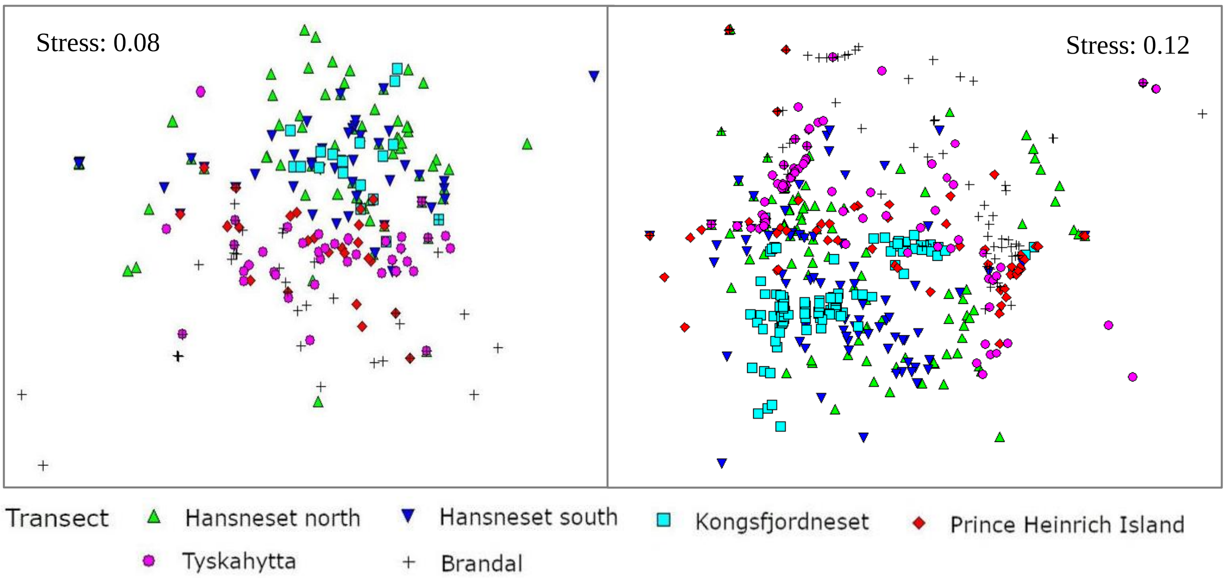

Figure 27 MDS plot based on the similarity of the presence/absence data on species level (left) and based on the cover data of macroalgae groups (right) until 70 m categorized into transects

Table 6 Results of ANOSIM (pairwise test and Global R, p) on species composition for sampling points until 70 m depth for presence/absence and cover data; evaluation of the factor transect: HN Hansneset north, HS Hansneset south, KN Kongsfjordneset, TH Tyskahytta, BL Brandal, PHI Prince Heinrich Island

Transect		**P/A**		**Cover**	
		R	**p**	**R**	**p**
HN	**HS**	0.033	0.002	0.034	0.004
HN	**KN**	0.471	0.001	0.423	0.001
HN	**PHI**	0.272	0.001	0.087	0.001
HN	**TH**	0.376	0.001	0.21	0.001
HN	**BL**	0.373	0.001	0.243	0.001
HS	**KN**	0.469	0.001	0.404	0.001
HS	**PHI**	0.241	0.001	0.085	0.001
HS	**TH**	0.352	0.001	0.257	0.001
HS	**BL**	0.401	0.001	0.377	0.001
KN	**PHI**	**0.667**	**0.001**	**0.503**	**0.001**
KN	**TH**	**0.656**	**0.001**	0.447	0.001
KN	**BL**	**0.818**	**0.001**	**0.782**	**0.001**
PHI	**TH**	0.077	0.001	0.16	0.001
PHI	**BL**	0.317	0.001	0.325	0.001
TH	**BL**	0.386	0.001	0.367	0.001

The results of the SIMPER analysis (Table 7) showed that the differences between Kongsfjord-neset and Prince Heinrich Island, Brandal and Tyskahytta were mainly due to coralline red algae which occurred in high amounts at Kongsfjordneset. Based on the presence/absence data their contribution to the total dissimilarity was higher than 20 % and on the cover data larger than 40 %. Microphytobenthos was responsible in second place for total dissimilarities at Prince

Heinrich Island and Tyskahytta compared to Kongsfjordneset for presence/absence data while for cover data kelps were also important comparing Kongsfjordneset and Prince Heinrich Island (Table 7). For both input data the dissimilarity between Kongsfjordneset and Brandal was the most significant (R ~ 0.8, $p < 0.05$). Apart from coralline red algae and zoobenthos the presence and the high cover of detritus at Brandal was responsible for the differences.

Table 7 Results of SIMPER for significant results indicating the contribution of single species to total dissimilarity in species composition for presence/absence and cover data; evaluation of the factor transect Kongsfjordneset, TH Tyskahytta, BL Brandal, PHI Prince Heinrich Island

Transect	Contribution of species to total dissimilarity [%]			
	P/A		**Cover**	
KN:PHI	coralline red algae	27.8	coralline red algae	44.4
	microalgae	17.9	kelp	22.0
	zoobenthos	11.3	zoobenthos	18.2
KN:TH	coralline red algae	28.8		
	microalgae	20.2		
	Desmarestia aculeata	9.8		
KN:BL	coralline red algae	23.0	coralline red algae	40.3
	zoobenthos	18.2	zoobenthos	19.6
	detritus *Saccharina latissima*	12.4	detritus	15.7

Based on the presence/absence data species composition was significantly different between both stations at Hansneset compared to Tyskahytta, when zoobenthos was excluded (Table 13 appendix). Results of SIMPER suggests that the differences were mainly due to the presence of microalgae at Tyskahytta and the appearance of *Phycodrys rubens* and coralline red algae at Hansneset (Table 14 appendix).

The results of the ANOSIM did not indicate significant dissimilarities between hard and soft bottom communities for either input data (Table 8). The highest R with a value of 0.47 was reached between hard bottom and soft bottom substrate. This value indicates some but no distinct differences. Only when zoobenthos was excluded from the community analysis, a significant dissimilarity was resulting ($R > 0.6$, $p < 0.5$, Table 15 appendix). In this case the contributing species were coralline red algae at hard bottom locations and detritus of *Saccharina latissima* and microalgae appearing on soft bottom (Table 16 appendix).

Table 8 Results of ANOSIM (pairwise test and Global R, p) on species composition for sampling points until 70 m depth for presence/absence and cover data; evaluation of the factor bottom substrate

		P/A		Cover	
Substrate		**R**	**p**	**R**	**p**
Hard bottom with silt	**Hard bottom**	0.166	0.001	0.196	0.001
Hard bottom with silt	**Soft bottom/drop stones**	0.171	0.001	0.031	0.064
Hard bottom with silt	**Soft bottom**	0.303	0.001	0.237	0.001
Hard bottom	**Soft bottom/drop stones**	0.295	0.001	0.179	0.001
Hard bottom	**Soft bottom**	0.466	0.001	0.388	0.001
Soft bottom/drop stones	**Soft bottom**	0.008	0.357	0.004	0.435

The MDS plot grouped with the bottom substrate shows an accumulation of the sample points for the presence/absence data (Figure 28 left). At the lower part of the plot lie the points with soft bottom and soft bottom with drop stones. The latter scatters more diverse, since the amount of drop stones varied as well. The upper part of the plot displays the sample points with hard bottom and hard bottom with silt. MDS plot based on the cover data shows a greater distribution of the samples (Figure 28 right).

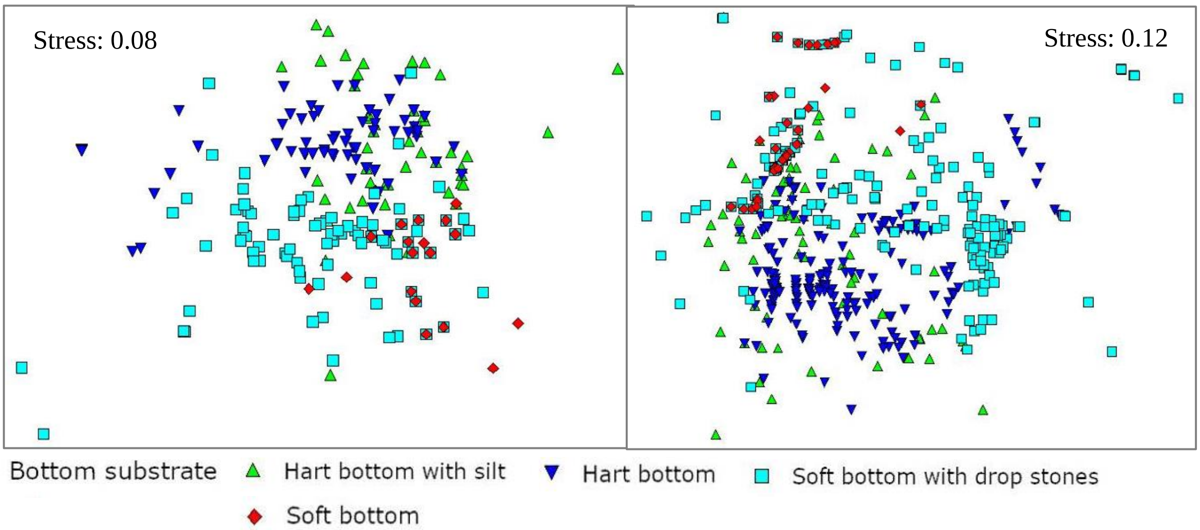

Figure 28 MDS plot similarity of the presence/absence data on species level (left) and based on the cover data of macroalgae groups (right) until 70 m factor bottom substrate

4 Discussion

4.1 Discussion of methods

Through this study the coastal benthic community has been evaluated over a vast area and an investigation of the macroalgal distribution was feasible in greater depth than ever before at Kongsfjorden. The recordings generated video footage of over 6.5 km length and an area of over 400 m^2 was investigated reaching down to almost 140 m depth. Furthermore, the data generation with a ROV provided a non-invasive research method. The benthic community remained undisturbed and a long-term investigation could be possible.

4.1.1 Comparison of the ROV and the DEM depth

The video recordings were connected to depth data measured by the ROV. Through the establishment of a DEM a validation of this depth data was possible. Reliable results were generated at locations with a flat or slight slope. Differences between the depth measured by the ROV sensor and the depth generated via the DEM were occurring at locations with steep bedrock. The differences were contingent upon the fact, that the depth from the DEM was measured with the coordinates of the ship and not the ROV. It should be considered as well that the ROV was driving above the ground and the macroalgal vegetation. Especially the kelp canopy can reach heights of up to 2 m. Thus, the depth of the sea bed is lower than indicated. For that reason, the evaluation of the benthic distribution and cover was conducted with a depth zonation with intervals of 2 m. A finer resolution would not be accurate. At the transects of Prince Heinrich Island, Tyskahytta and Brandal this 2 m resolution was adequate. Kongsfjordneset is lacking DEM data, thus no statement is possible. Greater variations than 2 m were recorded at Hansneset. Since the bedrock is steep here, the distance of the ship and the ROV has greater influence. Another inconsistency was the fluctuation in the elevation profile. This extreme depth alternations were not visible on the video. The ship was moving forward and backward, so the depth by the DEM was fluctuating. Possibly the movement of the ship und thereby the movement of the connecting cable was influencing the depth recordings in conjunction with the steep subsoil.

4.1.2 Evaluation of the transects

The transects were evaluated with a consistent pattern. Every 5 respectively 10 m frames were extracted from the video as sample points. This distance between the points was sufficient to document all communities that were visible on the videos. Several sample points had to be discarded since the ship was not driving with the same velocity as the ROV. Hence the extracted frames were too close to each other or even showing the same area. This problem occurred at both transects at Hansneset and Tyskahytta. At Hansneset the problem was arising because of the steep underground and at Tyskahytta because the ship drove turns that the ROV was not following.

The ROV was diving with a varying distance from the ground. Thus, the analysed areas of the transects differ. The three laser points, that were used to calculate the investigated area on the frames were not always visible. That is why presence/absence and cover data were collected to conduct an area independent evaluation.

A depth value was assigned to every frame and the evaluation of the benthic cover was conducted via this elevation profile. Using this method, it should be considered, that the replicates for every depth class varied. The ROV stayed longer in some depths and was passing through others more quickly.

4.1.3 Species identification

The quality of the frames was sufficient to determine the genus of the appearing individuals in the majority of the cases. Even the determination on species level was feasible. The analysis of the presence/absence data was therefore feasible on species level. However, the different species of *Acrosiphonia, L.digitata and S. nigripes* plus the filamentous red algae were not distinguishable. The evaluation of the cover data was not possible on species level. The individuals were growing partially to close to each other and a separation was not visible. For that reason, both data matrices (presence/absence and cover data) were evaluated, since they contain different information.

In this study it was possible to evaluate the benthic community of a vaster area and in greater depth. However, small macroalgae or epiphytes were not identifiable on the recordings and therefore excluded from the evaluation. Excluded were as well individuals growing under the kelp canopy, because they were not visible, though they all contribute to the community composition. For this reason, no diversity indices were determined. They would not have reflected the actual biodiversity, especially at the kelp forest.

4.2 Discussion of results

This study showed that macroalgae occurred in all studied transects along the fjord and benthic communities (including makrozoobenthos and microphytobenthos) were significant different between some of them. Macroalgae could be identified growing down to 74 m and a substantial detrital macroalgal biomass was quantified.

4.2.1 Benthic species and their distribution in Kongsfjorden

Macroalgal distribution along the fjord axis

Macroalgae were distributed throughout the fjord, mainly on hard bottom substratum but also to some extent on soft bottom with drop stones. Overall 16 of the known 84 macroalgal species of Kongsfjorden were recorded, which corresponds to 19 %. No new species were detected due to the limited identification potential of video transects. Most of the species belonged to the Arctic or Arctic-cold temperate distribution group (81 %). Three species (19 %) have a distribution into temperate regions. This reflects the Arctic location with Atlantic influence of the study area (Hop et al. 2012, 2016, Bartsch et al. 2016).

In general, Chlorophyta were recorded at the middle to inner fjord and at Hansneset north, where probably an ice berg scratched over the sea floor (Figure 29). The cover of Rhodophyta was high at the outer fjord and decreased with proximity to the inner fjord. Phaeophyceae were distributed at the entire fjord (Figure 29).

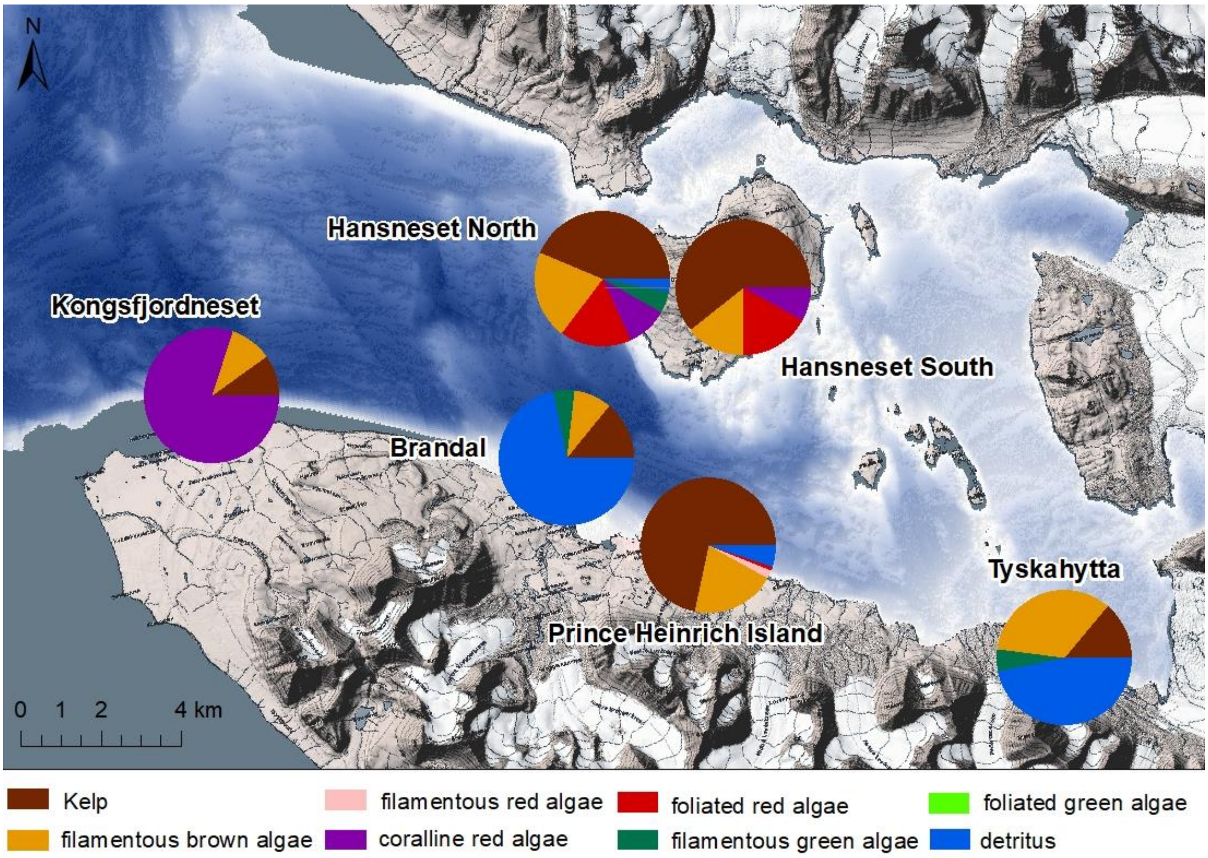

Figure 29 Distribution of macroalgae groups and detritus throughout the fjord. Pie charts based on the mean cover of all sample points of one transect

Chlorophyta were recorded mainly at the middle to the inner fjord. Especially *Acrosiphonia* was found in higher numbers at areas with physical disturbance. It is an opportunistic species, which was growing on areas abraded by ice or on pebbles, which entered the fjord by the melting glacier. The distribution corresponds to the study of Hop et al (2016), which found the two Chlorophyta at their innermost locations.

Phaeophyceae were found at the entire fjord. The species *Desmarestia aculeata* and *Saccharina latissima* were recorded even at difficult conditions for algae growth. *S. latissima* possesses widely branched haptera, which are attached to small gravel (Hop et al. 2012). *Desmarestia viridis* and *L. digitate/S. nigripes* were recorded from the middle to the outer fjord. They seem to be more dependent on hard substrate. Most of these results correspond to the previous study by Hop et al. (2016). However, *Laminaria digitata* was found then at the entire fjord, whereas *Alaria esculenta* did not occur at the innermost location.

Just at Brandal the species *Halosiphon tomentosus* and *Dictyosiphon foeniculaceus* were found. Possibly the storm cleared the kelp canopy away, so the underlying vegetation became visible. *Laminaria solidungula* was growing in the middle of the fjord, as the only endemic Arctic species. This species has a limited distribution and was not yet recorded at the outer or innermost locations (Hop et al. 2016).

Rhodophyta were growing at middle to outer fjord. Especially *Phycodrys rubens* occurred with a dense cover at the locations at Hansneset, which corresponds to previous studies (Hop et al. 2012,2016, Bartsch et al. 2016). Coralline red algae appeared with higher covers at the middle to outer fjord corresponding to the distribution of bedrock. No red algae were found at the inner part of the fjord. Furthermore, foliated and filamentous Rhodophyta were not growing abundantly at the south coast as well. In contrast, the locations of Hop et al (2016) at the northern coast of Kongsfjorden recorded several species of red algae even with a dominant distribution.

Macroalgal depth distribution along the fjord

The depth distribution of macroalgae was changing along the fjord axis. The deepest recordings were made at the outer fjord with kelp down to 30 m, filamentous brown algae down to 60 m and foliated red algae down to 68 m at Hansneset. Coralline red algae were found at the lowest depth with almost 72 m. Despite the strong seasonality of the light climate in Kongsfjorden and the Arctic in general, alternating from polar night to midnight sun (Pavlov et al 2019), macroalgae distribution can reach low depths. Thus far, the deepest record of kelp in an Arctic is 60 m in Disko Bay, Greenland and similar depth records were made for foliose red algae in southwest Svalbard (Wilce 2016). While evaluating the macrozoobenthic cover at Kongsfjorden Laudien et al. (2012) mentions coralline red algae at locations down to 75 m as well. In comparison, studies from Helgoland showed a shallower depth distribution with kelp growing down to 3 m, filamentous brown algae down to 12 m, foliated red algae down to 6 m and coralline red algae at depths of 23 m (Pehlke and Bartsch 2008, Lüning 1970).

With proximity to the inner fjord the lower depth limit of macroalgae decreased to shallower water and red algae were disappearing totally. The environmental conditions change along the axis of the fjord. Light attenuation increases with proximity to the glacier due to meltwater introducing inorganic and organic matter into the fjord (Svendsen et al. 2002). Hence there is a gradient in the extent of the euphotic zone. Throughout the year the highest water transparency can be found at the outer fjord with a low concentration of suspended particles (15 mg/dm^3). At the innermost part the concentration of suspended particles increases (> 340 mg/dm^3) and the euphotic zone might be limited to only 0.3 m (Svendsen et al. 2002). Furthermore, the salinity fluctuates caused by the freshwater discharge (Hanelt et al. 2004) with 90 % of the freshwater supply occurring within the three summer months (Svendsen et al. 2002). Hence macroalgae at the inner fjord are exposed to changing osmotic conditions and require therefore high physiological acclimation (Zacher et al 2009). These conditions might have inhibited red algae growth at the inner fjord.

With the altering environmental conditions in the Arctic, previous studies at Hansneset indicated, that the macroalgal distribution shifted to shallower waters. Phaeophyceae extended from eulittoral to the depth of 20 m in 1996/98 whereas at 15 m was already the depth limit of kelp in 2012/13 (Hop et al. 2012, Bartsch et al. 2016). At the video transects recorded in 2009 kelp was growing at Hansneset north until 18 m and at Hansneset south down to 30 m. These results lie closer to the results of the years 96/98. Furthermore, the species distribution resembles more the results of 96/98. However, in this study of the video transects no individual of *S. dermatodea* was found. A decrease in depth extension was prominent in this species at the study of Bartsch et al (2016) as well. The species possibly shifted to the uppermost sublittoral. It should be considered though, that the depth measurement at this study by the ROV was not as precise as the measurement by SCUBA diving and especially at Hansneset afflicted with inaccuracies.

Macroalgal detritus

The cover of detrital macroalgae was generally low at the outer fjord and increased at the inner fjord. The highest cover of detritus was found at Brandal reaching down to over 130 m. Piles of detached algae were forming. The different stages of degradation indicate a long-term accumulation of detritus. These results confirm previous studies stating that a majority of local macroalgal primary production is exported to deeper communities (Filbee-Dexter et al. 2018). There it enters the detrital food web. Ramirez et al (2016) showed that crustacea attach rapidly to macroalgae thalli reaching the sea floor in deep water locations. At Brandal macrozoobenthos was found on detritus at almost every depth zone even at the lowest areas recorded.

Detrital production rates are controlled by current and wave-driven hydrodynamic forces. The highest rates occur during severe storms as happened one day before the recording in Brandal (Krumhansl and Scheibling 2012). Furthermore, deep trenches facilitate the transport of detached macroalgae to the deep sea (Vetter and Dayton 1998) and the established DEM shows that a deep trench is located in proximity of the transect in Brandal (Figure 30). In conclusion, the detrital cover at this location was probably a result of the hydrodynamic situation due to the deep trench and has even increased due to the previous storm.

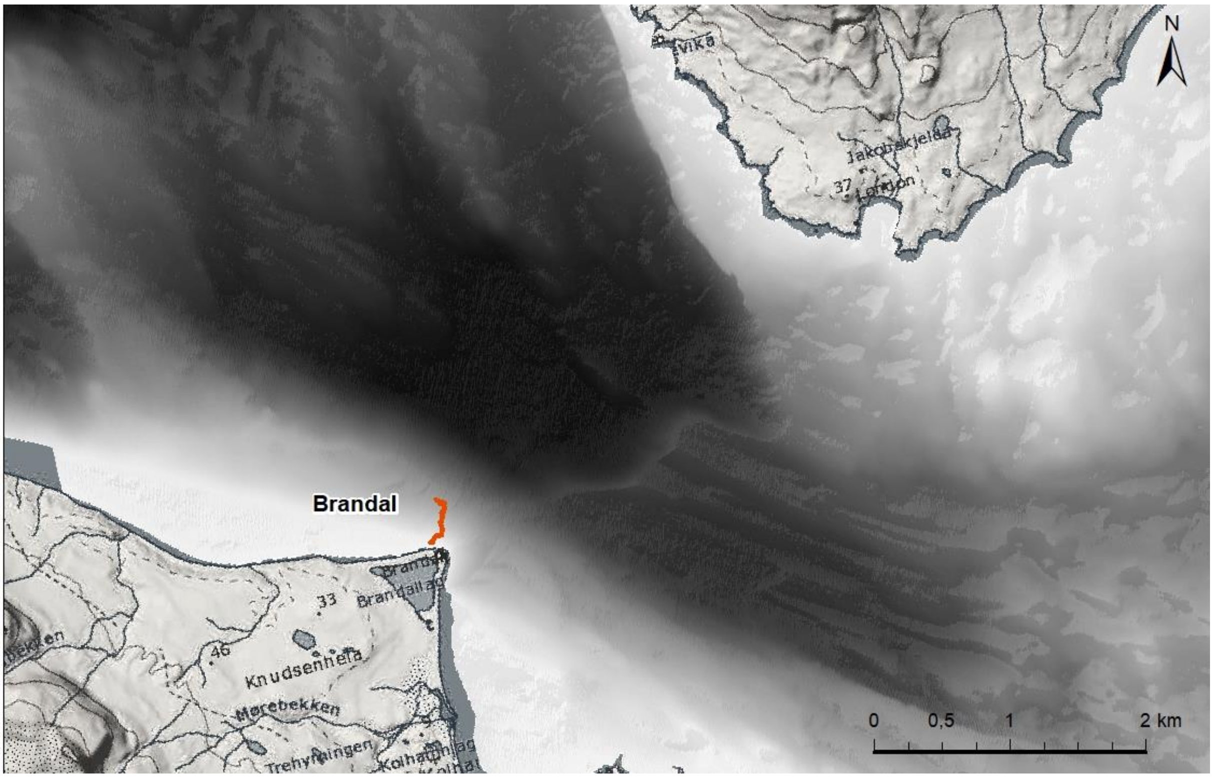

Figure 30 Deep trench next to the transect of Brandal, Norwegian Mapping Authority and Norwegian Polar Institute, modified

Microphytobenthos

Microphytobenthos in this study was just apparent at soft bottom locations and occasionally on silt from 15 to 60 m depth. The lack of microalgae on soft bottom at Brandal might have been a result of the storm due to a resuspension of the sea floor. Microphytobenthic cover at shallower depths to 15 m or on hard bottom was not detected at this study. However, in Kongsfjorden thick mats of microalgae dominated by diatoms are reported to grow on all kinds of substrata in shallow areas (Hop et al. 2002). A study by Wölfel et al. (2009) in Kongsfjorden showed that patches of microalgae were covering sandy sediments at water depths down to 30 m with high biomass (317 mg_{chla}/m^2) contributing in significant rates to the primary production

(Wölfel et al. 2009). Hence microalgae might have been present on hard bottom and at shallower depths at the six transects as well but were not visible due to the vegetation canopy or the quality of the video recordings.

Macrozoobenthos

Macrozoobenthos appeared throughout the fjord at all depths and on all kinds of substrate. The results of this study correspond to previous ones showing that zoobenthos differs regarding the bottom substrate (Beuchel et al. 2006, Laudien et al. 2004, 2012). Actiniaria, Ascidia, and Porifera were common at hard bottom locations like Hansneset and Kongsfjordneset or on drop stones at Prince Heinrich Island. In contrast, Polychaeta and Crustacea inhabited soft bottom substrate. Macroalgal grazing sea urchins occurred just at Kongsfjordneset. This corresponds to Hop et al (2016) where sea urchins where gazing on macroalgae at exposed costal study sites at the north of Kongsfjorden. At other sites the sea urchin population might have been controlled by predators. The common eider is regarded as a feeder on sea urchins and their breeding colonies are located at the inner half of the fjord (Hop et al. 2002). Furthermore, Kortsch et al. (2012) showed, that the abundance of sea urchins dropped to a low level at Kongsfjorden after 2003.

4.2.2 Species composition and community analysis

Depth is a dominant factor for the distribution of algae (Hop et al. 2002). In general, the sublittoral vegetation can be subdivided into three zones: upper, middle and lower sublittoral.

At Hansneset the upper zone was dominated by thick and leathery macrophytes. The middle layer showed dominance of lower branched or filamentous brown and red algae and the lowest zone was populated by crustose algae and individuals of red algae. Ice conditions in the upper sublittoral demand high tolerance and adaptability. Annual and pseudo perennial species like *Acrosiphonia* and *D. ramentacea* have clear advantages, producing high biomass in short growth periods (Hop et al. 2012). Since the ice cover in winter is decreasing the last years, strong abrasive effects of drifting ice are not that dominant anymore. A physical disturbance by ice was just recorded at Hansneset north.

The depth zonation at Prince Heinrich Island showed a similar distribution of sublittoral vegetation but was decreasing more quickly in depth probably due to the deficiency of light and the coralline red algae were lacking due to the soft bottom substrate.

At Kongsfjordneset sea urchins were controlling the macroalgal cover at the sublittoral and a high cover of coralline red algae became visible. Pale sea urchin and green sea urchin are the most important grazers of macroalgae in Kongsfjorden (Voronkov et al. 2013). However, they were just recorded in this abundancy at Kongsfjordneset and were controlling the macroalgal growth just at this location. The observed patches of kelp, mostly *Alaria*, were surrounded by individuals of *Desmarestia*. *D. viridis* produces and stores sulphuric acid. The changes in pH affect the behaviour of sea urchins causing them to stop and to move in the opposite direction. This chemical protection creates long-term refuges for kelp and associated macrobenthic communities (Molis et al. 2009).

At Brandal no dense kelp canopy was recorded. Thus species, which lie usually under this dense vegetation were detected by the ROV. Whether the lacking kelp canopy occurred due to the storm or was a long-term state cannot be assessed in this study.

The three zones of sublittoral vegetation were not detectable at Tyskahytta. The conditions do not favour macroalgal growth in general, just some individuals of *S. latissima*, *D. aculeata* and *Acrosiphonia* were growing in several shallower locations. Where thick sediment covered the ground and Sabellidae populated the areas in high abundance, macroalgal growth was inhibited. It was shown, that every transect had a distinct depth zonation and that the factor depth had an influence on the macroalgal cover. The community analysis through the entire fjord however showed, that the dissimilarities between the depth zones were not higher than the ones within a zone. Just the areas shallower 5 m were different to the deeper locations, but only the transects Brandal and Hansneset north reached shallower waters that depth. Another community analysis run in the depth range until 26 m with an interval of 2 m showed again no dissimilarities. In conclusion, the depth zones at the different locations were considerably changing. Hence, the location of the transect in the fjord had a more distinct influence. The outer location of the fjord was significantly different to the stations at the inner fjord. The analysis without zoobenthos showed a significant difference as well between Hansneset and Tyskahytta. Zoobenthos was recorded at the entire fjord and an inclusion in the community analyses as one group might have concealed differences in the macroalgae community.

As mentioned before, environmental gradients can be strong in glacial fjords. The inner locations of the fjord were greatly influenced by the glacier melting. The macroalgal community between soft and hard bottom substratum was significantly different considering the species composition without zoobenthos. Macroalgae were exposed to a thick layer of soft substratum and increased turbidity at the inner fjord (Svendsen et al. 2002). Hence algae growth was inhibited. Whereas the outer parts had little sediment on the hard substratum. An appropriate substratum determines of colonisation by macroalgae. Most species need hard substratum for settlement (Hop et al. 2012). However, based on the macroalgal cover data no dissimilarity between hard and soft bottom was found. Thus, there are more factors than the bottom substrate influencing the macroalgal distribution depending on the location like salinity or temperature.

4.3 Outlook

The Arctic contains a vast potential habitat for marine macrophytes. Presently they are not occupied because they are permanently ice covered or impacted by ice scouring (Filbee-Dexter et al. 2019). Warming occurs particularly fast in the Arctic. Sea ice associated ecosystems are projected to decline. This contains a potential for expansion of vegetated habitats, which support key ecosystem functions, enhance CO_2 sequestration and shoreline protection from erosion. Recent predictive models forecast the spread of marine macrophytes to the Arctic due to a temperature rise (Krause-Jensen and Duarte 2014). Furthermore, the models suggest borealization of Arctic kelp forests with a possible expansion of new habitats for fish and marine organisms to the high Arctic. However, a further change would result in the loss of an entire climate zone (Filbee-Dexter et al. 2019). There are documented cases from the last decade that at warmer edges kelp forest disappeared and were replaced by turf algae. These are algae with no three-dimensional seascape structure. Their occurrence is resulting from warming and eutrophication of the sea (Filbee-Dexter and Wernberg 2018). The forecasts are regionally specific and highly uncertain and macroalgal communities are complex formations.

This research work was to my knowledge the first and only video-based analysis of the macrophyte cover at Kongsfjorden. Six locations were analysed giving an insight of the macroalgal distribution and cover depended on the depth, the location in the fjord and thereby the bottom substrate. The generated GIS and DEM of Kongsfjorden could be used to link the macroalgal distribution and cover to environmental data. Through the evaluation of a large area via ROV the results might be described as a function of the environmental gradients, like turbidity, salinity and temperature. Hence models of the macroalgal distribution could be established. However, the considerations made in this research work are based on a one-time status documentation. A renewed recording and its evaluation could give valuable insights on macroalgal cover and distribution in this changing environment and could therefore be used to validate the predicting models.

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Appendix

Table 9 Replica, analysed area and area per macroalgal group for HN, HS and KN every 5 m

Depth lower limit [m]	Replica	Analysed Area [m²]	Area kelp [m²]	filamentous brown algae [m²]	foliated green algae [m²]	filamentous green algae [m²]	foliated red algae [m²]	filamentous red algae [m²]	coralline red algae [m²]
Hansneset north									
5	5	4.30	1.59	1.89	0.00	0.26	0.34	0.00	0.00
10	28	24.08	5.38	4.48	0.00	0.95	4.73	0.09	2.71
15	15	12.90	7.18	0.56	0.00	0.95	0.36	0.17	0.39
20	12	10.32	1.72	0.40	0.00	0.00	0.04	0.00	0.16
25	14	12.04	0.00	0.19	0.00	0.00	0.22	0.00	0.28
30	3	2.58	0.00	0.06	0.00	0.00	0.10	0.00	0.02
35	1	0.86	0.00	0.00	0.00	0.00	0.00	0.00	0.00
40	1	0.86	0.00	0.00	0.00	0.00	0.00	0.00	0.00
45	2	1.72	0.00	0.00	0.00	0.00	0.01	0.00	0.00
50	1	0.86	0.00	0.00	0.00	0.00	0.04	0.00	0.01
55	1	0.86	0.00	0.00	0.00	0.00	0.00	0.00	0.01
60	3	2.58	0.00	0.05	0.00	0.00	0.02	0.00	0.02
65	8	6.88	0.00	0.00	0.00	0.00	0.19	0.00	0.03
70	17	14.62	0.00	0.00	0.00	0.00	0.03	0.00	0.02
75	3	2.58	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Hansneset south									
5	0	0.00	0.00	0.00	0,00	0.00	0.00	0.00	0.00
10	4	3.44	3.44	0.00	0,00	0.00	0.00	0.00	0.00
15	13	11.18	10.32	0.65	0,00	0.00	0.01	0.00	0.17
20	27	22.97	10.15	2.31	0,00	0.00	2.49	0.00	1.17
25	36	30.20	5.51	3.69	0,00	0.00	4.33	0.00	2.11
30	26	23.14	1.94	0.94	0,00	0.00	1.72	0.00	1.12
35	11	8.02	0.00	0.06	0,00	0.00	0.20	0.00	0.17
40	1	0.86	0.00	0.00	0,00	0.00	0.01	0.00	0.00
45	5	3.95	0.00	0.01	0,00	0.00	0.10	0.00	0.00
50	3	3.83	0.00	0.00	0,00	0.00	0.04	0.00	0.00
55	4	4.41	0.00	0.05	0,00	0.00	0.12	0.00	0.00
Kongsfjordneset									
5	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	48	41.28	3.31	3.70	0.00	0.00	0.00	0.00	12.08
15	57	49.02	3.53	2.72	0.00	0.00	0.00	0.01	20.25
20	11	9.46	0.04	0.13	0.00	0.00	0.00	0.00	5.55
25	12	10.32	0.00	0.73	0.00	0.00	0.00	0.00	4.39
30	15	12.90	0.00	0.01	0.00	0.00	0.00	0.00	2.54
35	4	3.44	0.00	0.00	0.00	0.00	0.00	0.04	0.47
40	7	6.02	0.00	0.00	0.00	0.00	0.00	0.04	0.69
45	3	2.58	0.00	0.00	0.00	0.00	0.00	0.00	0.39
50	3	2.58	0.00	0.00	0.00	0.00	0.00	0.00	0.22
55	6	5.16	0.00	0.00	0.00	0.00	0.00	0.00	0.48
60	6	5.16	0.00	0.04	0.00	0.00	0.00	0.00	0.03
Prince Heinrich Island									
5	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	0	000	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	36	10.91	6.41	1.46	0.00	0.03	0.04	0.06	0.00
25	18	4.54	0.41	0.19	0.00	0.00	0.08	0.13	0.00

Table 9 continued									
30	29	6.93	0.00	0.09	0.00	0.00	0.00	0.00	0.00
35	10	2.87	0.00	0.18	0.00	0.00	0.00	0.00	0.00
40	6	2.09	0.00	0.00	0.00	0.00	0.01	0.00	0.00
45	14	5.51	0.00	0.00	0.00	0.00	0.00	0.00	0.08
Tyskahytta									
5	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	27	5.07	0.22	0.85	0.02	0.09	0.00	0.00	0.00
15	55	9.54	0.06	0.06	0.00	0.05	0.00	0.00	0.00
20	45	9.86	0.24	0.25	0.00	0.02	0.00	0.00	0.00
25	30	5.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Brandal									
5	3	1.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	23	9.25	0.94	0.80	0.01	0.56	0.00	0.00	0.00
15	3	1.38	0.18	0.21	0.05	0.23	0.00	0.00	0.00
20	5	2.38	0.33	0.38	0.02	0.19	0.00	0.00	0.00
25	4	2.00	0.41	0.09	0,.00	0.05	0.00	0.00	0.00
30	20	9.05	1.06	0.44	0.00	0.00	0.00	0.00	0.00
35	10	5.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
40	5	1.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00
45	2	0.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00
50	3	2.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00
55	6	2.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00
60	6	3.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00
65	4	1.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00
70	3	0.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00
75	8	2.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00
80	7	4.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00
85	3	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00
90	6	1.76	0.00	0.00	0.00	0.00	0.00	0.00	0.00
95	6	1.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100	6	1.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00
105	6	1.62	0.00	0.00	0.00	0.00	0.00	0.00	0.00
110	5	2.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00
115	5	2.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00
120	4	3.83	0.00	0.00	0.00	0.00	0.00	0.00	0.00
125	10	4.95	0.00	0.00	0.00	0.00	0.00	0.00	0.00
130	10	5.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00
135	39	21.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
140	9	4.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 10 Replica, analysed area and area per macroalgal group for HN, HS and KN every 2 m

	Depth lower limit [m]	Replica	Analysed Area [m²]	Area kelp [m²]	filamentous brown algae [m²]	foliated green algae [m²]	filamentous green algae [m²]	foliated red algae [m²]	filamentous red algae [m²]	coralline red algae [m²]
Hansneset north										
	4	4	3.44	0.73	1.89	0.00	0.26	0.34	0.00	0.00
	6	17	14.62	2.72	2.92	0.00	0.56	2.88	0.04	1.81
	8	6	5.16	1.51	0.65	0.00	0.39	0.99	0.04	0.65
	10	6	5.16	2.02	0.91	0.00	0.00	0.86	0.00	0.26
	12	5	4.30	2.02	0.22	0.00	0.34	0.09	0.04	0.00
	14	8	6.88	4.30	0.13	0.00	0.60	0.26	0.13	0.39
	16	5	4.30	1.72	0.39	0.00	0.00	0.02	0.00	0.09
	18	4	3.44	0.86	0.01	0.00	0.00	0.01	0.00	0.00
	20	5	4.30	0.00	0.22	0.00	0.00	0.03	0.00	0.08
	22	5	4.30	0.00	0.01	0.00	0.00	0.02	0.00	0.15
	24	6	5.16	0.00	0.01	0.00	0.00	0.07	0.00	0.11
	26	4	3.44	0.00	0.18	0.00	0.00	0.15	0.00	0.03
	28	2	1.72	0.00	0.05	0.00	0.00	0.09	0.00	0.01
	30	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	32	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	34	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	36	1	1.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	38	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	40	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	42	5	1.72	0.00	0.00	0.00	0.00	0.01	0.00	0.00
	44	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	46	9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	48	7	0.86	0.00	0.00	0.00	0.00	0.04	0.00	0.01
	50	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	52	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	54	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	56	0	0.86	0.00	0.00	0.00	0.00	0.00	0.00	0.01
	58	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	60	0	2.58	0.00	0.05	0.00	0.00	0.02	0.00	0.02
	62	0	2.58	0.00	0.00	0.00	0.00	0.09	0.00	0.02
	64	0	4.30	0.00	0.00	0.00	0.00	0.09	0.00	0.01
	66	0	0.86	0.00	0.00	0.00	0.00	0.01	0.00	0.00
	68	0	7.74	0.00	0.00	0.00	0.00	0.03	0.00	0.01
	70	0	6.02	0.00	0.00	0.00	0.00	0.00	0.00	0.01
	72	0	2.58	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Hansneset south										
	8	3	2.58	2.58	0,00	0.00	0.00	0.00	0.00	0.00
	10	1	0.86	0.86	0,00	0.00	0.00	0.00	0.00	0.00
	12	8	6.88	6.88	0,00	0.00	0.00	0.00	0.00	0.00
	14	1	0.86	0.86	0,00	0.00	0.00	0.00	0.00	0.00
	16	8	6.89	3.44	0,90	0.00	0.00	0.40	0.00	0.30
	18	11	9.34	5.77	0,76	0.00	0.00	0.66	0.00	0.38
	20	12	10.18	3.53	1,29	0.00	0.00	1.44	0.00	0.66
	22	14	11.36	3.10	2,25	0.00	0.00	1,81	0.00	0.75
	24	14	12.46	1.80	1,44	0.00	0.00	2.08	0.00	1.15
	26	17	15.95	1.29	0,38	0.00	0.00	1.10	0.00	0.86
	28	8	6.59	0.56	0,34	0.00	0.00	0.75	0.00	0.25
	30	9	6.98	0.69	0,22	0.00	0.00	0.31	0.00	0.22
	32	7	5.16	0.00	0,06	0.00	0.00	0.10	0.00	0.17
	34	3	2.05	0.00	0,00	0.00	0.00	0.10	0.00	0.00

Table 10 continued										
	36	1	0.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	38	1	0.86	0.00	0.00	0.00	0.00	0.01	0.00	0.00
	40	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	42	3	2.58	0.00	0.00	0.00	0.00	0.09	0.00	0.00
	44	2	1.37	0.00	0.01	0.00	0.00	0.01	0.00	0.00
	46	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	48	1	1.19	0.00	0.00	0.00	0.00	0.01	0.00	0.00
	50	2	2.63	0.00	0.00	0.00	0.00	0.03	0.00	0.00
	52	2	2.69	0.00	0.00	0.00	0.00	0.07	0.00	0.00
	54	1	0.86	0.00	0.01	0.00	0.00	0.04	0.00	0.00
	56	1	0.86	0.00	0.04	0.00	0.00	0.01	0.00	0.00
Kongsfjordneset										
	8	30	25.80	1.94	2.51	0.00	0.00	0.00	0.00	7.65
	10	18	15.48	1.38	1.19	0.00	0.00	0.00	0.00	4.43
	12	35	30.10	3.14	1.93	0.00	0.00	0.00	0.00	11.09
	14	17	14.62	0.31	0.66	0.00	0.00	0.00	0.00	6.79
	16	9	7.74	0.13	0.22	0.00	0.00	0.00	0.00	4.17
	18	1	0.86	0.00	0.04	0.00	0.00	0.00	0.00	0.47
	20	6	5.16	0.00	0.00	0.00	0.00	0.00	0.00	3.27
	22	10	8.60	0.00	0.73	0.00	0.00	0.00	0.00	4.04
	24	1	0.86	0.00	0.00	0.00	0.00	0.00	0.00	0.17
	26	1	0.86	0.00	0.00	0.00	0.00	0.00	0.00	0.17
	28	3	2.58	0.00	0.00	0.00	0.00	0.00	0.00	0.43
	30	12	10.32	0.00	0.01	0.00	0.00	0.00	0.00	2.11
	32	2	1.72	0.00	0.00	0.00	0.00	0.00	0.00	0.30
	34	1	0.86	0.00	0.00	0.00	0.00	0.00	0.00	0.09
	36	1	0.86	0.00	0.00	0.00	0.00	0.00	0.00	0.09
	38	4	3.44	0.00	0.00	0.00	0.00	0.00	0.00	0.39
	40	3	2.58	0.00	0.00	0.00	0.00	0.00	0.00	0.30
	42	1	0.86	0.00	0.00	0.00	0.00	0.00	0.00	0.13
	44	2	1.72	0.00	0.00	0.00	0.00	0.00	0.00	0.26
	46	1	0.86	0.00	0.00	0.00	0.00	0.00	0.00	0.09
	48	1	0.86	0.00	0.00	0.00	0.00	0.00	0.00	0.01
	50	1	0.86	0.00	0.00	0.00	0.00	0.00	0.00	0.13
	52	2	1.72	0.00	0.00	0.00	0.00	0.00	0.00	0.22
	54	2	1.72	0.00	0.00	0.00	0.00	0.00	0.00	0.22
	56	3	2.58	0.00	0.00	0.00	0.00	0.00	0.00	0.05
	58	4	3.44	0.00	0.04	0.00	0.00	0.00	0.00	0.03
	60	1	0.86	0.00	000	0.00	0.00	0.00	0.00	0.01
Prince Heinrich Island										
	16	7	2.03	2.00	0.01	0.00	0.00	0.00	0.00	0.00
	18	8	2.32	1.94	0.26	0.00	0.00	0.04	0.00	0.00
	20	21	6.56	2.47	1.19	0.00	0.03	0.08	0.06	0.00
	22	10	2.87	0.41	0.16	0.00	0.00	0.00	0.12	0.00
	24	7	1.57	0.00	0.02	0.00	0.00	0.00	0.01	0.00
	26	3	0.46	0.00	0.02	0.00	0.00	0.00	0.00	0.00
	28	21	4.41	0.00	0.05	0.00	0.00	0.00	0.00	0.00
	30	6	2.15	0.00	0.03	0.00	0.00	0.00	0.00	0.00
	32	5	1.57	0.00	0.18	0.00	0.00	0.00	0.00	0.00
	34	4	0.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	36	2	0.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	38	3	0.78	0.00	0.00	0.00	0.00	0.01	0.00	0.00
	40	2	0.89	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	42	4	1.52	0.00	0.00	0.00	0.00	0.00	0.00	0.05
	44	8	3.40	0.00	0.00	0.00	0.00	0.00	0.00	0.03
	46	2	0.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tyskahytta										
	8	10	1.78	0.05	0.34	0,01	0.04	0.00	0.00	0.00

Table 10 continued									
10	17	3.29	0.17	0.51	0.01	0.05	0.00	0.00	0.00
12	15	2.76	0.01	0.02	0.00	0.01	0.00	0.00	0.00
14	21	3.47	0.02	0.02	0.00	0.02	0.00	0.00	0.00
16	41	8.59	0.23	0.22	0.00	0.03	0.00	0.00	0.00
18	6	1.58	0.04	0.04	0.00	0.00	0.00	0.00	0.00
20	17	3.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22	20	3.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24	10	1.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Brandal									
6	20	7.84	0.44	0.54	0.00	0.39	0.00	0.00	0.00
8	4	1.84	0.25	0.17	0.00	0.12	0.00	0.00	0.00
10	2	0.60	0.24	0.10	0.01	0.06	0.00	0.00	0.00
12	2	0.92	0.14	0.17	0.00	0.18	0.00	0.00	0.00
14	1	0.46	0.05	0.05	0.05	0.05	0.00	0.00	0.00
16	1	0.46	0.07	0.12	0.02	0.02	0.00	0.00	0.00
18	2	0.92	0.07	0.16	0.00	0.09	0.00	0.00	0.00
20	2	1.00	0.19	0.10	0.00	0.08	0.00	0.00	0.00
22	1	0.31	0.03	0.00	0.00	0.02	0.00	0.00	0.00
24	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
26	8	3.99	0.88	0.38	0.00	0.04	0.00	0.00	0.00
28	12	5.44	0.21	0.09	0.00	0.00	0.00	0.00	0.00
30	3	1.31	0.35	0.05	0.00	0.00	0.00	0.00	0.00
32	5	3.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00
34	2	0.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00
36	5	1.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00
38	1	0.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00
40	2	0.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00
42	1	0.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00
44	1	0.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00
46	1	0.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00
48	1	0.52	0.00	0.00	0.00	0.00	0.00	0.00	0.00
50	1	0.87	0.00	0.00	0.00	0.00	0.00	0.00	0.00
52	2	0.65	0.00	0.00	0.00	0.00	0.00	0.00	0.00
54	3	1.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00
56	2	1.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
58	3	1.55	0.00	0.00	0.00	0.00	0.00	0.00	0.00
60	2	1.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00
62	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
64	4	1.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00
66	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
68	2	0.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00
70	1	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
72	2	0.62	0.00	0.00	0.00	0.00	0.00	0.00	0.00
74	5	1.91	0.00	0.00	0.00	0.00	0.00	0.00	0.00
76	3	1.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00
78	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
80	5	2.87	0.00	0.00	0.00	0.00	0.00	0.00	0.00
82	1	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00
84	2	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
86	1	0.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00
88	2	0.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00
90	3	0.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00
92	3	1.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00
94	3	0.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00
96	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
98	5	1.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100	1	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
102	3	0.89	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 10 continued

104	3	0.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00
106	1	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00
108	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
110	4	1.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00
112	2	0.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00
114	2	0.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00
116	1	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
118	1	0.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00
120	3	3.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00
122	5	1.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00
124	2	1.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00
126	3	1.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00
128	5	3.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00
130	5	2.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00
132	7	3.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00
134	26	14.98	0.00	0.00	0.00	0.00	0.00	0.00	0.00
136	12	6.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
138	3	1.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Community Analysis

Table 11 Results of ANOSIM (pairwise test and Global R, p) on species composition for sampling points until 70 m depth for presence/absence without fauna(left) and without detritus (right); evaluation of the factor depth

Depth [m]		P/A without fauna		P/A without detritus	
		R	**p**	**R**	**p**
70	**60**	0.156	0.002	0.204	0.001
70	**50**	0.215	0.001	0.236	0.001
70	**40**	0.199	0.001	0.113	0.001
70	**30**	0.2	0.001	-0.081	0.957
70	**20**	0.231	0.001	-0.097	0.992
70	**10**	0.411	0.001	0.141	0.003
70	**5**	0.299	0.001	**0.877**	**0.001**
60	**50**	0.027	0.107	0.017	0.205
60	**40**	0.002	0.414	-0.039	0.836
60	**30**	0.007	0.376	-0.166	1
60	**20**	0.041	0.046	-0.158	1
60	**10**	0.274	0.001	0.067	0.072
60	**5**	0.311	0.001	**0.844**	**0.001**
50	**40**	-0.036	0.95	-0.047	0.947
50	**30**	-0.048	0.946	-0.149	0.999
50	**20**	0.02	0.177	-0.127	1
50	**10**	0.348	0.001	0.156	0.001
50	**5**	0.429	0.001	**0.862**	**0.001**
40	**30**	0.023	0.125	-0.047	0.899
40	**20**	0.07	0.001	-0.058	0.962
40	**10**	0.36	0.001	0.215	0.001
40	**5**	0.357	0.001	**0.69**	**0.001**
30	**20**	0.028	0.001	0.009	0.119
30	**10**	0.166	0.001	0.244	0.001
30	**5**	0.274	0.001	0.479	0.001
20	**10**	0.036	0.002	0.08	0.001
20	**5**	0.143	0.002	0.204	0.015
10	**5**	0.195	0.009	0.094	0.125

Table 12 Results of SIMPER for significant results indicating the contribution of single species to total dissimilarity in species composition for presence/absence without detritus; evaluation of the factor depth

Depth [m]	Contribution of species to total dissimilarity [%]				
	P/A				
70:5	zoobenthos	21.9	**50:5**	zoobenthos	17.6
	Alaria esculenta	16.3		microalgae	13.9
	Phycodrys rubens	12.2		*Alaria esculenta*	13.7
	Acrosiphonia	11.3		*Phycodrys rubens*	10.3
	Desmarestia viridis	10.8		*Desmarestia viridis*	9.2
	Desmarestia aculeata	10.7		*Desmarestia aculeata*	9.1
	Laminaria digitata	5.6		*Acrosiphonia*	9.1
	Saccharina latissima	5.6		coralline red algae	6.8
60:5	zoobenthos	18.4	**40:5**	zoobenthos	16.4
	Alaria esculenta	13.8		*Alaria esculenta*	14.3
	coralline red algae	11.0		microalgae	12.5
	Phycodrys rubens	9.9		*Phycodrys rubens*	10.0
	microalgae	9.7		*Acrosiphonia*	9.7
	Desmarestia viridis	9.6		*Desmarestia viridis*	9.7
	Acrosiphonia	9.2		*Desmarestia aculeata*	9.5
	Desmarestia aculeata	9.2		coralline red algae	6.2

Table 13 Results of ANOSIM (pairwise test and Global R, p) on species composition for sampling points until 70 m depth for presence/absence without fauna (left) and without detritus (right); evaluation of the factor transect HN Hansneset north, HS Hansneset south, PHI Prince Heinrich Island, KN Kongsfjordneset, TH Tyskahytta, BL Brandal

Transect		P/A without fauna		P/A without detritus	
		R	**p**	**R**	**p**
HN	**HS**	0.047	0.002	0.019	0.02
HN	**KN**	0.488	0.001	0.415	0.001
HN	**PHI**	0.414	0.001	0.273	0.001
HN	**TH**	**0.515**	**0.001**	0.365	0.001
HN	**BL**	0.387	0.001	0.333	0.001
HS	**KN**	0.439	0.001	0.461	0.001
HS	**PHI**	0.384	0.001	0.244	0.001
HS	**TH**	**0.513**	**0.001**	0.345	0.001
HS	**BL**	0.417	0.001	0.341	0.001
KN	**PHI**	**0.764**	**0.001**	**0.664**	**0.001**
KN	**TH**	**0.777**	**0.001**	**0.639**	**0.001**
KN	**BL**	**0.835**	**0.001**	**0.818**	**0.001**
PHI	**TH**	0.072	0.001	0.08	0.001
PHI	**BL**	0.359	0.001	0.267	0.001
TH	**BL**	0.359	0.001	0.421	0.001

Table 14 Results of SIMPER for significant results indicating the contribution of single species to total dissimilarity in species composition for presence/absence without detritus; evaluation of the factor transect, HN Hansneset north, HS Hansneset south, PHI Prince Heinrich Island, KN Kongsfjordneset, TH Tyskahytta, BL Brandal

Transect	Contribution of species to total dissimilarity [%]			
	P/A without fauna		**P/A without detritus**	
HN:TH	microalgae	20.5		
	Phycodrys rubens	11.2		
	coralline red algae	10.8		
	detritus *S. latissima*	8.8		
	Desmarestia viridis	8.2		
HS:TH	microalgae	20.2		
	Phycodrys rubens	17.2		
	coralline red algae	9.4		
	detritus *S. latissima*	8.9		
	Saccharina latissima	8.3		
KN:PHI	coralline red algae	32.4	coralline red algae	29.0
	microalgae	23.0	microalgae	19.0
	Desmarestia aculeata	11.2	zoobenthos	11.6
	Saccharina latissima	9.8	*Desmarestia aculeata*	11.0
	Desmarestia viridis	7.2	*Saccharina latissima*	10.6
KN:TH	coralline red algae	32.5	coralline red algae	33.2
	microalgae	24.1	microalgae	23.6
	Desmarestia aculeata	9.7	*Desmarestia aculeata*	11.0
	detritus *S. latissima*	9.6	zoobenthos	8.3
	Desmarestia viridis	7.0	*Desmarestia viridis*	8.0
KN:BL	coralline red algae	28.7	coralline red algae	27.1
	detritus *S. latissima*	16.6	zoobenthos	18.5
	Desmarestia aculeata	10.5	*Acrosiphonia*	12.3
	Acrosiphonia	8.4	*Desmarestia aculeata*	12.0
	Saccharina latissima	8.3	*Saccharina latissima*	11.9

Table 15 Results of ANOSIM (pairwise test and Global R, p) on species composition for sampling points until 70 m depth for presence/absence without fauna (left) and without detritus (right); evaluation of the factor bottom substrate

		P/A without fauna		**P/A without detritus**	
Substrate		**R**	**p**	**R**	**p**
Hard bottom with silt	**Hard bottom with silt**	0.248	0.001	0.128	0.001
Hard bottom with silt	**Soft bottom with drop stones**	0.327	0.001	0.18	0.001
Hard bottom with silt	**Soft bottom**	0.336	0.001	0.145	0.001
Hard bottom	**Soft bottom with drop stones**	0.437	0.001	0.302	0.001
Hard bottom	**Soft bottom**	**0.628**	**0.001**	0.319	0.001
Soft bottom with drop stones	**Soft bottom**	0.02	0.238	-0.115	1

Table 16 Results of SIMPER for significant results indicating the contribution of single species to total dissimilarity in species composition for p/a without detritus; evaluation of the factor bottom substrate

Substrate		Contribution of species to total dissimilarity [%]	
		P/A without fauna	
Hard bottom	**Soft bottom**	coralline red algae	21.9
		detritus *S. latissima*	18.4
		microalgae	16.4
		Desmarestia viridis	7.1
		Phycodrys rubens	6.1
		Alaria esculenta	6.0

Table 17 Results of ANOSIM (pairwise test and Global R, p) on species composition for sampling points until 26 m depth for presence/absence (left) and cover data (right); evaluation of the factor depth

Depth [m]		R	p	R	p	Depth [m]		R	p	R	p
		P/A		Cover				P/A		Cover	
26	**24**	0.047	0.026	0.026	0.115	**20**	**12**	0.074	0.001	0.01	0.135
26	**22**	0.071	0.032	0.033	0.135	**20**	**10**	0.089	0.001	0.024	0.124
26	**20**	0.006	0.318	-0.012	0.688	**20**	**6**	0.231	0.001	0.194	0.001
26	**18**	0.102	0.003	0.151	0.001	**20**	**8**	0.078	0.001	0.008	0.208
26	**16**	0.057	0.076	0.014	0.295	**20**	**4**	0.283	0.001	0.095	0.044
26	**14**	0.056	0.029	0.067	0.033	**18**	**16**	0.154	0.001	0.128	0.002
26	**12**	0.091	0.016	0.076	0.022	**18**	**14**	0.182	0.001	0.205	0.001
26	**10**	0.104	0.004	0.11	0.001	**18**	**12**	0.166	0.001	0.105	0.002
26	**6**	0.197	0.002	0.199	0.001	**18**	**10**	0.13	0.002	0.096	0.001
26	**8**	0.1	0.01	0.086	0.011	**18**	**6**	0.134	0.001	0.137	0.001
26	**4**	0.252	0.024	0.216	0.031	**18**	**8**	0.181	0.001	0.126	0.001
24	**22**	-0.015	0.661	-0.031	0.91	**18**	**4**	0.097	0.145	-0.062	0.654
24	**20**	0.018	0.184	0.012	0.235	**16**	**14**	0.009	0.244	-0.005	0.549
24	**18**	0.277	0.001	0.324	0.001	**16**	**12**	0.103	0.001	0.035	0.023
24	**16**	-0.005	0.515	-0.011	0.581	**16**	**10**	0.179	0.001	0.086	0.002
24	**14**	0.029	0.09	0.034	0.059	**16**	**6**	0.304	0.001	0.257	0.001
24	**12**	0.092	0.008	0.098	0.009	**16**	**8**	0.134	0.001	0049	0.013
24	**10**	0.248	0.001	0.228	0.001	**16**	**4**	0.385	0.009	0.26	0.01
24	**6**	0.381	0.001	0.377	0.001	**14**	**12**	0.032	0.049	0.018	0.115
24	**8**	0.161	0.001	0.14	0.001	**14**	**10**	0.115	0.002	0.123	0.001
24	**4**	0.56	0.002	0.582	0,003	**14**	**6**	0.286	0.001	0.299	0.001
22	**20**	0.034	0.02	0.028	0.044	**14**	**8**	0.061	0.006	0.056	0.002
22	**18**	0.267	0.001	0.281	0.001	**14**	**4**	0.402	0.009	0408	0.006
22	**16**	0.011	0.168	0.011	0.143	**12**	**10**	0.055	0.027	0.037	0.048
22	**14**	0.021	0.035	0.011	0.189	**12**	**6**	0.225	0.001	0.216	0.001
22	**12**	0.087	0.001	0.065	0.001	**12**	**8**	0.005	0.25	0.004	0.295
22	**10**	0.209	0.001	0.163	0.001	**12**	**4**	0.225	0.05	0.193	0.039
22	**6**	0.393	0.001	0.357	0.001	**10**	**6**	0,126	0.001	0.096	0.001
22	**8**	0.129	0.001	0.09	0.001	**10**	**8**	0.008	0.262	-0.002	0.475
22	**4**	0.52	0,003	0.45	0.004	**10**	**4**	0.098	0.197	0.009	0.452
20	**18**	0.078	0.004	0.074	0.006	**6**	**8**	0.175	0.001	0.155	0.001
20	**16**	0.019	0.076	0.003	0.313	**6**	**4**	0.003	0.496	-0.123	0.919
20	**14**	0.019	0.105	0.014	0.152	**8**	**4**	0.219	0.065	0.118	0.132

The attached CD contains:

1) ROV protocols with geographic coordinates and video timecode
2) Extracted frames of all transects
3) Table with results of the image analysis: presence/absence and cover data of macroalgae, microalgae, detritus and zoobenthos of all frames
4) R scripts to process geographic data and results of image analysis
5) Bachelor thesis as pdf

Bachelor's thesis statement of originality

I hereby confirm that I have written the accompanying thesis by myself, without contributions from any sources other than those cited in the text and acknowledgements.

This applies also to all graphics, drawings, maps and images included in the thesis.

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Place and date Signature